telektronikk 4.04

100 YEARS ANNIVERSARY

Telecommunications Forecasting

Contents

Telektronikk
Volume 100 No. 4 – 2004
ISSN 0085-7130

Editor:
Per Hjalmar Lehne
(+47) 916 94 909
per-hjalmar.lehne@telenor.com

Editorial assistant:
Gunhild Luke
(+47) 415 14 125
gunhild.luke@telenor.com

Editorial office:
Telenor R&D
NO-1331 Fornebu
Norway
(+47) 810 77 000
telektronikk@telenor.com
www.telektronikk.com

Graphic design:
Design Consult AS (Odd Andersen), Oslo

Layout and illustrations:
Gunhild Luke and Åse Aardal,
Telenor R&D

Prepress and printing:
Rolf Ottesen Grafisk Produksjon, Oslo

Circulation:
3,500

Networks on networks

Connecting entities through networks – in technological, societal and personal terms – enables telecommunication. Networks occur on different levels, form parts of larger networks, and exist in numerous varieties. The artist Odd Andersen visualises the networks on networks by drawing interconnected lines with different widths. Curved connections disturb the order and show that networks are not regular but are adapted to the communication needs.

Per H. Lehne, Editor in Chief

Telecommunications Forecasting

Special

Guest editorial

KJELL STORDAHL

Kjell Stordahl is Senior Advisor in Telenor Networks

Welcome to *Telektronikk*'s special issue on telecommunications forecasting! And welcome to papers by international leading experts in the field of telecommunications forecasting.

Especially welcome to last year's Nobel Prize winner in Economics, Clive W.J. Granger and his colleagues with the paper *"Long-Term Technological Forecasting"* describing long-term forecasts for the mobile evolution in China. You will find five additional articles on long-term forecasting spanning from *"Technology Forecasting for Telecommunications"* to *"Long-Term Broadband Technology Forecasting"*, *"Forecasting Residential Broadband Demand with Limited Information – A Long-Term Supply and Demand Model"* and long-term mobile forecasts through the papers *"Mobile Market Dynamics"* and *"Modelling and Forecasting the Growth of Wireless Messaging"*.

This special issue contains three papers on demand side models analysing willingness to pay and price elasticities. The articles *"Estimating the Demand for VoIP Services"*, *"Understanding Residential Internet Service Adoption Patterns"* and *"The Demand and Pricing of a Portfoilo of Broadband Services"* have been written by well known international experts.

Many of the articles in this issue analyse new services like VoIP, broadband with the new technologies such as ADSL2+, VDSL, WLAN, WiFi, WiMax, and mobile systems with the new technologies GPRS, EDGE and WCDMA/UMTS. Two technical articles aim at understanding the new technologies and their possibilities and potentials. *"Towards the Next Generation Broadband Platform"* describes how a target network will be developed to offer new advanced telecommunication services, while *"Dynamic Spectrum Management – a methodology for providing significantly higher broadband capacity to the users"* describes how new copper based technology can increase the capacity to 100 Mb/s symmetric access on short distances.

In the article *"Models for Forecasting Cost Evolution of Components and Technologies"* a specific forecasting model for cost predictions has been developed. As described in several articles, knowledge of the new technology and the cost of implementing new technology is important for making forecasts. Especially, techno-economic analysis plays an important role for the evaluation of different technologies and their possibilities. The paper *"Roll out Strategies and Adoption Rate Forecasts for ADSL2+/VDSL"* shows how adoption rate forecasts are used to develop optimal broadband rollout strategies.

Uncertainties and risks are always connected to forecasts. What are the risks when making decisions based on the forecasts? In *"Analysing the Impact of Forecast Uncertainties in Broadband Access Rollouts by the Use of Risk Analysis"* an extensive risk analysis based on forecast uncertainties is carried out. The analysis quantifies the risk and shows the impact on the broadband rollout strategies.

The issue also contains forecasting articles on time series analysis of Internet traffic: *"Internet Traffic Dynamics"* and two more specific forecasting articles, *"Telecommunications Demand Forecasting with Intermodal Competition"* based on complex system relationships, and *"Reverse Modelling: How to answer a Question from your Manager about the Future"*. Finally, the issue ends with an article describing the broadband situation in Norway right now, *"Broadband in Norway"*.

A natural approach for making forecasts is to go through the history and collect relevant data – extract observations and develop forecasting models. *Let us take the same approach when describing the future perspectives of telecommunications forecasting!*

Telegraph networks were established more than 150 years ago. Alexander Graham Bell developed the telephone 130 years ago and telephone networks worldwide were slowly deployed after Bell's innovation. In 1946 Telenor introduced the telex service. A manual mobile telephone service was introduced in 1966. The Nordic circuit switched data communication network was established in 1980–81, at the same time as the Nordic Mobile Telephone System (NMT). In Norway Teletex and Videotex were introduced in 1984 and 1986, while ISDN was offered from 1994. The European Mobile System GSM was introduced in 1993. In the 1980s the network operators started to deploy optical fibre in their core networks, while the European networks were digitalised in the 1990s. The use of Internet gained speed after the release of World Wide Web at the end of 1990 and introduction of the first graphical Internet browser and WWW client, Mosaic, in 1993. The Internet development

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was followed by broadband utilisation of the twisted pairs and coax cables through DSL- and HFC-technology. The broadband technology opens up a great variety of possibilities like TVoDSL, VoIP, triple play, very high up- and downstream capacities, etc.

30 years ago a telephone access had no additional attributes. Now, a service may be characterized by capacity, service level agreement (SLA), multiple PC connections, firewalls, Internet addresses, etc. We see a variety of new services every year both in the mobile and the fixed network area. New complex relations between services are generated. Knowledge of substitutions and migration effects are important for understanding the dynamics between the services. In many countries the incumbent had a monopoly. Now, there are many competitors and the incumbents have been forced to open their markets through wholesale and Local Loop Unbundling. The regulators continuously develop new directives to induce more competition and lower prices.

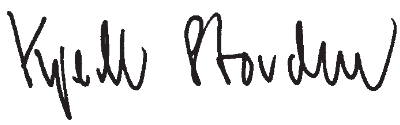
Making forecasts was a lot more straightforward 10–20 years ago. In Europe, the incumbents were controlling the market and competition was limited. There were only a few main technologies available, the number of services was limited, and the telecommunication demand time series were rather stable and regular. At that time it was easier to apply advanced economical and mathematical/statistical models.

Today, the need for telecom forecasting models has never been stronger and the challenges greater. Some key words for forecasting areas are: Established, enhanced and new services, Services offered by different technologies, Market segment forecasts for incumbent (wholesale, retail) and other operators, Market segment forecasts based on demographic and geographic classification, Subscribers, Subscriptions, Terminals and handsets, Traffic volume, Busy hour traffic, Revenue forecasting models, Composite forecasting models and many more.

The forecasts are crucial input for decisions regarding:

- Introduction of new services
- Business case analysis
- Network dimensioning and network planning (see *Telektronikk,* 99 (3/4), 2003)
- Strategies in the short, medium and long term
- Operations and investment costs
- Revenues
- Early warning, budget control
- Budget next year, long-term budget

It is my hope that this issue of *Telektronikk* shows parts of the variety of forecasting in the telecommunication area and contributes to better understanding and knowledge of this very complex and challenging area.



Kjell Stordahl obtained his MSc from the University of Oslo in 1972. He worked at the Research Department of Telenor for 15 years – seven years as manager of the teletraffic field. He was Chief Planning Manager in Telenor Networks from 1989 until 1996 and Manager of Market Analysis 1997–2002. Kjell Stordahl was appointed associated reporter and special reporter 1981–1988 in CCITT SGII for "Forecasting International Traffic". From 1985 to 1988 he participated in CCITT GAS 10 and developed a forecasting handbook. He has also worked for ITU's headquarters as a specialist on forecasting. From 1994 to 1997 he was on the Board of Telenor Consult AS. He was referee for Project Imagine 21 in the ESPRIT Programme 1999–2001. Kjell Stordahl was on the Technical Advisory Board of Virtual Photonics 2000–2002, and since 1992 he has participated in various projects funded by the European Commission: RACE/TITAN, ACTS/OPTIMUM and TERA, IST/TONIC and CELTIC/ECOSYS. He has published over 150 papers in international journals and conferences.

kjell.stordahl@telenor.com

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Long-term technological forecasting[*]

YONGIL JEON, KWANG R. HYUN AND CLIVE W.J. GRANGER

Yongil Jeon is Assistant Professor of Economics at Central Michigan University

Kwang R. Hyun is CTO of Innoace, part of SK Group in Seoul, Korea

Clive W.J. Granger is Nobel Laureate and Research Professor of Economics at University of California, San Diego

It would be a daunting task to look ahead at technology in five to thirty years, but it is not completely impossible. We investigate how to make such long term technological forecasts possible by using an example of the predictions made by Kahn and Wiener (1967). Furthermore, we can also inquire how many of the scientific questions will be resolved and become economically relevant. As an illustration, we predict the mobile telecommunications industry in China.

1 Introduction

Technological forecasting deals primarily with the fairly long term and seeks to determine what technology will likely be available and what the influence of important technological developments and innovations will be. Using technological forecasting to predict events ten years into the future is a particularly difficult task; even five years ahead is complicated enough. Most of the commonly used forecasting techniques would be irrelevant in attempting such a task. In spite of this, we intend to show in this paper that long-term forecasting is not completely impossible.

A very interesting book, *The Year 2000* by Kahn and Wiener (1967), bases forecasts on many types of trends, considers scenarios about how various movements will interact in the future, and ponders the future of scientific development. The study, which is the subject of the discussion in Section 2, came from the Hudson Institute, a private non-profit public policy "think tank" which is still active today. The objective was to use the data available in 1966 to forecast society and technology around the year 2000. However, when forecasting as far as thirty-four years into the future, it should not be expected that predictions will be considered precise either in size or in date.

The field of long-run forecasting offers a unique opportunity for researchers since evaluation of their work won't happen for quite some time. Jeon and Granger (2004a) employ two popular trend-fitting models: a random walk model with drift and a trend-stationary model (with equal weights and with exponential declining weights). Although the two models indicate similar long-term mean forecasts, their confidence intervals vary as the forecasting horizons increase. With regard to the trend-fittings, the uncertainty measure helps to differentiate between two similar models.

The common perception in the area of long-term technological forecasting is that countries tend to follow a specific and predictable path with regard to the various stages of growth.[1] That is, a country's growth path in the mobile telecommunications industry, for example, in cellular phone use per 100 inhabitants, will follow an S-shape, where the initial stage is marked by slow positive growth, followed by increasingly larger gains in growth. In the final stage it is the belief that the curve levels off as the growth rates in cellular phone use per capita stay or even decline.

It is of particular interest whether or not the Chinese telecommunications industry will follow a similar S-shape path in the near future. Due to China's large geographic and demographic presence and large potential for market expansion, foreign investors would especially like to know what demand will be for mobile services in China in the future. China is currently adding users at a rate of two every second, and in 2001 it overtook the US as the largest cellular phone market in the world.[2] China Mobile is currently the world's largest cellular operator in terms of users of mobile services.

Currently, it appears that China is still in a stage of increasing growth, but it is too soon to say how this path will change in the near future. In addition, many other countries we have examined have not exhibited the S-shape path, including Hong Kong, Italy, Luxembourg, and Taiwan (shown in Figure 1), whose

[*] *The views expressed in this paper are those of the authors only and do not necessarily represent those of SK Telecom or our affiliations. We are grateful to Kjell Stordahl, Taekwon Kim, Mark Reffitt and Eric Jones for helpful comments and suggestions.*

[1] *See Chapter 10 of Granger (1989) for details.*

[2] *See Xu (2002) for details. A survey of 15 Thomson Financial analysts predicts that mobile sales in China may rise to $25 billion US in 2006 from $19 billion in 2003, and that the sales of China Unicom (the other operator of mobile services in China) will rise from $7.9 billion US to $12.2 billion in 2006.*

 ISSN 0085-7130

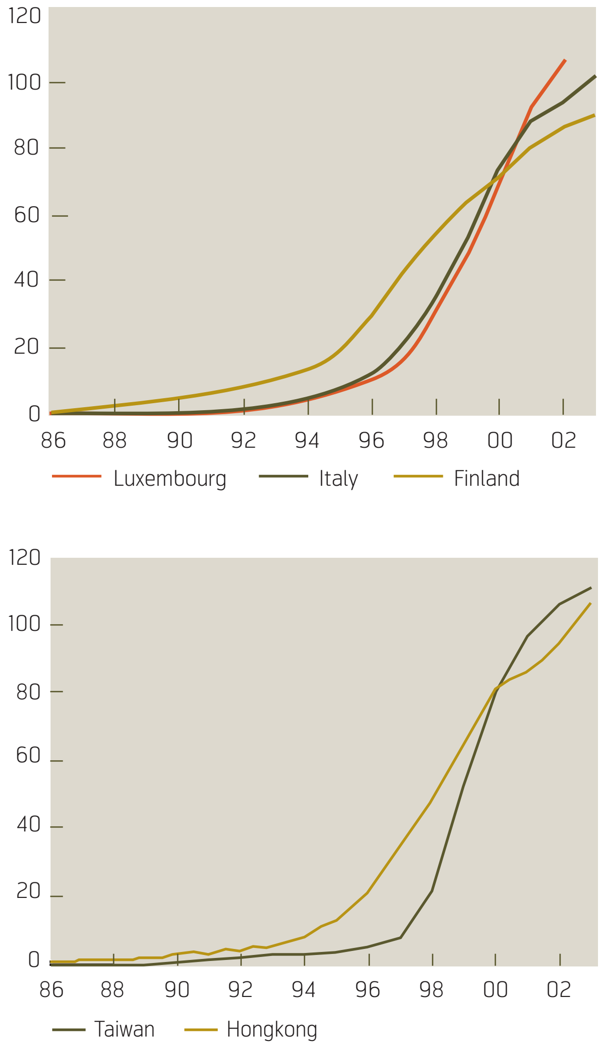

Figure 1 Cellular mobile subscriptions per 100 inhabitants in advanced countries

cellular mobile subscriptions per 100 inhabitants are more than 100 in 2003.[3)] Such a prediction presents a challenge for professional forecasters and, at this point, it is uncertain which path China will take in the coming years. We examine how to predict the trend through a time-series analysis, and provide some insight, at the very least, to those who would be interested to know how the world mobile telecommunications market will play out.

This paper unfolds as follows. Section 2 discusses Kahn and Wiener (1967) which illustrates the difficulty involved with long-range forecasting while also providing a useful template of how to approach the task. We illustrate the evaluation of their long term forecast on science and technology. Section 3 provides the background information on the telecommunication industry of the world in general and of China in specific. Section 4 reviews possible methods of technology forecasting and predicts Chinese cellular phone use per 100 inhabitants by analogy using comparable data from Korea, Japan and the US. Section 5 concludes.

2 Long-term forecasting science – Kahn and Wiener (1967)

In their book *The Year 2000* (1967), Kahn and Wiener make many long-term predictions regarding the world and what types of innovations we might expect in the future. Kahn and Wiener use a variety of forecasting techniques, including trend line fitting for population and economic forecasts, scenarios (thinking about plausible futures), and a form of Delphi when looking at scientific breakthroughs. Each of these techniques employed by Kahn and Wiener were successful on occasions. At the same time, however, some substantial future developments have been missed. Overall, Kahn and Wiener's study illustrates both the possibility of making some worthwhile long-run forecasts and the obvious difficulties of doing so.

For our purposes, we are specifically interested in the most technologically relevant predictions made by Kahn and Wiener. Using entirely subjective criteria, we identified that approximately one-fourth of Kahn and Wiener's 100 "Technical Innovations Very Likely in the Last Third of the Twentieth Century" were highly technological in nature, and thus relevant

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3) A Subscriber *is often defined as a user of a cellular handset and owner of a subscription. By the standard industry definition, the number of subscribers per 100 inhabitants may not exceed 100. There are and will be different types of* handsets *for different technologies, so a user may have more than one handset. Recent statistics for Western Europe show that the number of handsets in use is not much different from that of cellular mobile subscribers. A subscriber may have more than one* subscription. *Sometimes a subscriber has an active subscription and a non-active subscription. A subscriber can have one handset, but different SIM cards with different subscriptions. Thus, the number of subscriptions per 100 inhabitants can, of course, exceed 100. Another instance in which the number of subscribers can hold a greater than one-to-one relationship with inhabitants is when mobile operators sell prepaid mobile subscriptions to international tourists.*

The data source from the International Telecommunication Society *defines "cellular mobile telephone subscribers" as "users of portable telephones subscribing to an automatic public mobile telephone service using cellular technology that provides access to the Public Switched Telephone Network". We interpret the data in the form of number of subscriptions (subscription penetrations), rather than subscribers. That is, when the original data sets from the ITS allude to there being more than 100* subscribers *per 100 inhabitants, we infer that* subscriptions *per 100 inhabitants are greater than 100.*

to discuss in light of long-term technological forecasting. Of Kahn and Wiener's one-hundred predictions, thirty-five of these innovations have occurred, forty-eight have not, fourteen have partially occurred (that is, they are in very early stages), and three could not be classified because their statements were unclear. Listed below are some examples of highly technological forecasts we subjectively consider successful (with numbers from the authors' Table 16, page 51):

06 New or improved super performance fabrics (papers, filters, plastics)

07 More reliable and longer-range weather forecasting

11 Extensive and intensive use of high altitude cameras

29 Extensive and intensive centralization (or automatic interconnection) of current and past personal and business information in high-speed data processors

54 Automated grocery and department stores (becoming used)

70 Simple inexpensive home video recording and playing

71 Inexpensive high-capacity, worldwide, regional, and local (home and business) communication (perhaps using satellites, lasers, and light pipes)

74 Pervasive business use of computers for the storage, processing, and retrieval of information

81 Personal "pagers" (perhaps even two-way pocket phones) and other personal electronic equipment for communication, computing, and data processing program

84 Home computers to "run" households and communicate with the outside world

Examples of unsuccessful forecasts thus far:

24 Three-dimensional photography, illustrations, movies, and television

25 Automated or more mechanized housekeeping and home maintenance

31 Some control of weather and/or climate

55 Extensive use of robots and machines "slaved" to humans

85 Maintenance-free, long-life electronic and other equipment

The following examples depict the difficultly in interpreting predictions and determining their success. Some examples of what we consider "half successes" include:

14 Extensive use of cyborg techniques (mechanical aids or substitutes for human organs, senses, limbs, or other components)

20 Inexpensive design and procurement of "one of a kind" items through use of computerized analysis and automated production

51 Permanent manned satellite and lunar installations-interplanetary travel

57 Automated universal (real time) credit, audit, and banking systems

83 Inexpensive (less than $20) long lasting, very small battery operated TV receivers

Examples of forecasts that we could not judge:

59 Greater use of underground buildings

65 Major improvements in earth moving and construction equipment generally

Words such as "new or improved", "greater use", and "major improvements" are fairly subjective and can be very difficult to evaluate. Our list includes just twenty-two of the one hundred innovations that appeared in *The Year 2000*. Since there is nothing with which to compare Kahn and Wiener's forecast, it is unclear if having thirty-five out of one hundred correct based on our personal classifications is considered a success. Many of the less successful predictions seem destined to occur within the coming decades; it's merely a matter of time.

In addition, Kahn and Wiener list twenty-five "some less likely but important possibilities" and a further list of "ten far out possibilities," none of which have occurred by the year 2000, if ever. For example, the first list includes predictions of:

04 Room temperature superconductors

10 Conversion of mammals (humans?) to fluid breathers

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24 A technological equivalent of telepathy

The only example that comes close to occurring is:

15 Automated freeways

The “far-out” list (Table 20, page 56-7) includes anti-gravity, interstellar travel, and extremely cheap electricity.

Some scientific advances that have occurred but do not appear on the lists are the human DNA genome sequence map, cloning, and the development of the high-production rice and wheat which produced the “green revolution” that helped feed the world’s increasing population. The chapter on science and technology pays particular attention to nuclear energy, lasers, and holography, a choice which now seems rather strange. All are important to differing degrees, but for the latter two, less than anticipated in 1967, we believe.

3 Forecasting technology: an example of mobile telecommunications in China

Kahn and Wiener (1967) did not specifically forecast the emergence of the World Wide Web, but did correctly predict the use of home computers, linked together, and the widespread availability of all the information “in the Library of Congress”.[4)] In line with this, the issue with all forms of technological forecasting is *what* will be possible rather than *how* it will be achieved. Thus, although the web itself and its full implications were not forecast in the book, many of the basic properties of the system were indicated. This same idea can be applied when we look at the Chinese telecommunications industry. As more and different uses for cellular phones are becoming available, we cannot necessarily predict specifically how the Chinese telecommunications industry will change, but we can offer answers as to what will happen in terms of cellular phone usage.

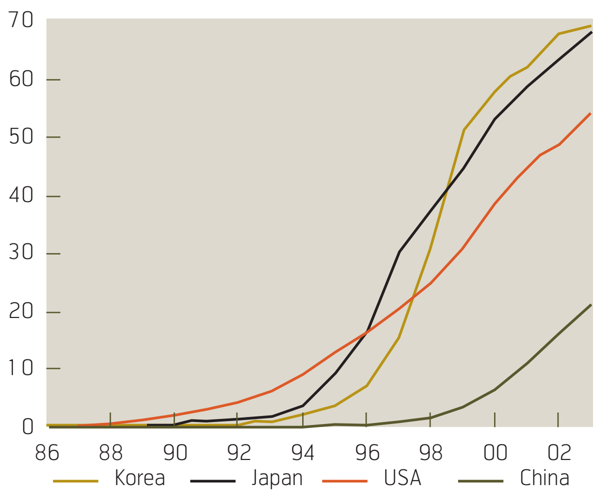

Figure 2 Cellular mobile subscriptions per 100 inhabitants in China and neighboring countries

For our analysis, we chose to first look at five countries that exhibit cellular phone density greater than ninety cellular phones per one-hundred inhabitants. These five countries include Finland, Italy, Luxembourg, Taiwan, and Hong Kong. As Figure 1 shows, each of these five countries has seen dramatic increases in cellular phone use starting around 1994. Although the slope of each of these countries’ curves has declined slightly around 2000, the slopes still remain very high and positive. It is believed that an S-shape must appear eventually since inhabitants of these countries are already using more than one cellular phone per person. However, Figure 1 indicates that this will not necessarily be the case anytime in the immediate future. It is interesting to note that of these five countries, four of them would be classified as “smaller-sized countries”, with Italy being the exception.

In order to help us predict what path China might take in the coming years, we chose to plot the curve for China along with those of Japan, Korea, and the US. In particular, Japan and Korea would be the best comparisons to China because they are advanced, adjacent, and have relatively large populations. While the US does not neighbor China, it shows a similar stage of cellular phone development with a large population. Thus, the US might also give us clues as to future movements in Chinese cellular phone use. As Figure 2 shows, cellular phone use per one-hundred inhabitants in Japan and Korea has taken off, particularly in the mid-to-late nineties. As we observed with the countries in Figure 1, the slope of Japan and Korea’s curves has begun to drop off a little bit; however, we still see no concrete signs of an S-shape. It is also evident from the US experience, and China in particular, that the countries are still in the early stages of cellular phone development. We predict that China will closely follow the paths of Japan, Korea and the US in the near future.

Let us first consider a general overview of the past and present states of the Chinese telecommunications market. Examining the history of the market and the

4) *Shy (2001) takes an example from the internet. The first email message was sent in 1969, but adoption did not take off until 1990. However, from 1990 the internet traffic more than doubles every year.*

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issues involved with it will help us gain further insight that should prove useful in attempting to predict the future of the Chinese mobile phone market.

The Chinese telecommunications market was sluggish prior to the late 1970s; in fact, it had the lowest teledensity among 140 leading countries.[5] The appeal to foreign investors was minimal due to China's poor infrastructure, and as a result the Chinese government made improving the telecommunications industry a priority, mostly through decentralization of the industry's administrative power. This policy has been mostly effective; by 1994, the infrastructure had improved enough to satisfy basic public demand, and the incumbent operator in the industry (China Telecom) owned the second largest fixed telephone network in the world.

Government deregulation of the industry, as noted, was the key factor making the market more competitive. One of the major decentralization plans was the merger of 16 smaller state-owned companies into one (now known as China Unicom). The drive towards a market-oriented economy proceeded, due largely to the increased demand for private networks caused by the poor quality and high prices of China Telecom's services. In response to this, the government acted to prevent private over-investment in the industry by taking a further step towards deregulation in 1998.[6] All networks and IT manufacturing are subject to regulation under the Ministry of Information Industry.

Under the new framework, China Telecom was vertically split into four new companies, each offering specific services, and as another competitive measure taken in 1998, China Mobile was required to provide roaming for China Unicom customers. As a result, China Unicom expanded from less than a 6 percent market share in 1998 to over a 22 percent share in 2000. This is indicative of the effectiveness of the deregulation and increased competition in the Chinese market. Nonetheless, both China Mobile and China Unicom are still state-owned and thus subject to tariffs and price floors set by the government regulators, although competition is still the key to the modern and future industry.

To generate more revenue from subscribers, the two companies have recently started to introduce other mobile services, such as simple messaging service (SMS). These services achieved little success in China, however, most likely due to the less convenient and slower technology used for such services. A similar attempt was made in Japan and South Korea utilizing better technology and it produced much better results. The SMS service, along with other mobile telecommunications possibilities, is regarded as one of the keys to modern success in the telecommunications market.

As of the first half of 2004, ten multinational cellular phone makers held seventy-three and a half percent of the total cellular phone market share in China. These cellular phone makers are Motorola (12.1 %), Nokia (11.9 %), Samsung (9.9 %), Ningbo Bird (9.6 %), TCL (8.2 %), Konka (5.6 %), Dbtel (5.5 %), Amoi (3.9 %), Soutec (3.6 %), and Sony Ericsson (3.4 %). These numbers point to the increasingly large market share being held by Chinese upstarts which began around 2000. While Motorola, Nokia, and Ericsson have been around since the early nineties, it is the new Chinese players such as Ningbo Bird and TCL that have experienced recent rapid growth. The rapid growth experienced by the Chinese brands has occurred because these brands have crafted their strategy to fit China's national situation and built a merchant network that extends to the rural county seats.

In an effort to regain their primacy in the Chinese cellular phone market, the Western multinationals have had to rethink their strategies. This effort has included increasing product segmentation, jazzing up their brands, tweaking pricing, designing products specifically for China's 300 million mobile-phone users, and revamping distribution to reach smaller cities. Western cellular phone companies have had to come to grips with the fact that China is so large that it is not possible to define it as a single market. These companies look at every market as different, and try to determine the best distribution or business model to cater to that market. As an example of this new approach by Western cellular phone companies, in May 2003, Nokia introduced the first of its China-specific phones which featured a pen-based character-input system that recognizes Chinese characters.

While the Western multinationals have survived the first onslaught by Chinese cellular phone companies, more shake-ups may be on the way. Currently, all Chinese cellular phones run on only one of two networks: a network which uses the GSM standard run by China Mobile, and a network that uses CDMA technology operated by China Unicom. Each of these locally based companies does some handset sales to customers in China. On the horizon for 2005 is the

5) *The next few paragraphs rely on information from Xu (2002).*

6) *It considered private investment a waste of public resources since the telecommunications companies were still state-owned.*

onset of third-generation networks which will add new carriers to the mix and likely reshuffle the competitive balance in the Chinese telecommunications market once again.

4 Forecasting Chinese cellular phone use by analogy

Several techniques for technological forecasts have been suggested, such as the Delphi method, identifying precursor events, trend-curve fitting, and forecasting by analogy.[7)] The Delphi method includes surveying experts in the technological field concerned, although it is not easy to identify a group of experts and to extract a useful forecast from them. Identifying precursor events is similar to using leading indicators in macroeconomic forecasting. However, the identification of what events are relevant and how the information should be incorporated is generally very subjective.

The question for popular fitting trend curves is which curve to fit. The common selections are exponential, linear, logistic, and Gompertz curves. Since the S-shape is dominant in technological forecasting, the last two curves are the most common because they incorporate both lower and upper limits, which are either estimated or selected from other criteria. Obviously, if the upper limit is badly selected, the two popular methods will produce very poor forecasts. Figures 1 and 2, as discussed in the previous section, do not indicate the S-shape path for cellular phone subscriptions, showing still increasing patterns without any definite upper limits. In contrast, the number of land-line telephones per 100 members of the population is often assigned an upper limit of 80, which will fix parameters of the model. Furthermore, cellular phone companies recently have been offering lower rates in order to attract potential cellular subscribers from these areas, which as a result has generated lower revenues per customer. To combat and offset this, cellular phone companies have turned their focus towards offering data services such as internet access, cameras, stock quotes, and music (MP3 music players) and movie downloads, among countless other possibilities. This should postpone the final stage of the S-shape curve in the cellular phone market by increasing its upper limits continuously.

As an alternative to these popular methods, we employ a strategy of forecasting by analogy. When forecasting the Chinese growth path in cellular phone use per 100 inhabitants, forecasting by analogy is adopted by finding a situation in an earlier time and in a different location where society has many features comparable to the Chinese situation. The experiences in Japan and Korea can be used as analogous situations to China since Japan and Korea are advanced, adjacent, and have relatively large populations. The US is an acceptable analogy because it has recently experienced a similar stage in cellular phone development and also has a large population spread out over a vast geographic area.

Let y_t be cellular phone subscriptions at time t. Since the data is obtained at discrete time points, the data series is transformed into a continuous time process by joining all adjacent points through linear interpolation. That is, the data may not actually exhibit five cellular phones per 100 inhabitants, but linear interpolation allows us to calculate the exact time period for which each country experiences five cellular phones per 100 inhabitants. The annual data sets between years 1986 and 2003 are taken from various annual issues of the *Yearbook of Statistics* from the International Telecommunication Society.

When y_{t_1} and y_{t_2} are available at times t_1 and t_2, the time lapse, calculated as $t_2 - t_1$, is of special interest. For instance, there were 3.418 Chinese cellular telephone subscriptions per 100 inhabitants in 1999, 6.671 in 2000, and 20.879 in 2003. That is, t_1 for y_{t_1} = 5.000 is year 1999.49 corresponding to May 2000 by linear interpolation (as the methodology will be explained later). And t_2 for y_{t_2} = 20.879 represents the end of year 2003 by default. We focus on $t_2 - t_1$, the time lapse between y_{t_1} = 5.000 and y_{t_2} = 20.879 cellular phone subscriptions per 100 people. This time gap for China is 3.51 years. $t_2 - t_1$ is calculated similarly for Japan, Korea and the US, and the comparison of these gaps is used as an analogy for forecasting Chinese cellular phone usage in the future.

The method of interpolation indicates that Japan reached y_{t_1} = 5 cellular phone subscriptions in year 1994.26 (that is, March 1995), Korea in year 1995.39 (April 1996), and the US in year 1992.36 (April 1993). In the mean time, Japan reached y_{t_2} = 20.879 in year 1996.31 (March 1997), Korea in year 1997.36 (April 1998), and the US in year 1997.10 (January 1998). Therefore, in order to promote the cellular phone usage from y_{t_1} = 5.000 to y_{t_2} = 20.879 it took 2.05 years ($t_2 - t_1$ = 2.05) for Japan, 1.97 years for Korea, and 4.74 years for the US. In sum, Korea and Japan experienced a shorter time lapse than both the US and China, with the US exhibiting the longest lapse. Consequently, the Japanese and Korean data are stretched in the time dimension after y_{t_2} = 20.879

7) *Refer to Granger (1989) for more details.*

	Original data		Korean path		interpolation		Chinese forecast	
	China	Korea	by Korean raw data		for Korean path		by Korean path	
Year	Values	Values	Year	Values	Year	Values	Year	Values
1986	0.000	0.017					1986	0.000
1987	0.000	0.024					1987	0.000
1988	0.000	0.048					1988	0.000
1989	0.001	0.094					1989	0.001
1990	0.002	0.187					1990	0.002
1991	0.004	0.383					1991	0.004
1992	0.015	0.620					1992	0.015
1993	0.053	1.071					1993	0.053
1994	0.130	2.166					1994	0.130
1995	0.295	3.683					1995	0.295
1996	0.550	7.095					1996	0.550
1997	1.058	15.246					1997	1.058
1998	1.900	**30.875**					1998	1.900
1999	3.418	**51.303**					1999	3.418
2000	6.671	**58.315**					2000	6.671
2001	11.314	**62.077**					2001	11.314
2002	16.137	**68.319**					2002	16.137
2003	20.879	**70.129**	2003.000	20.879			2003	20.879
2004			2004.138	**30.875**	2004	29.661	2004	29.661
2005			2005.918	**51.303**	2005	40.767	2005	40.767
2006			2007.697	**58.315**	2006	51.627	2006	51.627
2007			2009.477	**62.077**	2007	55.567	2007	55.567
2008			2011.257	**68.319**	2008	58.954	2008	58.954
2009			2013.036	**70.129**	2009	61.069	2009	61.069
2010					2010	63.911	2010	63.911
2011					2011	67.419	2011	67.419
2012					2012	69.075	2012	69.075
2013					2013	70.093	2013	70.093

Table 1 Forecasting Chinese cellular phone subscriptions per 100 inhabitants by Analogy – an example of Korean path

while the US data are contracted, so that they are used by analogy for the forecasting values in China after 2003.

For example, the ratio of $t_2 - t_1$ in Korea with respect to China is multiplied in the time formation, in order to adopt the analogy of Korea. That is, the original Korean data in Table 1

$$(y_{t_2}, y_{t_3}, y_{t_4}, \ldots, y_T)$$

is transformed to

$$(y_{t_2^{**}}, y_{t_3^{**}}, y_{t_4^{**}}, \ldots, y_{T^{**}})$$

Where $t_2^* = t_2$, $t_3^* = t_3 + (t_3 - t_2) \cdot ratio$, $t_j^* = t_j^* + ratio$ for $j = 4, 5, \ldots, T$, and $t_j^{**} = t_j^* + p$ for $j = 2, 3, \ldots, T$, with $t_2 = 1997.36$, $p_{Korea} = t_2^{China} - t_2^{Korea} = 2003.00 - 1997.36 = 5.64$ and the corresponding

$$ratio = \frac{t_2^{China} - t_1^{China}}{t_2^{Korea} - t_1^{Korea}} = \frac{3.51}{1.97}.$$

The data series after time-span transformation of Korean data for producing Chinese forecasting is indicated as Korean path in Table 1.

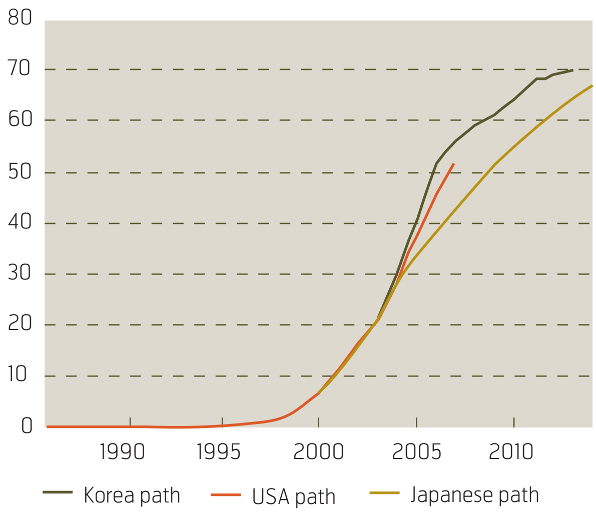

Figure 3 Forecasting cellular phone subscriptions per 100 inhabitants in China by analogy

In the next step, straight lines are taken between two adjacent forecasting values of Korean path data, in order to calculate the discrete values of years. Thus the discrete time process

$$(y_{t_2}^{**}, y_{t_3}^{**}, y_{t_4}^{**}, ..., y_T^{**})$$

is interpolated to get

$$(f_{2004}, f_{2005}, f_{2006}, ...).$$

Hence, the forecasting value in Chinese cellular phone subscriptions per 100 inhabitants for the year 2005 is 40.767, 58.954 for 2008, which is the year of the Beijing Olympic Games, 63.911 for 2010, and 70.093 for 2013, shown in Table 1 under "Chinese forecast by Korean path". These forecasting values consist of both in-sample Chinese data between 1986 and 2003 and out-of-sample Korean projection for Chinese between 2004 and 2013. The same procedure is repeated for Japanese and US data.

Figure 3 shows, by analogy, Chinese cellular phone usages predicted by using the experience from three advanced countries. Figure 3 indicates the forecasting values from the US experience for the relative short-term, until year 2007, since the in-sample data in the US is contracted. The Japanese and Korean historic data, however, extend the forecasting values, making relatively long-term forecasts. Interestingly, Figure 3 indicates the convergence among various forecasting values made by three countries, which shows the robustness of our prediction. That is, the intervals of forecasting values are reasonable and tight.

Figure 3 predicts that in 2008 China will have, on average, 52 cellular phone subscriptions per 100 inhabitants with a lower bound of 46.6 and upper bound of 59.0. The Chinese population in year 2003 is 1.288 billion. When the increase of annual population is assumed to be 2 percent, the Chinese population is expected to reach 1.422 billion in 2008. As a result, the total cellular phone subscriptions are predicted as 740 million (that is, 1.422 billion * 0.52), with the interval of (663 million, 839 million). In 2013, 67 cellular phone subscriptions per 100 inhabitants are expected with the interval of (64.38, 70.09).

It should be noted, however, that the forecast may not be reliable when the analogy is not complete. China will host the Olympic Games in 2008, which should lead to a major economic boom and, as a result, substantial demand increases for cellular phones in China, whereas the three other countries had already experienced those changes before the technical booms in the cellular phone market had taken place.

The differences in the adoption of new 3G technology within these countries may also affect how the forecasted results pan out. In Asian countries like China, Korea, and Japan, this new technology, which enables users to record movies, watch TV, or conduct bank transactions, has caught on rapidly relative to Western countries like the US, where it has yet to become widely used. Transportation is one possible explanation for this difference. In China, like Korea and Japan, more people tend to use public transportation and are able to spend more time with the more visual aspects of mobile phone technology whereas US inhabitants spend a greater portion of their time in automobiles and are unable to use cellular phones for much more than verbal communication. Another reason for the slower acceptance of 3G technology in Western countries is that they are simply not as integrated as Asian nations due to the widespread availability of information offered by existing mediums such as television, internet access via personal computers, cable TV, and newspapers. Therefore, the effect on forecasting is that the potential ceiling for cellular phone use will likely be reached sooner in Western countries than in Asia. That is, the potential uses for cellular phones will grow faster and higher, adding to the potential for demand increases in the sector.

These factors are expected to cause any analogy-driven forecasts to be significantly understated due to the differences between the compared countries.[8)] That is, we expect growth in cell phone use in spite of these factors, but by incorporating them into predictions as well, the further increase in demand should become obvious. Regardless of these differences, forecasting by analogy still serves as a useful tool for predicting the Chinese cellular phone industry.

5 Conclusion

We can examine how many of the scientific questions will be resolved and become economically relevant. For example, will the technology-driven expansion of cellular phone use continue in the future? It is possible to estimate an answer over the course of the next ten years, but to do so beyond that period is a much more difficult and complex task. In this respect, it is doubtful if anyone could have done much better than Kahn and Wiener (1967), even though their forecasts turned out to be far from perfect.

As an alternative to the time series model that we considered in this paper, a structural economic model explaining the Chinese telecommunications market can be built with some expectations. First of all, China's population density (combined with urbanization ratio) will exhibit a positive relationship with cellular phone usage per 100 inhabitants. Secondly, higher income levels will also be a positive factor for mobile telecommunications growth. China has experienced double digit economic growth in recent history, which we would expect to lead to an increase in cellular phone usage in the near future. Finally, as China's land lines have increased, so has the number of cellular phone subscriptions, exhibiting a positive relationship between the two variables. From 2000 to 2003, the number of cellular phones per 100 people has increased from 6.671 to 20.879 while the number of land lines has also increased. In correspondence to this, the percentage of all phone users (land lines included) that used cellular phones has increased from 37.1 percent in 2000 to over 50 percent in 2003.

China is not the only developing country within which we expect a significant increase in the use of mobile services and this opens many opportunities for future research. The world's largest potential markets for mobile telecommunications also include India, Africa, and Eastern European countries. It is expected, for example, that the number of cellular phone users in India will double from 40 million to as many as 100 million by the end of 2005.[9] The most aggressive expansion is taking place in the country's rural areas, where roughly 60 % of its one billion plus people reside. It is likely that the number of cellular phones in India will exceed the amount of fixed lines before the end of 2004, although there are still many Indians that simply cannot afford cellular phones. Appropriately, the analysis found in this paper is applicable to forecasting cellular phone uses in these other countries as well. Prior to this, such predictions would have been extremely difficult, if not impossible. With this framework as a guide they now become feasible.

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[8] *China's one-child policy can be yet another factor that would skew the results of forecasting by analogy, since none of the other three countries have such a policy. Many rural Chinese inhabitants tended to avoid this rule in order to have at least one son by not reporting their daughters to government officials. In fact, many of these female children escaped to the larger cities with poor qualifications for high paying jobs since they are unable to gain any formal education under Chinese law. To them, cellular phones have become a necessity as those young ladies need personal connectivity due to their inability to possess private land line phones. Their existence is not recorded in the formal government statistics, which may understate forecasts by analogy.*

[9] *Granger and Jeon (2004b) discuss how to incorporate China and India in global models.*

 ISSN 0085-7130

Yongil Jeon is an Assistant Professor of Economics at Central Michigan University. He received his PhD in Economics from the University of California, San Diego in 1999, under the supervision of Nobel Laureate Professor C.W.J. Granger. He has held the position of postdoctoral research fellow at the Center for Basic Research in the Social Sciences (CBRSS) at Harvard University and has been a full-time visiting professor at UCSD. His work has produced over twenty refereed journal publications in the research areas of time series modeling, forecasting theory, macroeconomics, banking, and applied econometrics. Dr. Jeon is a 2004 recipient of the Provost Award for Outstanding Research and Creative Endeavors at Central Michigan University.

yjeon@mail.cmich.edu

Kwang R. Hyun received his B.S. degree from the Control and Instrumentation Engineering Department of Seoul National University, Seoul, Korea, and his MS and PhD from the Department of Electrical and Computer Engineering, University of Florida, Gainesville, Florida. He was an IBM Graduate Fellowship recipient during the doctoral degree program. His work experience includes work with IBM, Unidata, Cyberlane, and Innoace as well as consulting projects in various industries. He has been involved with the DSP algorithms development and their implementation for mobile telecommunication equipment. His current interests are mobile handset development, mobile middleware platform development, mobile internet applications and mobile networking. Dr. Hyun is a member of IEEE, and serves as the CTO of Innoace, which belongs to SK Group in Seoul, Korea.

krh@innoace.com

Clive W.J. Granger obtained his BA in Mathematics at the University of Nottingham in 1955 and his PhD from Nottingham in 1959. He held a Harkness Fellowship at Princeton in 1960 and positions of Assistant Lecturer, Lecturer, Reader, and Professor in the Departments of Economics and Mathematics at Nottingham from 1956 to 1974. From 1974 he has been Professor of Economics at the University of California, San Diego. In 1995 he was Visiting Fellow at All Souls College, Oxford and in 1996 he held the position of Visiting Fellow Commoner at Trinity College, Cambridge. He has been a Guggenheim Fellow, is a Fellow of the American Academy of Arts and Sciences, of the Econometric Society, and of the International Institute of Forecasters. He was recently named a "Distinguished Fellow of the American Economic Association". His interests are largely in time series analysis, forecasting, applied econometrics and finance, and he has roughly 200 publications or submitted papers, including ten books. In 2003 he was awarded the Nobel Prize for Economics.

cgranger@ucsd.edu

Long-term broadband technology forecasting

KJELL STORDAHL

Kjell Stordahl is Senior Advisor in Telenor Networks

The paper gives an overview of the relevant broadband technologies, describes their market positions and possibilities. Diffusion models are used to make long-term broadband forecasts for the Western European residential market. The forecasts are separated for the main broadband technologies ADSL, ADSL2+/VDSL, Cable modem and other technologies (FTTx, BWA) based on market share predictions for each technology. The long-term forecasts are evaluated and compared with other broadband forecasts for the Western European market.

1 Introduction

In 2004 the Norwegian Government gave the following statement on broadband:

> *The Government looks at deployment of the broadband network as establishment of a national infrastructure, which during the coming years will be as important for evolution of modern Norway as the telephone network, power line network, railway network, roads, water and sewage network earlier have been for the Norwegian Society.*

The same statement applies also to other countries. The broadband network provides new possibilities and advantages for the business and public sector by giving access to an advanced high capacity electronic infrastructure. The technology and the network will be a fundament for application of information technology, for innovation, rationalisation and value creation. In addition broadband will change the behaviour of households in the private sector significantly over the next years.

The broadband network is the last step of the evolutionary part of the telecommunication network starting with telegraph, telephone, telex, fax, low capacity data network (packet and circuit switched), Nordic mobile systems, GSM, GPRS, Internet and leased lines.

The broadband networks in North America and Western Europe were mainly established just before 2000. During the first two years the HFC technology was dominant in both areas, but in most countries of Western Europe, DSL has now taken over as the leading technology.

Still there are many challenges for rolling out broadband. A lot of different broadband technologies are available. In most countries a lot of competitors are involved in the market. Regulatory bodies have opened the broadband market by introduction of Local Loop Unbundling (LLU) giving other operators the possibility to lease the incumbent's copper pair. Nowadays the regulatory bodies examine the market to check if the incumbent has Significant Market Power (SMP) and will in that case use some regulating tools to reduce the incumbent's market position. The main actors in the broadband market are: incumbents, operators owning different types of infrastructure (fibre, radio, twisted copper), virtual operators, energy companies, wholesalers, Internet Service Providers (ISP), service providers, manufactures, vendors.

To be able to make the right decisions in this very dynamic market, it is vital to make broadband forecasts. This paper concentrates on long-term broadband forecasts, which are used for project investments and investments for establishment of broadband technology platforms.

During a period of 12 years (1992 – 2004) long-term forecasts have been developed as part of techno-economic broadband assessments for analysing various broadband technologies through the European programs RACE, ACTS and IST, by the projects RACE 2087/TITAN, AC 226/OPTIMUM, AC364/TERA and IST-2000-25172 TONIC financed by the European Commission. *This paper documents broadband forecast modelling performed by the CELTIC project Ecosys*.

2 Making long-term broadband forecasts

10 – 20 years ago it was much more straightfoward to make forecasts in the telecom market. In Europe, it was limited competition and the incumbents were controlling the market. There were only a few services available and a limited number of technologies and networks, and the telecommunication demand time series were rather stable and regular. At that time it was easier to apply advanced economic and mathematical/statistical models for long-term forecasts.

 ISSN 0085-7130

This paper will describe the methods developed to forecast the long-term demand for broadband access. In order to make the forecasts, it is necessary to have an overview of the relevant broadband technologies and understand the strengths and weaknesses of each technology. The paper gives an overview of alternative technologies and shows the variety and the complexity of technologies.

It is of course important to sample the historical evolution of the demand for each technology and analyse the data. However, when long-term forecasts are modelled, it is also important to have a good understanding of the abilities of each new technology. The paper shows that techno-economic analysis of the relevant technologies is crucial for evaluating the long-term potential of the technologies. In ([2], [10], [17], [19], [22], [27], [28]) techno-economic analysis of broadband technologies is a substantial part of the forecast modelling.

An important part of the techno-economic analysis is the forecasting models for cost predictions of network components and technologies [1].

The position of the dominating broadband technologies is influenced by the supply side because mass production generates low production costs and low tariffs for the subscribers for having a useful business case. The rollout and coverage of the various technologies are also of great importance. Finally, the rest market, which cannot be covered by the dominating technologies, gives possibilities for alternative technologies.

3 Broadband technologies

In the early 1990s the following capacity classifications were recommended:

- Narrowband: [– 128 kb/s]
- Wideband: < 128 kb/s – 2 Mb/s>
- Broadband: [2 Mb/s –]

However, the concept wideband has disappeared and broadband is now defined as capacities larger than ISDN. During the last few years a lot of new broadband technologies have been developed. Figure 3.1 gives an overview of various broadband technologies.

The first platform for mobile communications was established when the Nordic countries in 1980 introduced the Nordic Mobile Telephone System (NMT). In 1993, the second generation (2G) mobile system, GSM, was established in Europe. Later, GPRS with the possibility for data communication was introduced, and recently an enhancement of GPRS – EDGE – offering even larger access capacity. Recently the third generation mobile system (3G), UMTS – WCDMA, has started the rollout in many countries opening for much higher bandwidth in the access. It is well known that license auctions in many countries of Western Europe generated extremely high costs for many mobile operators. The Nordic countries held a "beauty contest" and managed to keep the license fees on a normal level. New mobile technologies with considerably higher capacity are being developed. One of them, the High Speed Downlink Packet Access (HSDPA) is a relevant future mobile technology.

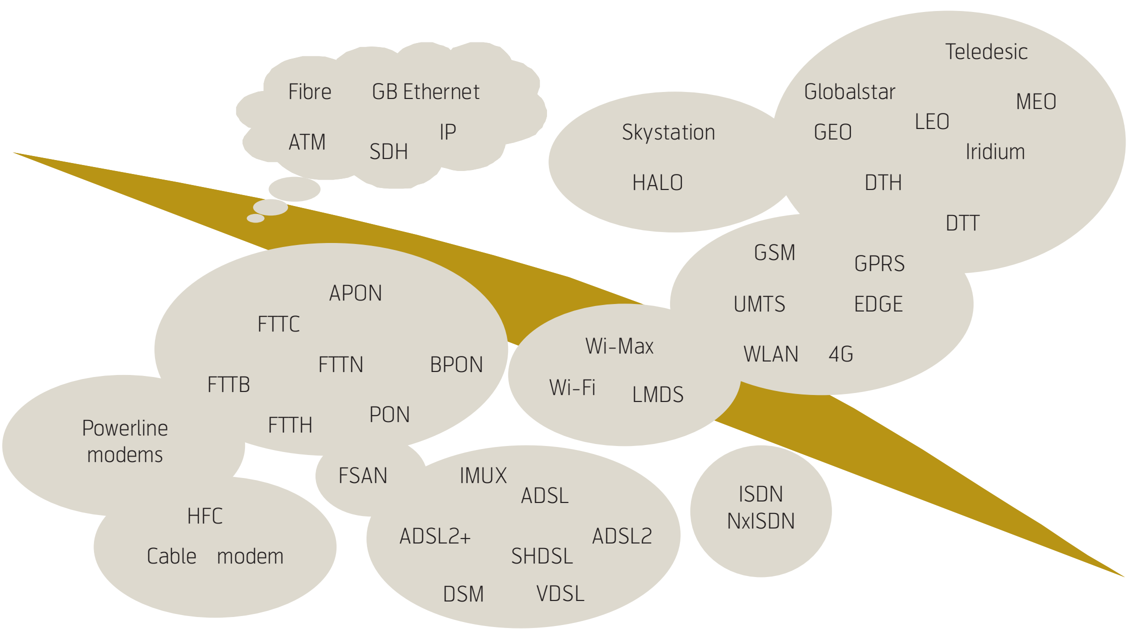

Figure 3.1 Different broadband technologies

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Parallel to the mobile and fixed network broadband evolution, new technologies have been developed for nomadic applications. WLAN has been introduced on a lot of hot spots, like gas stations, airports, railway stations, hotels, cafés, bars, restaurants, etc. In addition new technologies for fixed broadband radio transmission like WiFi, WiMax are under way. The hot spots are also called IP zones since they use the IP network as a backbone network for the broadband traffic.

Local Multipoint Distribution System (LMDS), WiFi and WiMax are fixed wireless broadband access systems for the fixed network. LMDS was already four years ago a promising broadband technology. However, the system did not succeed, because of too expensive components and too low production volumes. The new fixed wireless broadband access systems (WiFi and WiMax) are now in a similar position. Especially WiMax has the possibility either to give high capacity or to have a long reach. The system may be an interesting technology in areas not covered by DSL technology.

The Direct To the Home satellite solution (DTH) also give possibilities for broadband communication. However, the number of satellites and the transponder capacity are limited. In addition, the signals interface and return unit are too expensive for the residential market. Hence, the potential for the systems will be part of the business market, which so far is not covered by cheaper broadband technologies.

The Digital Terrestrial Television network (DTT) constitutes a broadband alternative. The local television masts can be used for downlink broadband transmission. In Norway, Bømlo has been established as a pilot area for the system. The downlink is using a dedicated frequency on the DTT system while the return channel is ISDN or GPRS on the mobile. Within some time a dedicated frequency on the DTT for the return channel will be specified.

Another business concept was the balloon sky station. The plan was to place balloons in the air to cover large populated areas. The capacity would be relatively higher than for satellites, but the maintenance cost is large and uncertain.

Another interesting broadband technology is the power line technology (PLC). The concept of transmitting broadband signals through the power lines has high revenue potential, especially for the power line companies. So far the technology has generated too high radiation effects, and specific improvements are necessary to have a new competitive broadband technology. The European Commission is now supporting the PLC technology, trying to generate heavier competition in the European broadband market. However, there are still uncertainties regarding the future radiation effect of these systems.

Countries like Norway and Germany have a very high ISDN penetration, Norway probably the highest ISDN penetration in the whole world. The ISDN network has the possibility to transfer broadband traffic. Telenor introduced in 2004 the service NxISDN with the possibility to use more than one twisted copper pair. *The service called SMAKS offers up to 256 kb/s as a flat rate service (no traffic charge), which covers 100 % of Norway*. The service is offered only in the business market, since the monthly tariff is rather high.

Because of increased capacity demand, an extensive part of the transport networks in Europe are covered by fibre. Fibre is also deployed in some parts of the access network. In many access areas fibre rings with service connection points have substituted parts of the conventional copper tree structure. New operators are entering the broadband market and deploy their own fibre infrastructure in parallel with the incumbent. Some operators have installed Fibre To The Home (FTTH) and Fibre To The Building (FTTB) with in-house Ethernet solutions. Especially in Sweden, FTTB have been deployed extensively to large building complexes. FTTH – fibre to individual houses is much more expensive, because of digging and civil work expenses. The solutions offer the triple play concept for TV, Internet and telephony at the same time. So far the fibre technology has potential to catch

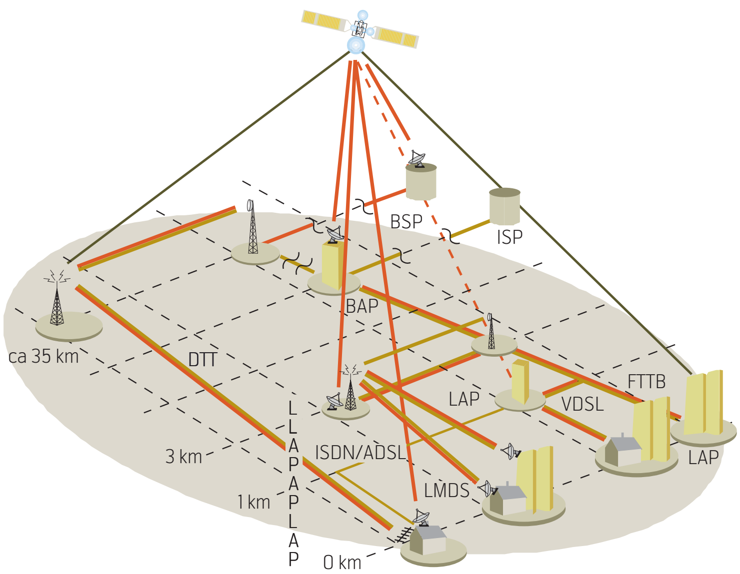

Figure 3.2 Physical network structures for some important broadband services

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medium and large size companies, which already need high broadband capacity. Further, the FTTB is a competing broadband technology in dense access areas where fibre is deployed to large building complexes. Another technology is Fibre To The Curb (FTTC) where fibre is deployed deeper in the access network. The deployment strategy for green field areas is usually to deploy tubes with the possibility to install fibre for future demand for both the business and the residential market. The fibre solutions will be even more competitive in the future with significantly increasing capacity demand.

The Passive Optical Network (PON) solutions do not offer a subscriber access, but represent alternative broadband technology for transmitting the traffic in the access network. In the future also Coarse WDM (CWDM) systems can be used in the same way.

The Hybrid Fibre Coax (HFC) system, also denoted cable modem, was the first real broadband technology to be established in the residential market. The technology is still the dominating one in North America but has lost its position to the DSL technology in Europe. The system uses parts of the traditional cable television network by splitting the network into separate small islands with cable tree structure, which are connected with a fibre droop from the head end to the separate coax islands. A return channel is also established.

Finally, the Digital Subscriber Line (DSL) utilising the traditional twisted pair, is the broadband technology with the highest market share on a worldwide scale. There is a set of different DSL technologies which are continuously evolving. There are some important factors to bear in mind regarding the DSL technology:

1 The broadband access could be symmetric (SHDSL) or asymmetric (ADSL)

2 The access capacity decreases with the length of the subscriber line

3 The access capacity increases with the copper diameter

4 The signal to noise proportion increases with the electrical power on the suscriber line

5 New coding is used to improve the signal to noise proportion. The system is called rate adaptive system or READSL

6 The access capacity or the subscriber line length can be increased by doubling the frequency (from 1.1 MHz to 2.2 MHz). The new technology is called ADSL2+.

7 Further increase of the frequency is utilised with VDSL and long range VDSL.

8 ITU develops recommendations for frequency plans for the various DSL technologies to minimize the noise and cross talk on the copper bundles.

9 New electrical power plans for dedicated copper lines improve the capacity and line length of the other copper lines in the bundle.

10 Dynamic Spectrum Management (DSM) is expected to offer a significant performance improvement of the DSL technology. The system is based on establishment of a control centre, which dynamically allocates spectrum sizes to each copper line depending on the signal to noise proportion. See the paper in this journal "Dynamic Spectrum management – a methodology for providing significantly higher broadband capacity to the users" [6].

11 Usually both households and businesses have a set of twisted pairs as broadband connection. It is possible to use more than one twisted pair by using the concept of wire bonding in order to increase both capacity and line length for the customer.

Figure 3.3 illustrates the possibilities with different DSL technology.

In [7] in this journal there is a comprehensive description of the evolution towards the next broadband network platform. The paper addresses major trends and technology development in networking, which is of crucial importance for making good broadband technology forecasts.

So far the DSL technologies for the residential market are dived into two main groups regarding downstream capacity:

- ADSL class
- ADSL2+/VDSL class

It is assumed that ADSL has a downstream capacity of up to 8 Mb/s with ADSL2+/VDSL from 10 Mb/s upward. A new procedure is now going to be implemented. It is called dynamic bandwidth control giving the subscriber the possibility to choose the needed bandwidth at the right time. Anyhow, it is important

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to plan the demand for low and high access capacity when the broadband network is dimensioned.

The most important broadband technologies are:

- ADSL
- ADSL2+/VDSL
- HFC (Cable modem)
- FTTH/FTTB
- WLAN/WiFi/WiMax

In this paper it is assumed that broadband traffic on mobile terminals and fixed network PCs mainly complement each other. In addition it is assumed that fixed wireless broadband access systems are relevant alternatives for covering sparsely populated areas and also supplements for nomadic movements.

The ability and the possibilities of the different technologies have been analysed in [23], [29], [33], [34], [35], [38].

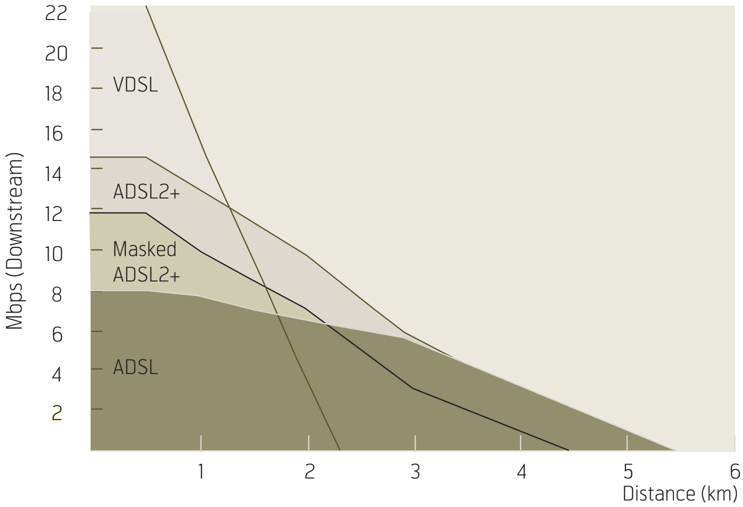

Figure 3.3 Downstream capacity and line length possibilities for various DSL technologies

4 Broadband rollout

The broadband rollout has a crucial impact on the broadband *penetration*. To be able to evaluate the penetration, we need to know the broadband *coverage* of the country. Suppose that the rollout at time t gives the broadband coverage C_t, and that the penetration at that time is P_t. *Take rate* is the proportion between demand and coverage in an area. A Country consists of a set of areas where broadband is rolled out and a set of areas without any broadband availability. Let the take rate at time t be T_t. Then

$$P_t = T_t \, C_t$$

The above equation tells us that the penetration depends on the broadband take rate, which reflects the genuine demand based on the broadband application availability, the broadband tariffs, the service quality, etc. This is commented on in more detail later in this paper. In addition the penetration is dependent on broadband coverage.

The same relation is valid not only for the total broadband penetration, but also for the penetration of different broadband technologies. Figure 4.1 shows the European mean coverage for DSL and HFC (Cable modem) respectively, distributed on urban, suburban and rural areas.

The areas are defined as:

- Urban areas: areas with population density greater than 500 inhabitants/km^2
- Suburban areas: areas with population density between 100 and 500 inhabitants/km^2
- Rural areas: areas with population density less than 100 inhabitants/km^2

The figure shows that the DSL coverage in Europe is much higher than the HFC coverage, which also reflects the penetrations of the two most dominating technologies in Europe.

The figure also shows that HFC has a limited coverage in sparsely populated areas. The reason is the original coverage of cable TV networks in Europe. The cable television networks were mainly deployed in dense areas, because deployment in urban areas was rarely cost-effective. Hence, there are definite limitations of the potential for HFC in Europe because of cable TV coverage. Techno-economic

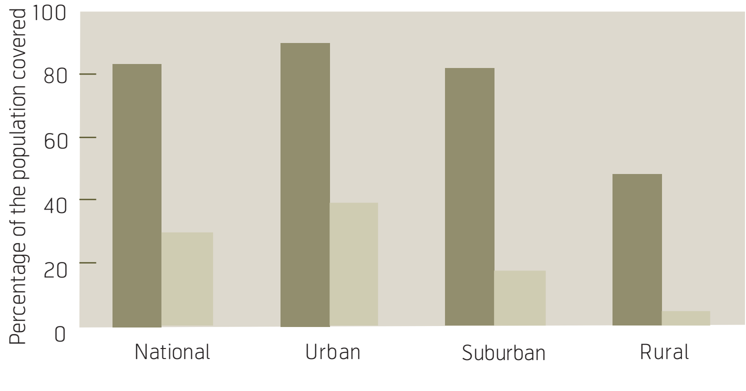

Figure 4.1 DSL and Cable modem coverage in urban, suburban and rural areas in Western Europe (EC: Connecting Europe at High Speed: National Broadband Strategies Dec 2003[13], IDATE)

ISSN 0085-7130

calculations show that further expansion of cable TV networks is not a good business case. One important reason is the possibility for the households to buy small dishes and subscribe via a DTH satellite operator like Viasat or Canal Digital instead of connecting an expensive expansion of a cable TV network. Therefore, the expansion of the HFC coverage will only be performed by upgrading the established cable TV infrastructure to two-way broadband and not by expanding the original network.

A conclusion is that the rollout plans and the rollout possibilities for different broadband technologies are important factors for future broadband coverage and for the broadband penetration forecasts.

5 The broadband rest market

The European Commission and also Governments in the European countries are following the broadband deployment very closely. The reasons are all the benefits broadband communication and the broadband network create for society. Broadband supports the ICT evolution and generates innovation, rationalisation, new working possibilities and additional value for households and companies. Therefore, the Commission and the national Governments support the broadband deployment and also give economic assistance and advice for rolling out the broadband network. In countries like Sweden and Canada, the Governments have given substantial economic support to the broadband deployment. Other countries rely on a more market driven broadband rollout where the actors and operators take care of the deployment. At this stage of the rollout part of the traditional market and the rest market are the last parts to be covered.

The broadband rest market in European terms is usually defined as the coverage which cannot be realised cost efficiently by the DSL technology. This is a difficult issue, since the size of the rest market continuously changes because of improvements of the DSL technology. 2 – 3 years ago the rest market was a rather significant part. In Norway the size of the rest market at that time was estimated to be about 25 %. However, mini DSLAMs (very small DSLAMs) were developed, reducing the rest market significantly. Further improvement of the DSL technology is expected, which will limit the rest market even more.

The DSL rest market is limited by the size of the access area and also by the length of the copper line. The number of subscribers in an access area must exceed a limit in order to get a DSLAM in the area. In addition, the line length must not exceed a given length in order to offer a subscriber a DSL access.

More extensive analysis of broadband technologies and rollout in rural areas and in the rest market is found in [13], [16], [26], [36].

Where DSL technology is not relevant, other broadband technologies will be installed to offer broadband in the rest market. Relevant technologies are:

- WiFi
- WiMAX
- DTT (digital terrestrial television network)

6 Techno-economic assessments

The long-term broadband forecasts are based on results from techno-economic calculations.

The techno-economic calculations evaluate the "economic value", i.e. expressed by net present value or pay back period of rollout of different broadband technologies. The assessments have been carried out for rollout on a national level and on specific areas like urban, suburban, rural and especially the rest market to examine the potential of the different broadband technologies.

The main results from the techno-economic calculations show that it is difficult for new broadband technologies to capture significant market share in areas where cable modem and/or DSL are already deployed. The reason is low subscription prices for the established technologies, which is explained by large mass production on a worldwide basis.

The potential for the upcoming technologies will be in market segments which are sparsely populated and not covered by cable modem or DSL. Even expensive wireless broadband access systems may be offered to the business market in these areas.

There is a close link between techno-economic calculations and the broadband forecasts. To be able to perform the techno-economic calculations, it is important to use the forecasts as input. An evaluation of the technologies is then carried out. The next step is to adjust the forecasts for different technologies and perform new techno-economic calculations. This process is continued until the results are quite stable.

To be able to carry out these calculations, a very advanced techno-economic tool is needed.

Within the European programs RACE, ACTS and IST, the projects RACE 2087/TITAN, AC 226/OPTIMUM, AC364/TERA and IST-2000-25172 TONIC have in the 1992 – 2003 period, developed a methodology and a tool for calculating the overall financial budget of any access architecture. The tool handles the discount system costs, operations, maintenance costs, life cycle costs, net present value (NPV) and internal rate of return (IRR). The tool has the ability to combine low level, detailed network parameters of significant strategic relevance with high level, overall strategic parameters for performing evaluation of various network architectures. In [43] are found more detailed descriptions of techno-economic modelling and the tool.

Telecommunication demand forecasts are input to the tool and to the techno-economic calculations. The Tonic tool is widely used to analyse economic consequences of implementing new network platforms. Important parts of the tool are:

- Service definitions
- Subscription and traffic forecasts
- Service tariff predictions
- Revenue model
- A topology model mapping geographic areas with given penetrations into the tool
- Network component cost data base including more than 300 network components
- Network component cost prediction model
- Investment model
- Operation and maintenance model
- Model for economic calculations
- Risk analysis model

The following steps are needed in the techno-economic evaluations of the network solutions:

The services to be provided must be specified. The market penetration of these services over the study period will be defined. The services have associated tariffs. From the combination of yearly market demand forecasts and ARPU predictions the tool calculates the revenues for each year for the selected service set.

Next, the architecture scenarios to provide the selected service set must be defined. This requires network planning expertise for design of the network and the relevant network components. However, the tool includes several geometric models facilitating the network planning by automatically calculating lengths of cables and ducting. These geometric models are optional parts of the methodology and the techno-economic tool can be used without them. The result of the architecture scenario is a so-called shopping list. This list contains the volumes of all network cost elements (equipment, cables, cabinets, ducting, installation etc.) for each year of the study period and the location of these network components in different flexibility points and link levels.

The costs of the network components are calculated using an integrated cost database containing data gathered from many European sources. Architecture scenarios together with the cost database give the Capital Expenditure (CAPEX) for each year.

The tool contains a forecasting module for cost predictions of network components. The module includes extended learning curve forecasts, which are based on worldwide mass production as an important explanatory variable. See the paper “Models for forecasting cost evolution of components and technologies” [1] in this issue.

In addition Operational Costs (OPEX) is calculated based on operations and maintenance parameters for the component and the maintenance system. The OPEX costs are divided into different components, such as cost of repair parts including civil work and operations and administration costs. Typically the OPEX are driven by services, say by number of customers and number of critical network elements.

CAPEX costs together with the OPEX costs give the life-cycle costs of the selected architecture scenario. Finally, by combining service revenues, investments, operating costs and general economic inputs (e.g. discount rate, tax rate), cash flows and other economic factors the NPV, IRR, Payback period etc are calculated. The methodology is described in more detail in [43].

New mobile systems have been examined by techno-economic analysis regarding market opportunities and rollout strategies ([20], [31], [32], [39]).

7 Broadband penetration status

Data sources

Broadband information has been gathered from a lot of different sources. Project partners in the CELTIC project Ecosys have collected up-to-date data from the broadband evolution. Other important sources have been consultant reports from Point topic [9], OVUM [11], Jupiter [14], Forrester [18] and a set of reports from the European Commission ([12], [15], [21]). It has been difficult to use the forecasts from the consultant reports because the main part of the reports underestimates the expected broadband evolution. One exception is however the last report from OVUM.

An evaluation of the broadband reports from the consultant companies from the 2000 – 2004 period is the continuous underestimation of the expected broadband evolution in Western Europe. During the first

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part of the period the DSL technology was significantly underestimated because the first forecasts probably took to much account of the HFC broadband evolution in North America.

Parallel broadband forecasts have been developed independently through the European programs RACE, ACTS and IST, by the projects RACE 2087/TITAN, AC 226/OPTIMUM, AC364/TERA and IST-2000-25172 TONIC financed by the European Commission. This paper documents broadband modelling performed in the CELTIC project Ecosys.

In the TONIC project broadband forecasts were modelled and presented in two deliverables (Western Europe, 2001) [40] and (Country groups, Western Europe, 2002) [30]. These forecasts have been developed based on principles shown in this paper. These forecasts are significantly higher than all forecasts developed by consultant companies in the period 2001 – 2003. Next section shows that there is a very high growth in the broadband penetration in 2004, which clearly indicates significantly higher penetrations than what was expected by the consultant companies.

Broadband status

Updated broadband statistics from Point topic from Q4 2003 (ultimo 2003) to Q1 2004 (first quarter 2004) and Q2 (second quarter 2004) are presented in this section [9]. The broadband demand status of all Western European countries is shown. *The statistics include the sum of the business market and the residential market*. The next chapters present forecasts for the residential market only. *In addition the statistics cover DSL and Cable modem, but not other broadband technologies*. The reason for using Point topic statistics is that the statistics are updated with Q2 2004 data.

The broadband penetration relative to the number of households from end 2003 to the first half of 2004 for all countries in Europe is shown in Figure 7.1.

The figure shows that Denmark, Netherlands, Switzerland and Belgium are in front, while runners up are Iceland, Norway, Sweden and Portugal. However, during the last year Sweden has lost her position as one of the top three broadband countries in Western Europe. The large countries France, Germany, Italy and UK have a penetration of about 15 % in the first quarter of 2004. However, Germany is now losing her position, in spite of an aggressive DSL rollout the first years. France and Italy have a significant growth and also a hard competition among the broadband operators.

The mean penetration, *sum business and residential market* for the Western European countries was 14.5 % at the end of 2003 and 17.1 % after Q1 2004. Second quarter 2004 the penetration is 18.9 % – an increase of 4.4 % in six months. The mean penetra-

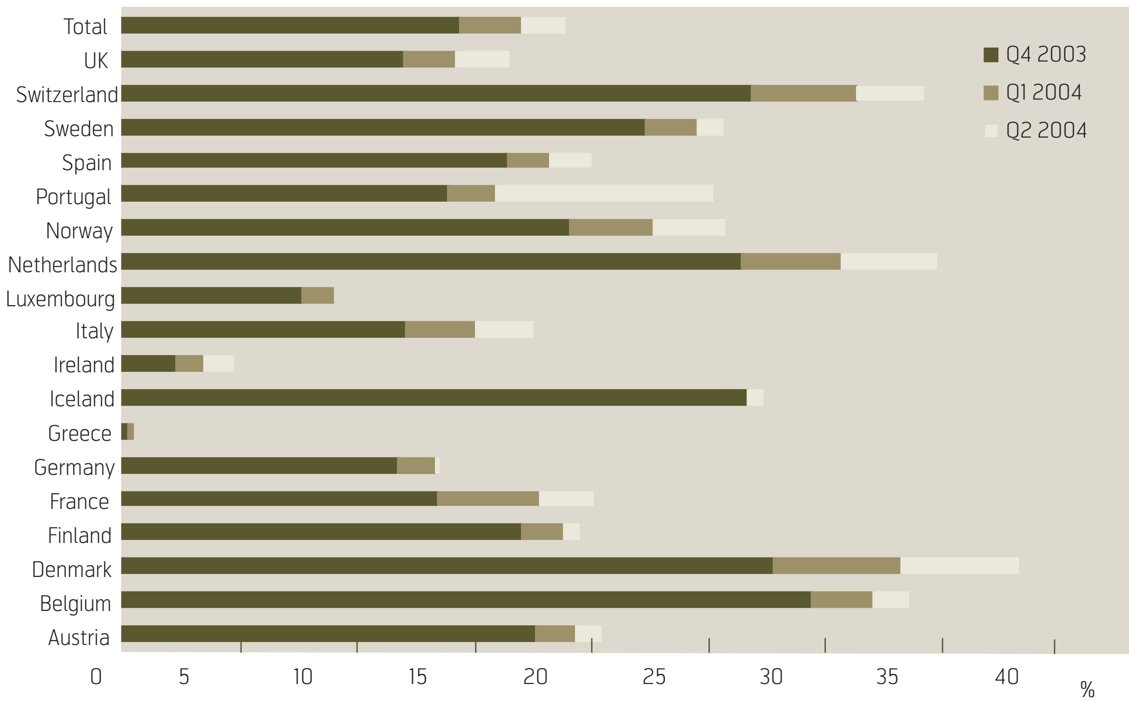

Figure 7.1 Broadband penetration (DSL and cable modem) as sum of residential and business accesses Q4 2003 – Q2 2004 for Western European countries

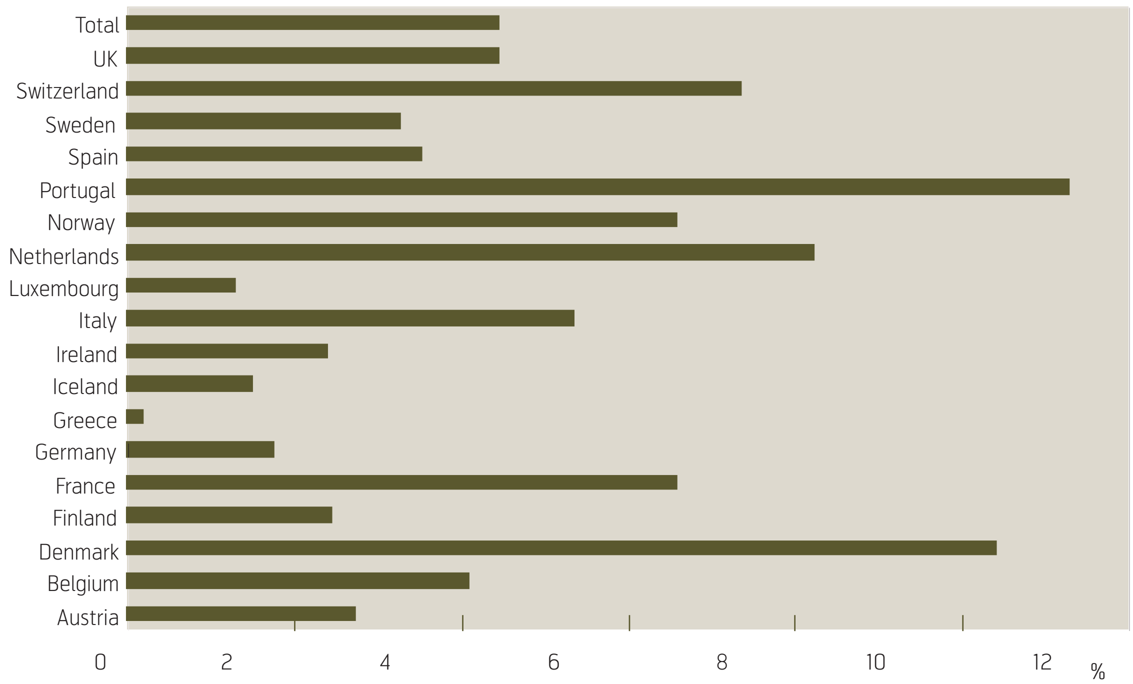

Figure 7.2 Broadband penetration (DSL and Cable modem) growth as sum of residential and business accesses from Q4 2003 to Q2 2004 for Western European countries

tion for the Western European *residential market* was 11.4 % at the end of 2003. Hence, 3.1 % of the penetration is caused by the business market, which constitutes a market share of about 22 %. The business market has a faster growth than the residential market. Q2 2004 penetration data for the pure residential market, Western Europe, is not available at the moment. Based on the given market share, the residential penetration (DSL + Cable modem) is estimated at 15.0 % medio 2004. Penetrations by other technologies have to be added. At the end of 2003, the broadband penetration of other technologies in the residential market was 0.2 %.

The half-year broadband penetration growth, Q4 2003 to Q2 2004 for sum residential and business market for the West European countries is shown in Figure 7.2. The figure shows that Portugal, Denmark, Netherlands, Switzerland, France, and Norway had a very significant broadband growth during the first six months of 2004.

The mean growth in broadband penetration among countries in Western Europe from Q4 2003 to Q2 2004 for the sum of residential and business access is 4.44 % measured per households. The adjusted quarterly growth for the residential market is 3.5 %. If the broadband market evolve with the same speed the rest of the year, the yearly growth of the residential market is estimated to be 7.0 %.

8 Broadband technology forecasts

Drivers for broadband evolution

Important drivers in the broadband market are of course the applications. The evolution of applications generates continuously higher broadband penetration. The evolution of narrowband Internet is an important part of the picture. Now, a significant part of these subscribers are converting to broadband each year. Another important factor is the PC penetration. The PCs are broadband terminals and until now, the broadband subscribers need a PC. In Norway the PC penetration is about 80 %. However, in some European countries the PC penetration is low and may be a barrier for the broadband evolution. Figure 8.1 shows the PC penetration in some OECD countries.

One important aspect is the distribution of broadband content. Interesting applications are: Streaming, Surfing, Peer-to-Peer, Music-on-demand, Video-on-demand, Games, *e*Learning, Electronic newspapers, Electronic books, Gambling, Broadcasting, etc. The operators and service providers are also bundling the services. The HFC and FTTx operators offer triple play.

Other important drivers are national objectives for offering schools, community centres, libraries, etc. high speed broadband. In the national communication plan for Norway, *e*Norge2005, all schools shall have minimum 2 – 10 Mbit/s broadband access by 2005.

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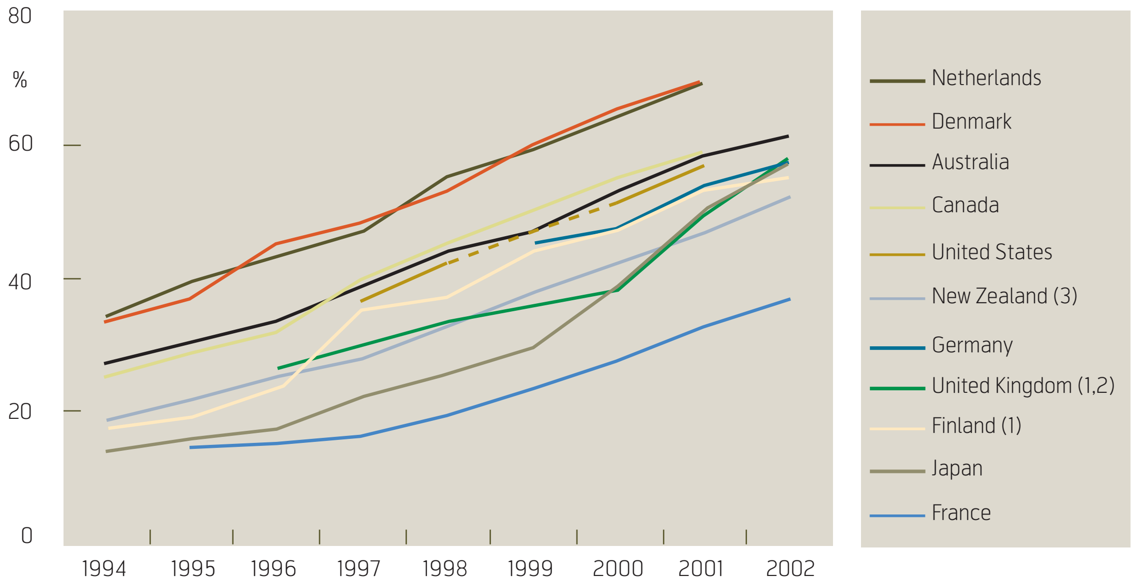

Figure 8.1 Access to home computers. Selected OECD countries (EU Community Survey on Household Use of ICTs, 2002) [21]

Larger schools shall have minimum 10 – 100 Mbit/s connections. In addition the Government is monitoring the broadband coverage very carefully. Some Governments in Western Europe may follow Sweden and Canada, who have supported the broadband rollout with significant investment means. If the broadband rollout in the rest market is too slow, public means may be used to support broadband deployment in these areas.

Another very interesting broadband driver is voice over IP (VoIP). Since broadband access gives the possibility for voice communication, different players are establishing IP-based voice communication on the broadband accesses. Several operators with large core networks, like the incumbents, are developing VoIP with high service quality. Other players in the broadband market establish VoIP services without investing in their own infrastructure. Telio was the company in Norway who offered VoIP without their own infrastructure.

Broadband classification of technologies for the residential market

The broadband technologies are described in chapter 3. For the residential market the technologies are divided into four main groups:

- ADSL
- ADSL2+/VDSL
- Cable modem (HFC)
- Other technologies

Other technologies are mainly: Fixed wireless broadband access systems (FWA), Fibre to the home, Fibre to the building systems, Power line systems, Direct to the home satellite with return channel, and Digital terrestrial television systems.

Broadband technology modelling

The broadband forecasts for the different technologies are modelled by beginning with the broadband penetration forecasts development for the total broadband demand in the Western European residential market. Based on experience from the last few years, diffusion type models have proved to have the best abilities for long-term forecast modelling. A discussion on the forecasts is found in the last chapter of this paper. Also Technology Future Inc. uses diffusion type models for long-term technology forecasts. See [5] in this journal. In [5] and [12] it is shown that the aggregated long-term demand for a set of information and telecommunication services, ICT, in the household segment has a diffusion pattern. [25] gives an overview of different diffusion models used to model telecommunication demand. In this analysis a four parameter Logistic model has been applied for the long-term forecasts.

In this paper the analysis is mainly based on mean values from the Western European market. The models will be improved by modelling the demand in homogeneous groups of European countries. Then more dedicated information will be used regarding rollout speed and coverage of various technologies for the different countries.

Predictions of market share evolution between different broadband technologies have been developed based on a set of Logistic forecasting models. Migrations between technologies are handled when ADSL2+/VDSL and other broadband technologies are catching market shares from ADSL and cable modem. Finally, the broadband penetration forecasts for the technologies are found by multiplying the total forecasts with the market share forecasts for the technologies.

Broadband coverage

The number of cable TV subscribers in 2003 was about 55,000,000 in Western Europe. Since the roll-out of the cable TV has become saturated, new subscribers will mainly be connecting to the existing networks. OVUM [11] predicts about 2 % additional cable TV subscribers per year. At the same time the number of households increases by 0.8 % per year. OVUM estimates that the penetration of cable TV subscribers will increase to 36 % in 2008.

Figure 8.2 shows the cable modem and DSL coverage in Western Europe (Dec 2003). The difference between cable TV coverage and cable modem coverage is due to the heavy expenses in upgrading cable TV networks to a two-way broadband network (HFC). Some of the networks are rather small and some other networks may be of poor quality and not usable for upgrading. Therefore, the cable modem coverage will probably not be very much higher.

On the other hand, the DSL coverage will continue to grow. Figure 8.2 shows that the DSL mean coverage is about 80 %, but much less in rural areas. The DSL is deployed very intensively in Western Europe and is going to have a coverage of more 95 % in the long run. The limitations for coverage are too long copper lines and/or too small local exchange areas. The predictions are estimated by using a Logistic model with 97 % saturation level. However, new technology will probably reduce the size of this rest market. Figure 8.2 gives predictions for the DSL and cable modem coverage.

Residential broadband penetration forecasts for Western Europe

Figure 8.3 shows the evolution of residential broadband penetration from 1999 to 2003.

The figure shows that the broadband penetration evolution during the first years was close to an exponential growth. The demand is expressed in percentage of total number of households. The observations indicate that Logistic models are relevant alternatives for forecasting the penetrations.

Figure 8.4 shows the long-term Western European residential broadband subscription forecasts. The saturation level in the model has been estimated based on historical data, demographics and also expert opinion. The other parameters in the model are estimated.

The figure shows fast increase in the broadband penetration in Western Europe during the next years and the point of inflexion around 2005 – 2006. The situation among countries in Western Europe is of course very different. Greece has a very limited penetration, while the Nordic countries and Belgium, Netherlands and Switzerland have a very high penetration.

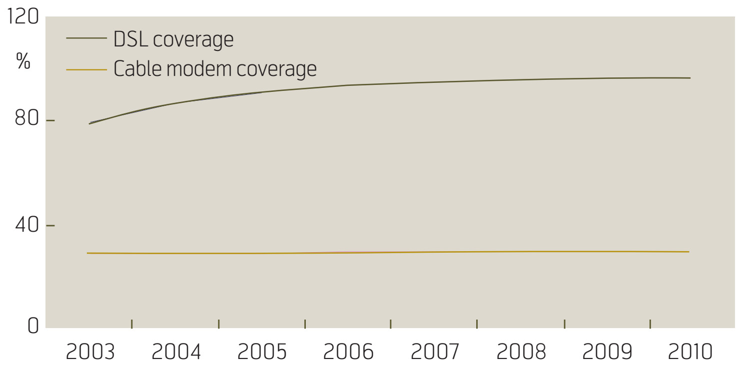

Figure 8.2 DSL and cable modem coverage

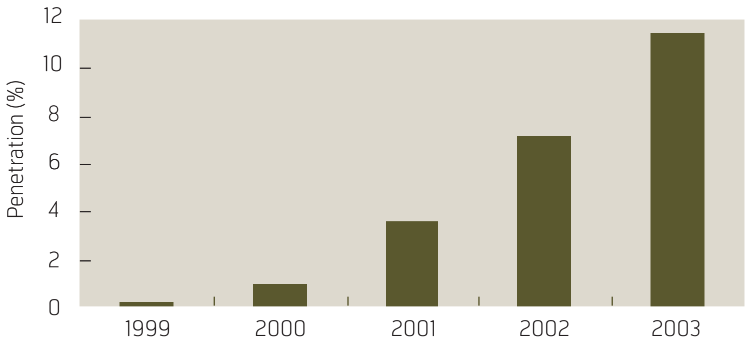

Figure 8.3 Residential broadband penetration, Western Europe, 1999 – 2003

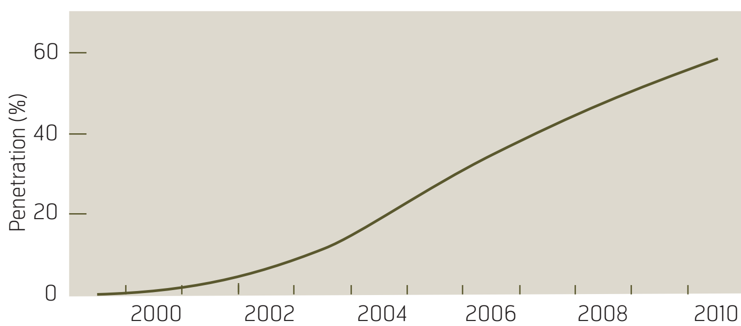

Figure 8.4 Broadband penetration forecasts for residential market, Western Europe

Market share evolution

The market share evolution of cable modem 1999 – 2003 is shown in Figure 8.5. The figure shows that the market share for cable modems (HFC) starts with nearly100 % in 1999, but cable operators lost more than 60 % of the market in the first two years. As mentioned earlier, the cable modem market share has decreased significantly compared with the dominating position in 1999. At that time the number of broadband subscribers was very limited.

The cable modem market share depends on the coverage. Figure 8.2 shows the predicted mean coverage for DSL and cable modem in Europe. The cable modem penetration in the residential market was 3.1 % in Western Europe at the end of 2003. The coverage was 29.0 % and the take rate 10.7 %. The DSL penetration was 7.9 % and the coverage 79 %, which gives a 10.0 % take rate.

The total broadband take rate in cable modem areas is higher than the take rate in other areas. One reason is a more intensive competition in these areas. Cable modem areas are also rather dense areas, where households probably have a higher willingness to pay for broadband subscriptions. In addition the broadband rollout started earlier in cable modem areas. It is estimated that the broadband take rate at the end of 2003 is 3 % higher in cable modem areas than in other areas. The DSL take rate at the end of 2003 in cable modem areas is estimated at 5.3 %, while the DSL take rate in areas without cable modem is estimated at 12.7 %. In addition other technologies start to take minor market shares.

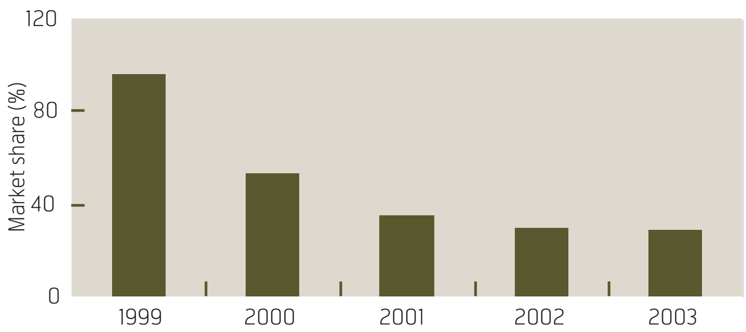

Figure 8.5 Cable modem market share evolution in Western Europe

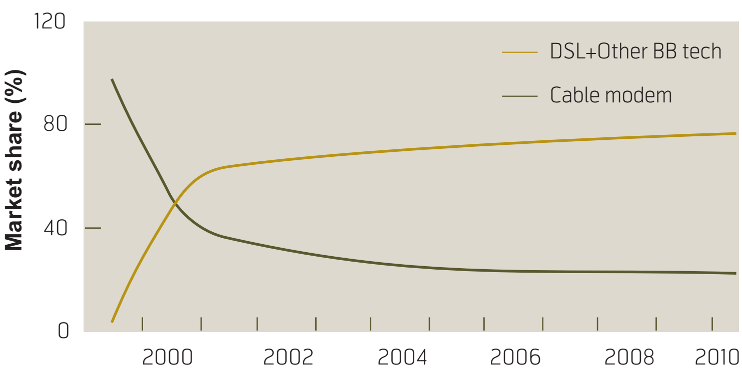

Figure 8.6 Predicted market share evolution between cable modems (HFC) and DSL + other broadband technologies

Figure 8.6 shows the market share forecasts for cable modem in Western Europe.

It is assumed that cable modem operators manage to maintain their broadband position in cable modem areas. Based on the coverage predictions until 2010 for DSL, cable modem and other technologies, the long-term market share for cable modem is estimated to be about 22 %.

The predicted market share evolution for cable modem is modelled indirectly by subtracting market share forecasts for DSL and other broadband technologies from 100 %. The market share forecasts for DSL and other broadband technologies are modelled by a four parameter Logistic model where the long-term market share is set to be 100 % – 22 % = 78 %. Forecasts for the two evolutions are shown in Figure 8.6.

However, there are some uncertainties regarding the market share forecasts. The cable operators bundle the broadband services and the cable television services (TV channels). Therefore, it is difficult for other operators to compete. When ADSL2+ and VDSL are introduced, other operators have the possibility to offer cable television services based on the multicast functionality and traditional broadband services. New operators have the possibility to offer triple play by offering broadband, cable television and telephony. Thus, it may be more difficult for the cable operators to maintain their rather dominating position in the cable areas.

The long-term forecasts show saturation for cable modem on a 22 % level. Even that level may be a little bit too high for Western Europe.

Now, the question is what role the new broadband technologies are going to play in the coming years. The most important technologies for the residential market are FTTB, FTTH, FWA (WiFi, WiMax) and possibly PLC (Power Line Connections). The market share for the new technologies has been reasonably low in the period 2000 – 2003. The market share is shown in Figure 8.7.

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By end 2003 there were about 375,000 FTTB/FTTH broadband accesses in Western Europe, while the number of FWA was about 31,000 and the PLC accesses were about 12,000. A significant part of the FWA accesses are business customers. The total number of broadband households was 18,400 million at the end of 2003.

Techno-economic calculations have shown that new broadband technologies have problems surviving in the broadband market. The main reason is a lack of significant mass production possibilities. If a technology enters the market too late, then the mass production potential is reduced and the network components will not be cheap enough.

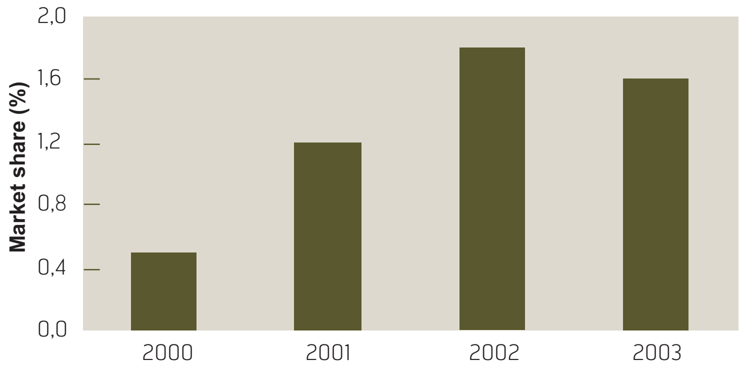

Figure 8.7 Market share other broadband technologies than DSL and cable modem

The broadband penetration in the West European market was 11.4 % at the end of 2003. In the course of the next two years the broadband penetration is predicted to be more than 25 %. Therefore it is crucial for the upcoming new technologies to enter the market and to catch more significant market shares before the established technologies will be even more dominating.

Techno-economic calculations show that it will be extremely difficult to produce broadband solutions with lower CAPEX and OPEX than DSL and cable modem. The best strategy for the new technologies is to enter the rest market before the established broadband technologies reach this part of the market. Because of long line length and high rollout costs for DSL, the FWA solutions may be an alternative in parts of the rest market. In 2010 the DSL coverage is estimated to be about 97 %. Hence, the FWA solutions should have a chance of catching the additional 3 %.

However, there is also a question of service capacity and quality, not only a question of price. In the long term, new demands for very large capacity will be generated. Therefore, FTTH and FTTB and even FTTC (Fibre To The Curb) will be attractive broadband solutions. Especially Sweden and Denmark are in front in the rollout of these access solutions. Strategies for fibre rollout will be:

- To deploy fibre to large building complexes
- To deploy fibre to the homes when building out green field areas
- To renew old infrastructure because of failures

Figure 8.8 shows that the development of market share for new broadband technologies is rather slow. It is difficult to make forecasts for the market share evolution even if we have some observations. The fibre accesses will continue to evolve because of new capacity demanding applications. In addition, the market will be covered by different broadband solutions because of political decisions combined with a market driven approach.

Based on the given arguments, the market share for the new technologies is assumed to be about 7.5 % in 2010. A four parameter Logistic model models the market share evolution. The market share forecasts are shown in Figure 8.8.

The next step is to separate the DSL services ADSL, ADSL2+ and VDSL. The DSL services are described in detail in chapter 3. So far ADSL2+ and VDSL are rarely introduced in the Western European access networks. Telenor started already in 2001 a large VDSL trial with 700 households. During the next years ADSL2+ and VDSL will be deployed gradually.

Techno-economic calculations show that an ADSL2+/VDSL rollout based on cherry picking gives fairly good business cases for the network operators. The rollout strategies are described in more detail in the paper “rollout Strategies and Forecasts for VDSL/ADSL2+” [3] in this journal. One indicator

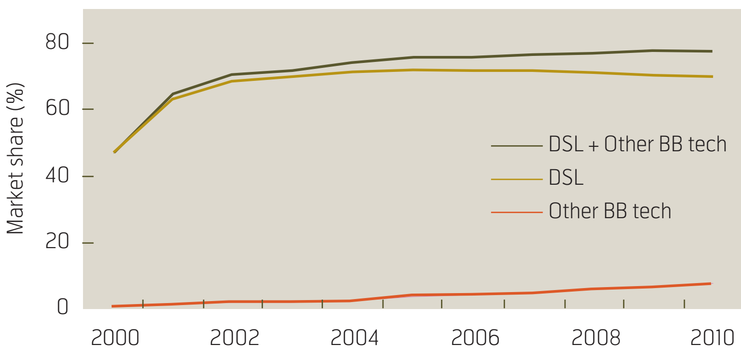

Figure 8.8 Market share forecast for DSL and other broadband technologies

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for the evolution is the new DSLAM exchanges, which have interfaces for both ADSL line cards and ADSL2+ line cards. It is important to note that the production cost of ADSL and ADSL2+ cards are at the same level. Therefore, there will be a significant increase in the high capacity demand for DSL. Since there are no historical demand data, it is of course difficult to predict the future market share evolution of ADSL2+ and VDSL. However, because of low additional production costs, especially for ADSL2+, there will be a very significant increase in the coming years.

ADSL2+ and VDSL offer higher broadband capacity than ADSL. During the next few years new high capacity broadband applications will be introduced. Now, streaming applications are very popular in some market segments, but the access capacity limits the usage. The incumbents are working hard to create new income possibilities on broadband to compensate for the loss on ISDN/telephony. New concepts of broadband contents are underway. ADSL2+ and VDSL will offer TVoDSL and in addition VoD and individual choice possibilities of events and old TV programs. Specific content applications will be: entertainment, online games, gambling, *e*learning, music on demand, "voice books" on demand, electronic newspapers and journals etc. Other broadband applications are: "teleshopping" and auctions, surfing, downloading and exchanging software, back-up services, remote broadband storage, home office, video and multimedia conferences, file and information exchange, data base upgrades and tele-surveillance. The peer-to-peer applications in the residential market are about to start to evolve. There will be a significant increase in demand in the coming years for exchange of personal content like digital pictures, digital film sequences – either personal or streamed, videograms, greetings cards, email with broadband content, personal video and multimedia conferences – for example birthday video conferences.

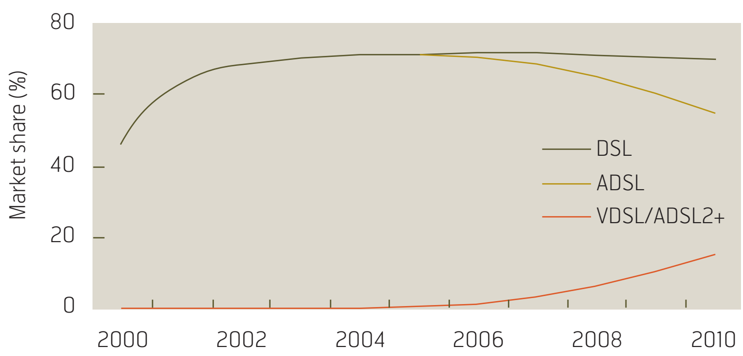

Figure 8.9 Predicted market share evolution for ADSL and ADSL2+/VDSL

One of the first steps for the incumbents is to introduce TVoDSL. The technology will be based on multicasting. However, the market segment in this area is limited because DTH satellites, the CATV network and some FTTH/FTTB operators already offer TV distribution. The next step will be to introduce the more advanced broadband services and applications. The evolution and speed in developing new broadband products will influence the demand for ADSL2+/VDSL.

The ADSL2+/VDSL market share forecasts are based on the assumption of a diffusion type evolution starting in 2004. The premises for the forecasts are that the main part of the Western European operators start to use the cherry picking strategy without additional infrastructure investment. The coverage of ADSL2+/VDSL is about 50 %. It is assumed that operators at the end of the period (2010) will also be deploying fibre deeper into the access network and expand the coverage to about 65 %. Premises for the market segmentation for Western Europe is 90 % HFC coverage inside a radius of 2 kilometres from the exchange (DSLAM). Hence, the potential for ADSL2+/VDSL in 2010 will be 60 % minus 20 % multiplied with the estimated HFC coverage of 22.4 %. The future tariffs for ADSL and ADSL2+/VDSL and the content delivered are of course important factors for the market share of the different services. So far, there is limited information about what consumers will choose. Multinomial logit models have been used to examine ADSL and VDSL demand in the Norwegian market. Significant demand for VDSL was identified [8]. It is assumed that 35 % of the consumers in 2010 will choose ADSL2+/VDSL instead of ADSL where possible. The latter assumption is uncertain, especially because we do not know the future tariffs nor the broadband content of the services. Then the market share for ADSL2+/VDSL is estimated to be about 15 % in year 2010. Figure 8.9 shows the market share forecasts for DSL, ADSL and ADSL2+/VDSL.

Market share and penetration forecasts for different broadband technologies

An overview of the market share forecasts for the different technologies is given in Figure 8.10. The figure shows that the DSL technology in the future will be the dominating broadband technology in Western Europe and that the ADSL2+/VDSL services will gradually substitute ADSL. However, the evolution is reduced because of long subscriber line lengths and the need for heavy investments in the access network for parts of the subscribers. The figure shows that the cable modem market share decreases significantly in the period 2000 – 2010, while the market share for new technologies increases.

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The penetration forecasts for the broadband technologies are found by multiplying the total penetration forecasts with the market share forecasts for the technologies. The forecasts are found in Figure 8.11. The figure shows that ADSL is the dominating broadband technology in the period 2000 – 2010, but the penetration decreases at the end of the period. The main reason for this is substitution effects with ADSL2+ and VDSL, which have shown a very strong growth from 2007 to 2010. In parallel the cable modem penetration increases even when the market share is reduced. Also the penetration of other broadband technologies increase in the period.

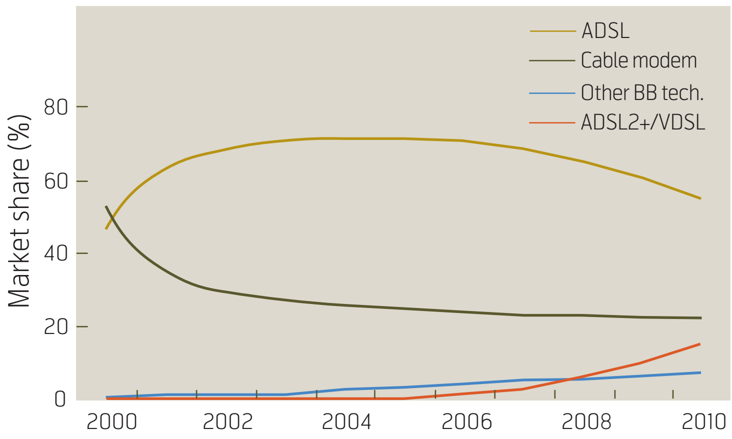

Figure 8.10 Market share forecasts between ADSL, ADSL2+/VDSL, Cable modem and other technologies for the West European market

9 Forecast uncertainties

There are a lot of uncertainties connected to the forecasts. Since the broadband forecasts are developed through qualitative and quantitative information, statistical modelling and also subjective input to the modelling, it is difficult to express the uncertainty by a pure statistical model.

However, it is important to analyse the impact of the broadband forecasting uncertainty. The long-term forecasts are mainly used as input for rollout decisions of different broadband technologies and for establishing new network platforms. Techno-economic assessments are used to calculate net present value, internal rate of return and pay back period for the various projects.

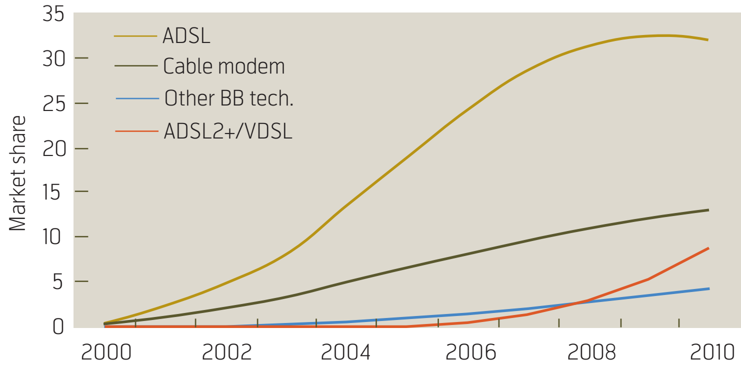

Figure 8.11 Penetration forecasts for broadband technologies in Western Europe

A relevant method for evaluating forecast uncertainty is to apply a risk analysis [42]. The paper "Analysing the impact of forecast uncertainties in broadband access rollouts by use of risk analysis" [4] in this issue shows how risk analysis can be used for this type of evaluations. In [24 and [37] risk analysis on broadband investment is combined with option theory for evaluation of uncertainty to decide the right time for broadband rollouts.

10 Broadband forecasts comparisons

Comparison of forecasts is a subject on its own. In this chapter some comparisons of long-term broadband will be shown and discussed. However, the intention is not to give a complete picture of all long-term broadband forecasts produced.

In 1994 the RACE 2087/TITAN project performed a Delphi survey among 100 experts from 10 Western European countries on the future broadband residential market [44]. Demand curves for broadband accesses and applications together with forecasts for long-term broadband demand for the Western European market were estimated based on the Delphi methodology. In 1997 a new Delphi survey was carried out in the AC 226/OPTIMUM project [41]. At that time no broadband demand data were available, since the broadband services were not yet introduced in the residential market. The forecasts from the two surveys are shown in Figure 10.1.

The aggregated penetration forecasts per household from the first Delphi survey (1994) based on the sum of 2 Mb and 8 Mb accesses were estimated to be 14 % in 2005 and 20 % in 2010. Now we see that these 10 year old forecasts have been a little bit pessimistic. However, at that time neither the DSL technology nor the HFC/cable technology were known.

The aggregated forecasts from the 1997 Delphi survey predict 18.2 % penetration in 2005 and 48.5 % in 2010. These forecasts are rather good. The 2005 forecasts are probably a little bit lower than the expected penetration for 2005, and the 2010 forecasts are so far in the right range. The figure shows that high broadband capacity (25 Mb) forecasts are too

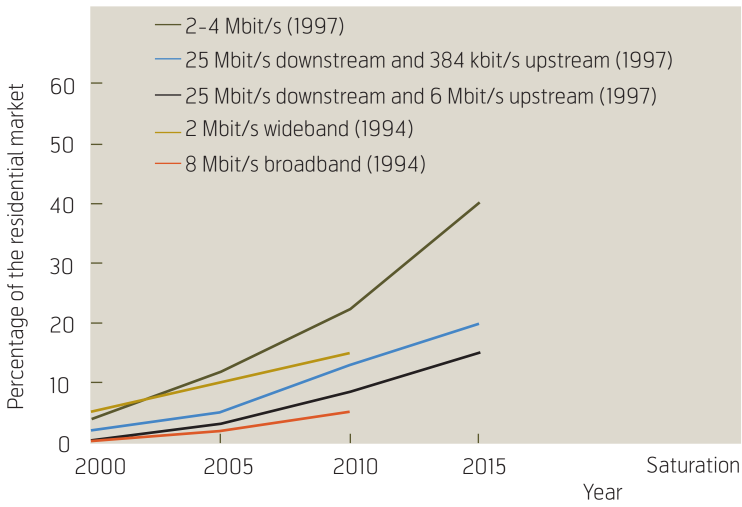

Figure 10.1 Broadband access penetration forecasts per household in the residential market from Delphi surveys performed in 1994 and 1997

optimistic. ADSL2+ and VDSL, which were not specified at that time, are evolving now, but not very fast. The broadband forecast from AC364/Tera is based on the results from the 1997 Delphi survey with some adjustments [41].

Now many companies are making long-term forecasts for the broadband evolution. New broadband forecasts were developed in IST 2000-25172 TONIC in 2001 [40]. It is of course easier to make broadband forecasts when historical demand data are available. This paper presents some of the forecasts. Figure 10.2 gives a comparison of the following forecasts for the Western European residential market:

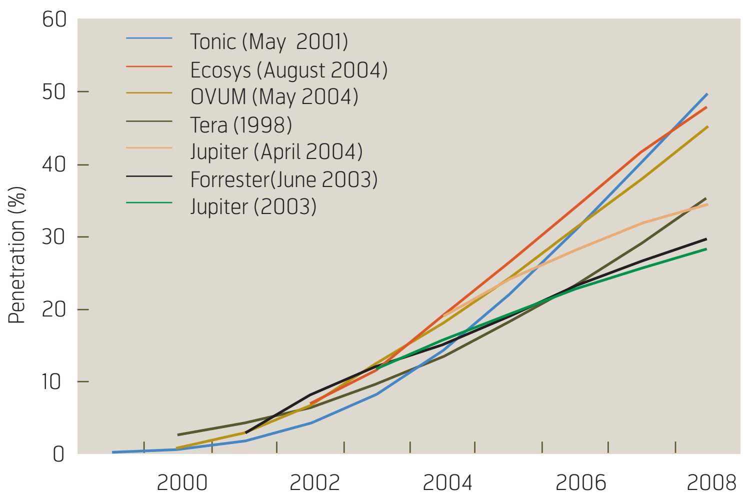

Figure 10.2 Comparison of long-term broadband penetration forecasts per household

- Tera (1998)
- Tonic (May 2001)
- Jupiter (2003)
- Forrester (June 2003)
- Jupiter (April 2004)
- OVUM (May 2004)
- Ecosys (August 2004)

The broadband penetration ultimo 2003 was 11.4 %. The Tonic (2001) forecasts and the Tera (1998) forecasts underestimate the penetration in 2003 by 1.7 % – 3.2 %. However, the yearly growth in the period 2003 – 2008 is larger than the Jupiter (2003 and 2004) forecasts and the Forrester (2003) forecasts.

Chapter 7 in this paper gives an overview of the quarterly DSL and cable modem increase Q1 and Q2 for the sum of the residential and business markets in 2004. The adjusted half year growth for the residential market is estimated to be 3.5 %, which gives a yearly growth of 7 % for DSL and cable modem. Taking into account the growth of other broadband technologies, the broadband penetration in Western Europe will increase from 11.4 % to 18.5 – 19 % at the end of 2004.

Jupiter (2004), OVUM (2004) and Ecosys (2004) forecasts for 2004 seem to have the right predictions for 2004. However, Jupiter (2004) have more pessimistic long-term forecasts. The long-term forecasts can be divided into two groups:

Group 1: Tonic (2001), Ecosys (2004), OVUM (2004): High long-term forecasts

Group 2: Tera (1998), Jupiter (2004), Forrester (2003), Jupiter (2003): Low long-term forecasts

In Group 2 Tera (1998) shows a much stronger growth at the end of the studied period than the others. The Jupiter (2004) forecasts, which probably will be on the right level ultimo 2004, have a turning point at the end of 2004. It explains the deviations from Group 1 long-term forecasts. Netherlands, Belgium, Denmark and Switzerland have the highest broadband penetration in Western Europe, with a level for the sum of residential and business of about 35 %. Still the broadband growth in these countries is increasing, which indicates a much higher turning point than 19 %.

Therefore, it is reasonable to believe that the Group 1 forecasts are the best forecasts.

11 Conclusions

Long-term broadband technology forecasting is not a very easy subject. Experience has shown that it is nearly impossible to make long-term forecasts without understanding the evolution of new broadband technologies and new broadband network platforms. Knowledge of broadband technologies regarding possibilities and limitations is important for the forecasting.

In order to make good long-term broadband forecasts, techno-economic analysis of the relevant broadband technologies has to be performed. Each technology generates investments and operations and maintenance costs for the rollout, which is dependent on the characteristics of the various access areas in the countries. Techno-economic analysis has the ability to show the economic value of the various technologies. Therefore, the techno-economic analysis is crucial for technology rollout strategies and for broadband forecasts.

Long-term broadband forecasting models for the Western European market take into account the penetration status for the various technologies until 2003/ medio 2004. Then long-term forecasts are developed for the period 2004 – 2010. The broadband forecasts are segmented in separate forecasts for ADSL, ADSL2+/VDLS, cable modem and other broadband technologies.

The analysis shows that ADSL, cable modem/HFC and FTTC/FTTB solutions for large building complexes are the cheapest broadband technologies. In many countries in Western Europe the cable modems/ HFC have limitations because of low CATV coverage. Other broadband technologies have to fight for market share where the mentioned broadband technologies are not deployed. Especially the rest market, with too long copper lines is a potential market for these technologies.

The broadband subscription growth in Western Europe is estimated to be 7 % in 2004 and the long-term forecasts for 2008 probably close to 50 %.

So far the broadband forecasts are mainly based on Western European mean values. The forecast modelling can be improved by making separate broadband forecasts for each country by including explanatory variables such as broadband coverage, broadband roll plans, service offer, tariffs etc.

The experience from using Delphi surveys for making long-term broadband forecasts, before broadband demand data were available, has been very good. However, it is difficult to make general conclusions based on the results from two Delphi surveys.

Comparisons of earlier forecasts from consultant companies and forecasts from the EU Commission funded techno-economic projects RACE 2087/ TITAN, AC 226/OPTIMUM, AC364/TERA and IST-2000-25172 TONIC show that the forecasts from techno-economic projects seem to be more offensive and probably give better forecasts.

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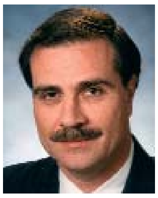
 ISSN 0085-7130

Technology forecasting for telecommunications

LAWRENCE K. VANSTON AND RAY L. HODGES



Lawrence K. Vanston is President of Technology Futures, Inc.

Ray L. Hodges is Senior Consultant with Technology Futures, Inc.

For the last twenty years we have been actively applying formal technology forecasting to the telecommunications industry. Over those years we have learned much and the personal computer and the Internet have made the job easier. However, the fundamentals of forecasting have remained the same, as has the basic challenge of balancing imagination and realism in thinking about the future.

Technology forecasting in telecommunications has been a success story. This may seem like a bold statement given the recent debacle in the telecommunications industry, caused in part by some extremely poor forecasts. However, as we discuss later, the most notorious of these forecasts were produced by forecasting amateurs and consumed by uncritical investors and decision makers. Further, almost all of the problems experienced by the industry were forecastable and indeed forecasted.[1)] The lesson is that good forecasting matters and that decision-makers need a rudimentary understanding of the principles of technology change and adoption.

The successes over the last twenty years are many and include good forecasts in the following areas: digital switching, digital transmission, fiber transport, SONET/SDH adoption, optical data rates, cellular adoption, digital cellular substitution, wireless/wireline competition, Internet demand, broadband access (e.g. DSL and cable modems), bandwidth demand, and DTV/HDTV, to name a few. Active forecasting areas where technology forecasting is crucial, but where it is still too early to gauge success, include VDSL, PONs, VoIP, IP PABXs, 3G wireless, wireless LANs, and the future increases in access bandwidth.

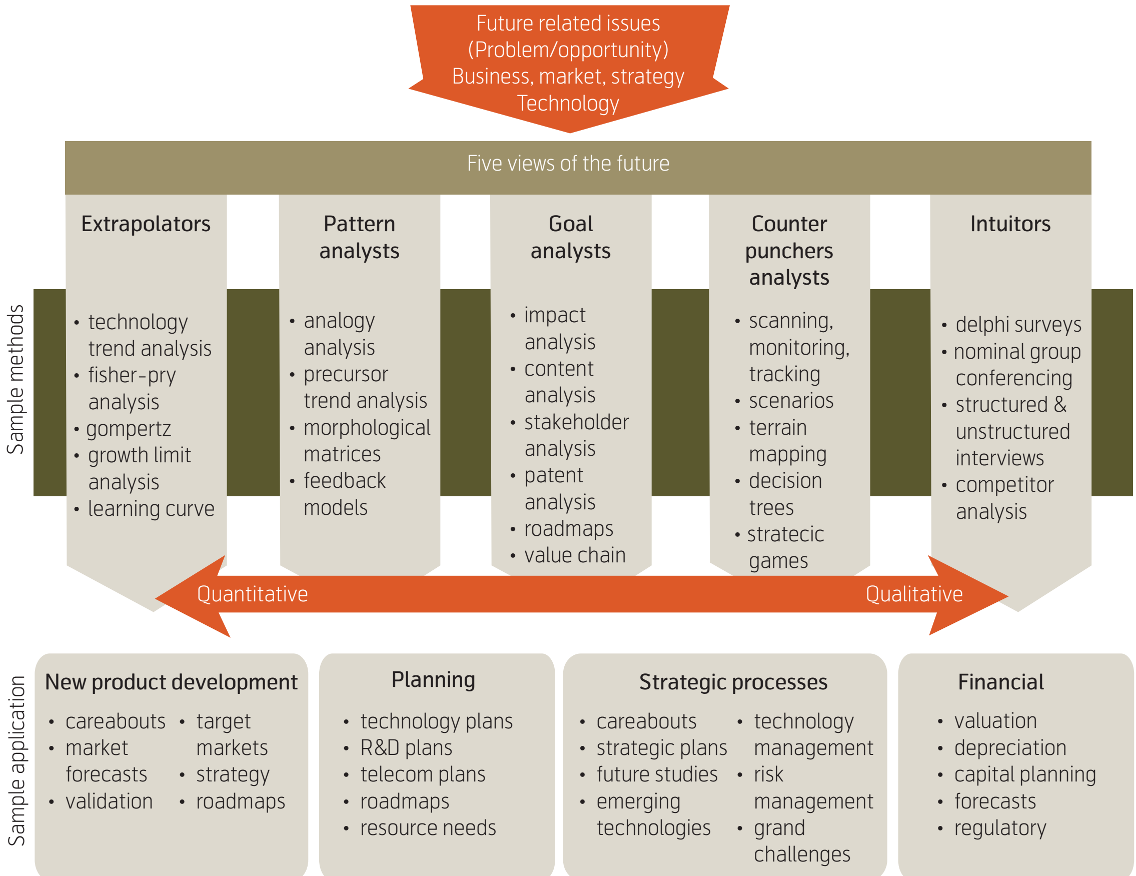


Figure 1 Five views of the future™ (Copyright © Technology Futures, Inc. 2004)

1) *See for example [1]. Other examples are provided herein.*

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Technology forecasting toolkit

The technology forecasting tools that we have used the most in telecommunications are reasonably simple:

- Substitution and market adoption models, such as the Fisher-Pry and Gompertz curves;
- Technology performance and price/performance models, such as the Pearl curve and learning curves;
- Expert opinion methods, such as the Delphi method and structured interviews; and
- Structured thinking tools such as impact wheels and nominal groups.

It is beyond the scope of this paper to describe all of these tools, but they are worth learning because they can help the forecaster make good forecasts and help decision makers discriminate between good and bad ones [2].

A useful way of looking at technology forecasting, and classifying tools, is what we call the Five Views of the Future™ [3], which are represented by the extrapolator, the pattern analyst, the goal setter, the counter-puncher, and the intuitor as shown in Figure 1. An appreciation of all five views is most likely to produce good forecasts, good communication, and good decisions. The extrapolator and pattern analysis views, exemplified by substitution and adoption models, are the most visible in our published telecommunications forecasts, partially because of the need for quantitative results. However, we employ all five views and 90 % of the work is in the background, including almost always a qualitative analysis of drivers and constraints.

In this article, we review a number of past and current forecasts to give you an idea about our experience with technology forecasting and what we see for the future. These will be forecasts that TFI has produced, because we know them, they are public, and they are good examples, albeit mostly from the US.[2)] This is not to say we are the only producers of good forecasts. We are not being patronizing when we say that Telenor has for years been a leader in telecom forecasting. Also, in the last decade, the overall quality of commercial forecasting has improved tremendously.

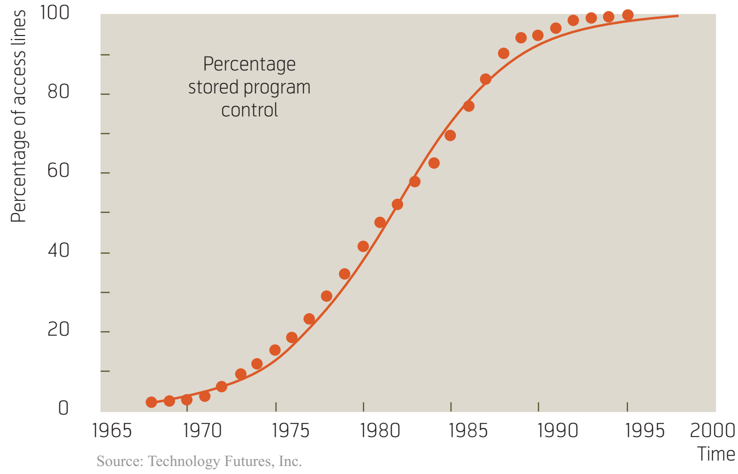

Figure 2 Percentage of telephone access lines served by SPC switching

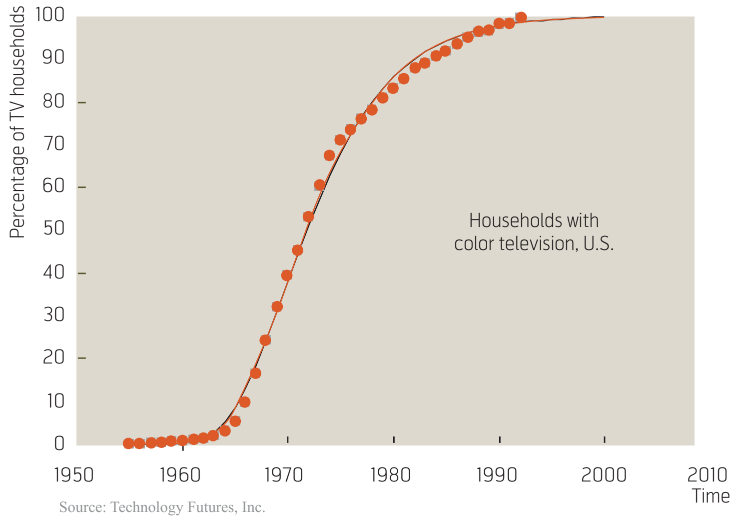

Figure 3 Percentage of US TV households with color televisions

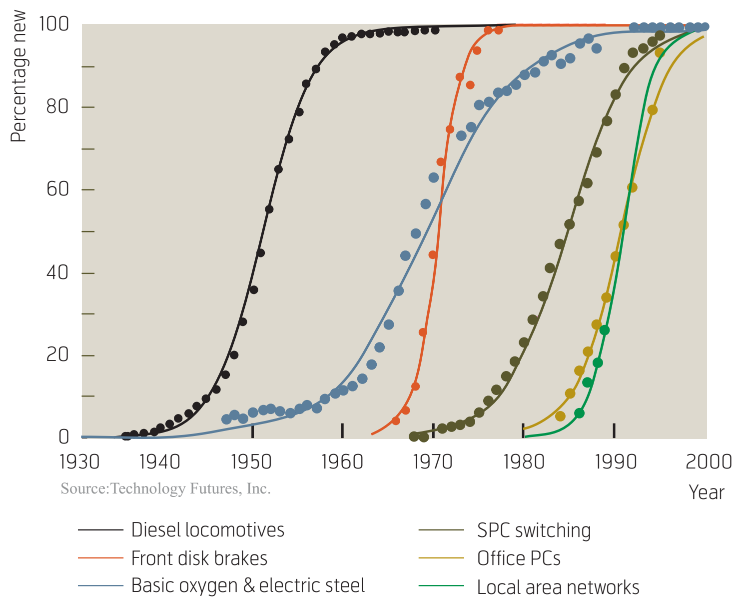

Figure 4 Fisher-Pry examples

2) *Many of the TFI forecasts presented here were sponsored by the Telecommunications Technology Forecasting Group (TTFG) comprised of major North American local telephone operators.*

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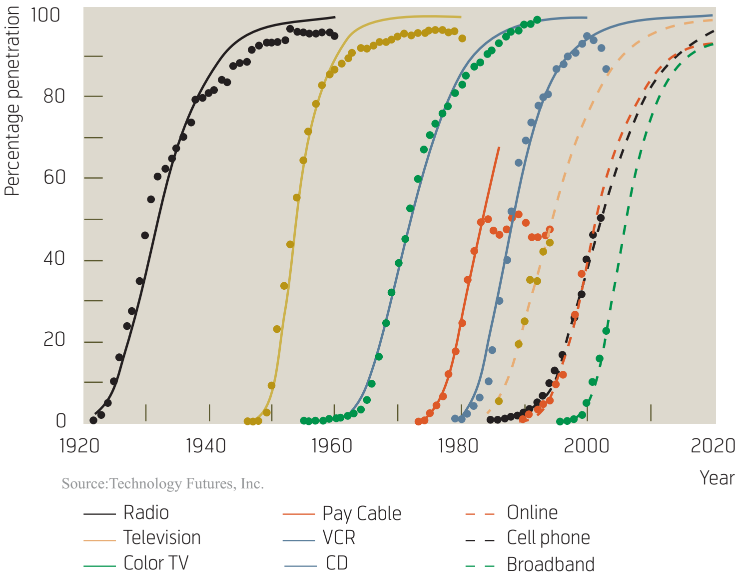

Figure 5 Gompertz examples (US)

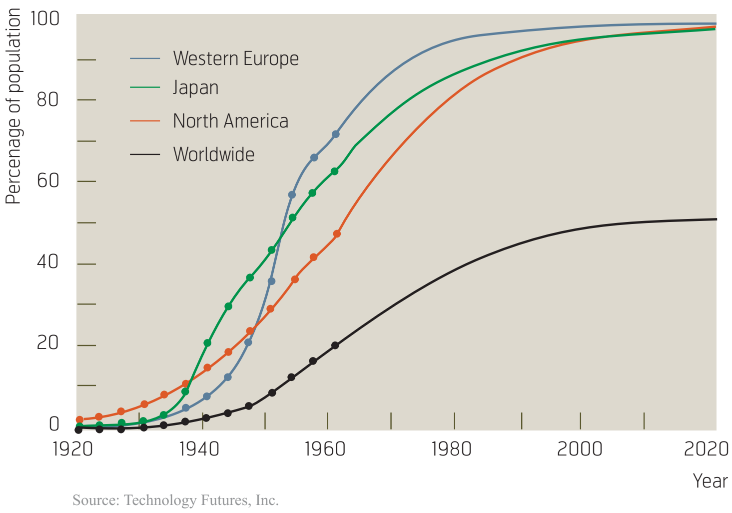

Figure 6 Adoption of cellular telephony

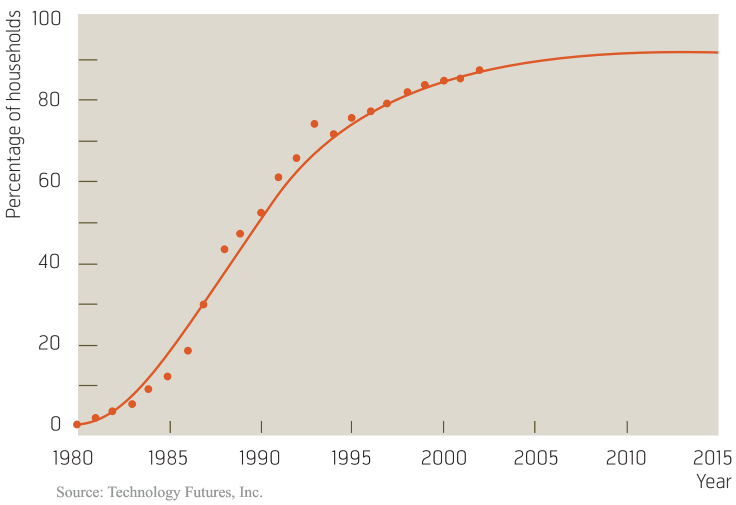

Figure 7 Television households in China

Patterns of technology adoption

The general pattern of technology adoption or substitution is an S-shaped curve when the percentage of the installed base captured by the new technology is plotted over time. For example, Figure 2 plots the adoption of stored program control (SPC) switching by US local telephone companies, measured as a percentage of access lines. Another example is shown in Figure 3, which shows the adoption of color television, measured by the percentage of US TV households.[3)]

The switching example uses a special case of the Logistic model (also used in forecasting) called the Fisher-Pry model [5], given by the formula:

$$y(t) = 1 / (1 + e^{-b(t-a)})$$

The Fisher-Pry model is symmetrical about the 50 % penetration point, given by the **a** parameter. The **b** parameter governs how fast the adoption proceeds. It is a constant for any given Fisher-Pry adoption, but it varies among adoptions as apparent from Figure 4. The Fisher-Pry model is especially applicable to technology-driven adoptions where new technology displaces old technology because it is technically and economically superior.

The color TV example uses the Gompertz model, given by the formula:

$$y(t) = e^{-e^{-b(t-a)}}$$

The Gompertz model also forms an S-shaped curve, but it is asymmetric, with the adoption slowing down as it progresses. The Gompertz model is usually better for consumer adoptions. Again, the **b** parameter governs the rate of adoption which varies by technology as shown in Figure 5. The **a** parameter gives the inflection point which occurs at 37 % substitution.

The Fisher-Pry, Gompertz, and Logistic models can be applied at the country, regional, or worldwide levels, although for a given technology substitution or adoption, the **a** and **b** values, as well as the ultimate penetration level (not always 100 %), may vary. For example, Figures 6, 7, and 8 show the penetration of cellular telephony worldwide and for several regions, television penetration in China, and broadband penetration in Western Europe.

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3) *For a more detailed explanation of these models see [4].*

Using technology market adoption models for forecasting

With any of the models, we can forecast the future course of a partially complete substitution. Using regression methods, the appropriate model is fit to the historical data to obtain best-fit estimates of the parameters **a** and **b**. For example, Figure 9 shows the Gompertz model fitted to historical broadband penetration data assuming that ultimately 95 % of US households adopt broadband, a reasonable assumption given the drivers and the fact that broadband penetration in Korea already exceeds 75 % as shown in the figure.

Figure 10 shows an example using the Fisher-Pry model. In this case, we are forecasting the percentage of the installed base of PABX lines that use Internet Protocol switching, based on published historical data and a short-term forecast. (It is common to use planning data or short-term forecasts to slightly extend the available data for forecast of the complete substitution.)

Forecasting adoptions before and at introduction

We can apply these methods even in cases where the substitution has just begun, or has yet to begin, by using appropriate analogies, precursor trends, evaluation of the driving forces, or expert opinion. For example, Figure 11 shows TFI's 1999 broadband forecast when broadband penetration was about 1 %, too early for curve fitting. In that case we used the average **b** value of .21 for the consumer electronic adoptions. As it turned out, broadband has been one of the faster adoptions with a **b** value of .25.

Another example using an analogy comes from TFI's 1995 HDTV forecast shown in Figure 12. The forecasts assumed HDTV penetration in the US of 1 % at year end 2000. This was based on experience with other media technologies which indicated it usually takes three years to complete trials and another two years to go through the early commercialization stage and reach 1 % adoption. The forecast also assumed that once the adoption of HDTV began, it would be adopted at the same rate that color television was; in other words it would have the same Gompertz **b** value. The forecast we made in 1995 is not too different from our current HDTV forecast shown in Figure 13. Of course, now we have historical data and can use curve fitting as well as analogies.

A third example of using substitution analysis without historical data comes from TFI's 1989 forecast of SONET, North America's version of SDH. As shown in Figure 14, a simple analogy was used (fiber pene-

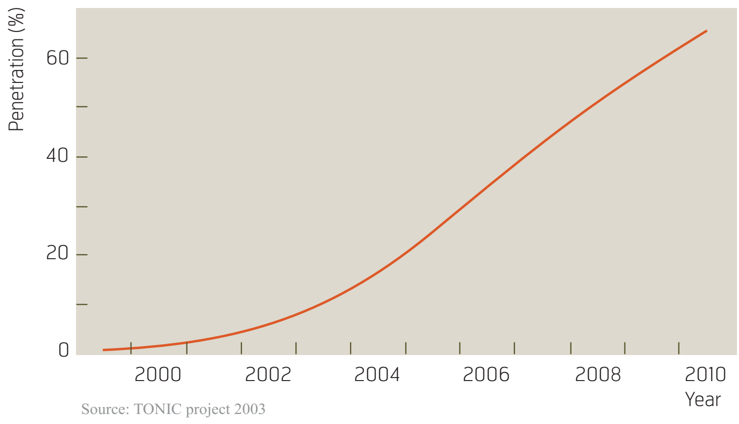

Figure 8 Broadband adoption, Western Europe [10]

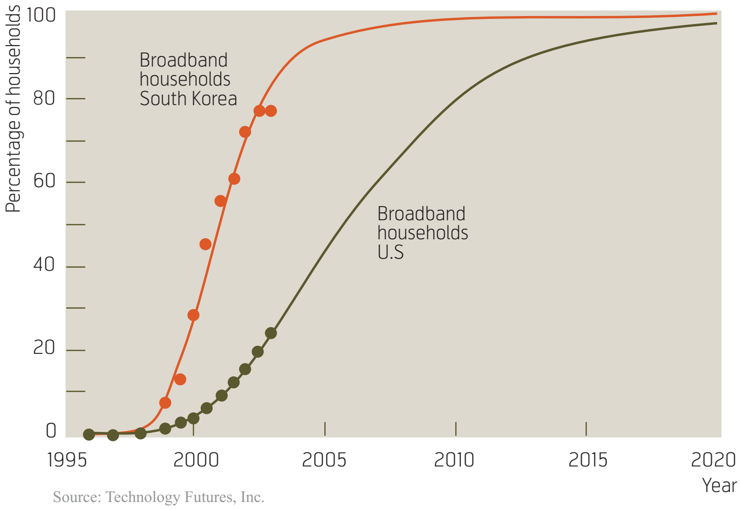

Figure 9 Broadband households (Data Sources: US Federal Communications Commission and Ministry of Information and Communication Republic of Korea)

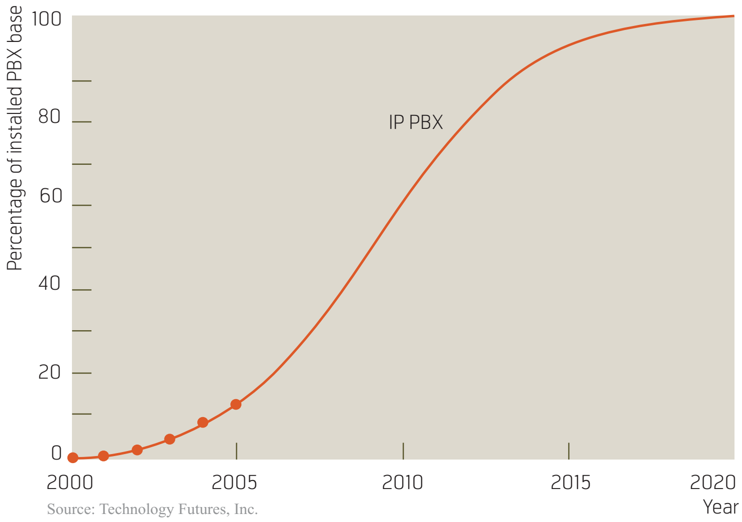

Figure 10 IP PABXs (US)

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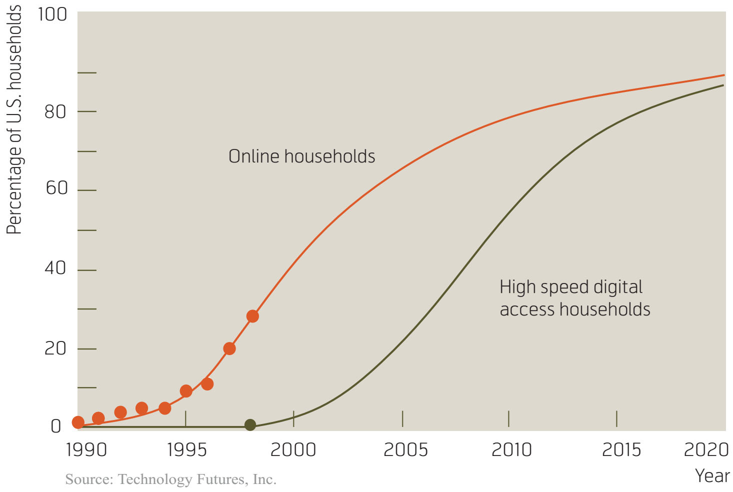

Figure 11 Forecasting by analogy – Broadband (1999 Forecast) [11]

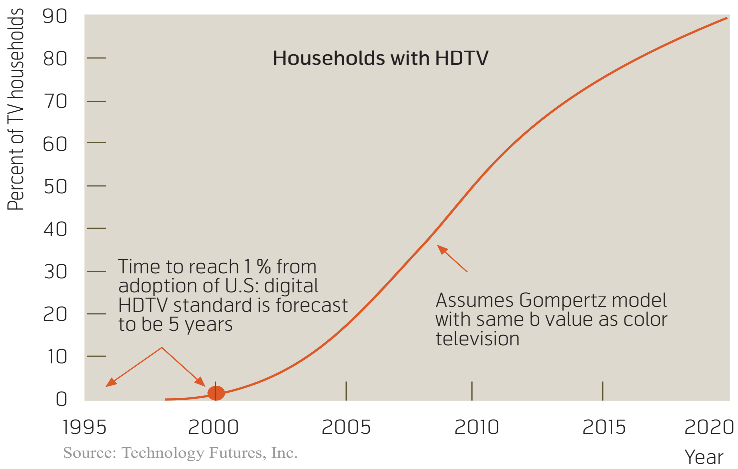

Figure 12 Forecasting by analogy – HDTV (1995 Forecast) [12] (This graphic appeared in Introduction to Technology Market Forecasting, 1996, p. 25)

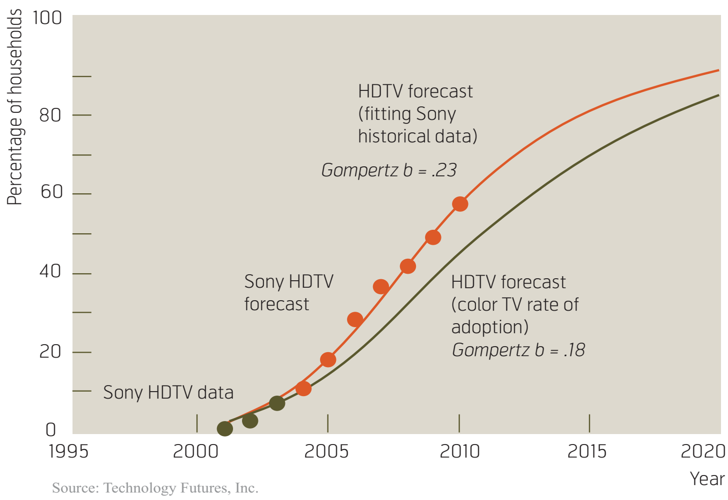

Figure 13 HDTV and DTV adoption (2004 Forecast)

tration of interoffice facilities), but this was supplemented by the results of an expert opinion survey which indicated the reasonableness of the forecast.

A final example of using substitution analysis without historical data employs trend analysis and linked substitutions to forecast the deployment of very high-speed broadband (24 Mb/s and above), which generally requires fiber to or close to the customer's home. TFI's current forecast of subscribers to higher data rate broadband is shown in Figure 15. This forecast reflects the assumption that the average date rate increases by about 40 % per year, the typical rate experienced with analog modems (see Figure 16) and consistent with Moore's Law. To achieve these subscriber levels, a larger percentage of households must have very highspeed broadband available. Figure 17 shows the minimum availability to support the subscriber forecast, which provides a reasonable scenario for fiber deployment.[4)]

Caveat

We have had good luck forecasting substitutions that have not started yet. For example, the early HDTV, broadband, and SONET forecasts shown above have proven reasonably accurate. However, this type of forecasting is inherently uncertain because we have four basic questions:

- Will the new technology be successful at all?
- When will it begin to be adopted?
- What is the ultimate penetration?
- What will be the rate of adoption?

Drivers and constraints

A method we have found extremely useful in addressing the four questions listed above involves listing the drivers and constraints for the substitution. For example, the drivers for VoIP include:

- The growth of data traffic relative to voice traffic
- The growth in broadband access
- The overall improvement in Internet performance
- VoIP's ability to use generic software and hardware
- The avoidance of subsidies, taxes, and access charges

[4)] *The quantitative relationship is based on analogies to other adoptions, specifically, cable television, pay cable, and pay-per-view, [6].*

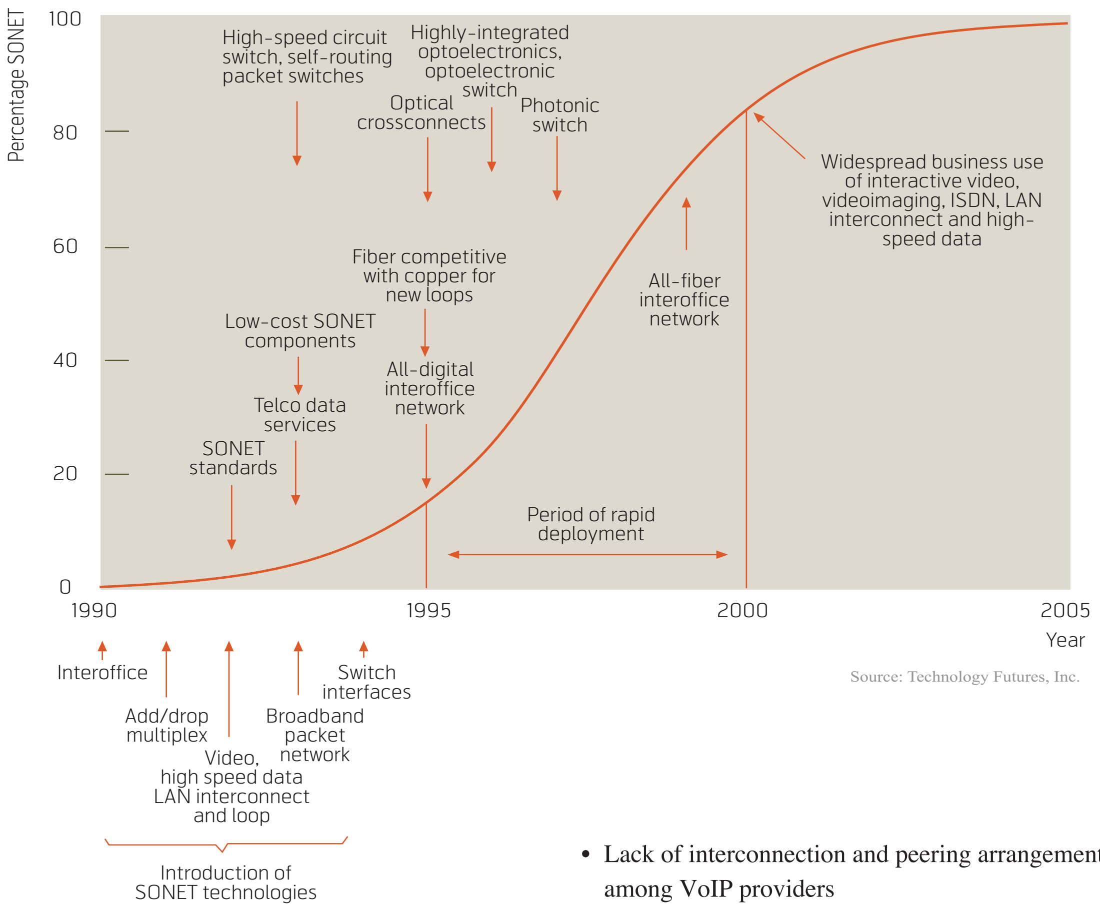

Figure 14 Adoption of SONET/SDH (1989 TFI Forecast) [13]

- The ability VoIP provides to integrate voice with other applications such as instant messaging, web conferencing, and call center information
- The potential to be a common denominator for a number of different voice standards
- The potential for quality exceeding toll-grade telephony
- The potential for greater privacy

Working against the drivers are a number of constraints on VoIP adoption, including:

- Some types of VoIP require that the user has Internet access
- Some types of VoIP require broadband access
- Potential delays, restrictions, and cost burdens to add surveillance capabilities required by law enforcement
- The need to provide location information for emergency services
- Lack of interconnection and peering arrangements among VoIP providers
- Reputation of having inferior quality
- Some types of VoIP are considerably more insecure and less private
- Defensive responses from traditional carriers

Clearly there are both significant drivers and constraints for VoIP adoption. The first question to ask is: What is the balance? In the case of VoIP, the

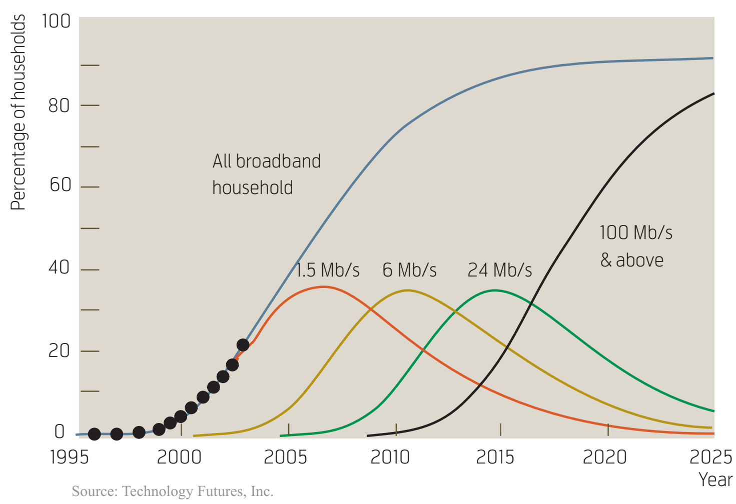

Figure 15 Broadband households by nominal data rate, percentage of households (US)

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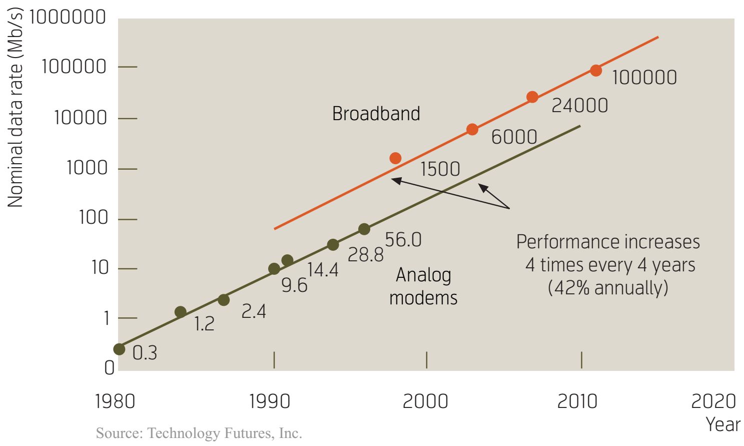

Figure 16 Trend in residential access data rates

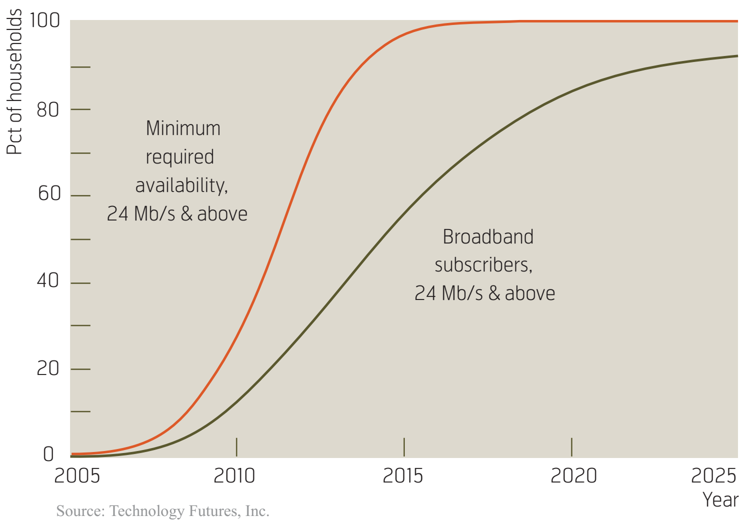

Figure 17 Broadband minimum availability – 24 Mb/s & above

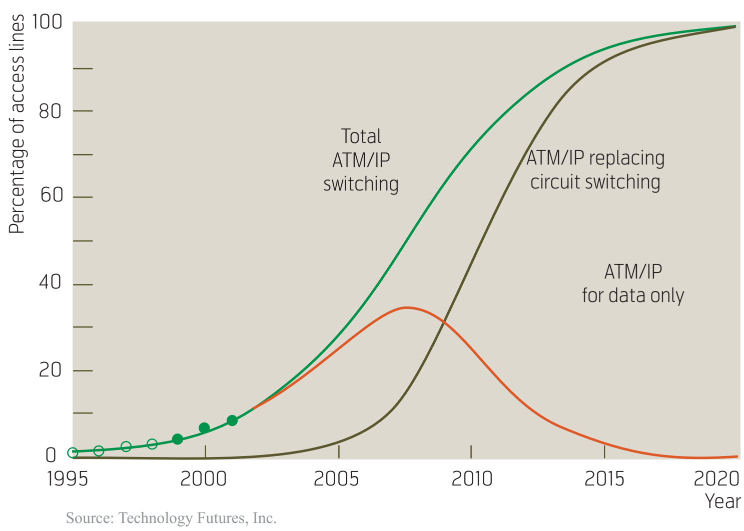

Figure 18 Adoption of VoIP for local telephone switching in the US (2003 TFI Forecast) [14]

drivers and constraints appear to be reasonably balanced. The second question is: Are the constraints likely to be overcome over time? For VoIP, it appears that all of the constraints are likely to be overcome within a few years and none of them stops progress in the meantime. This argues that the substitution of VoIP for traditional circuit switching will indeed take place, but not overnight, and will follow a typical, moderate substitution pattern such as the one shown for US telephone operators in Figure 18. For situations and applications where VoIP is most favorable – cross-border telephony, enterprise networks, and China, for example – we expect faster substitutions.

Multiple scenarios

We often use multiple scenarios to capture and convey uncertainty, especially for substitutions that have not started yet. For example, our distribution fiber forecasts have long used alternative scenarios. Figure 19 shows our 1989 forecast which had two scenarios: an aggressive one with US telephone companies quickly rolling out video services and a slower one reflecting the evolution toward broadband services in general. The late scenario still looks reasonable, and, while the early scenario clearly did not happen, it anticipated the plans (ultimately abandoned) formulated in the mid-1990s by several US telephone operators. Our post-1989 distribution fiber forecasts have reflected three scenarios based on alternative strategies for meeting the broadband demand. Figure 20 shows the current version of the scenarios, reflecting the fact that, in the US at least, there remains considerable uncertainty.

Using substitution models to forecast sales

The S-shaped curves, which measure penetration of the installed base, can be easily used to derive the distribution of *first time* sales (or additions) of the new technology. (It is the annual change in the installed base curve.) First time sales largely define total sales in the period before a replacement market develops. This curve is usually bell-shaped, although not necessarily symmetrical as shown in Figures 21 and 22 for the SPC switching and color TV examples. First time sales peak at the inflection point in the penetration curve. For example, the worldwide cellular penetration forecast (shown in Figure 6) implies the first time handset sales shown by the brown curve in Figure 23. Note that the brown curve clearly indicates that rapid growth in handset sales that occurred in 2000 was not sustainable.

Using substitution models to forecast growth rates

The annual growth rates of installed base and sales are often of interest. For example, it is common to speak of a market growing at X %. For services, the growth in the installed base is important (e.g. the percentage of households subscribing to broadband); for equipment sales, the growth of additions (e.g. sales of cellular handsets) is of interest. Figure 24 shows the percentage growth rate for the installed base assuming the Fisher-Pry model and no growth in the total market.

Note from the figure that the growth rate is high at first, but 20 % of the way through the substitution it falls off rapidly. Thus, the percentage increase follows a pattern opposite of the adoption curve – just when the adoption curve becomes steep, the growth rate plummets. Additions are getting larger, but from a larger installed base, which deflates percentage growth. (The falloff is even more dramatic with the Gompertz model or for equipment sales.)

When bad forecasts win

These observations about growth rates are of far more than academic interest because claims of rapid growth are made often and, when the underlying dynamics are ignored, big mistakes can be made. For example, an often cited contributing factor to the over-building of fiber facilities was the widely-publicized statistics and forecasts of the growth in Internet bandwidth. These held that Internet bandwidth was doubling "every 100 days" or "every 3 or 4 months" [7,8], equivalent to an annual growth rate in the neighborhood of 1100 %. Less fantastic were reports of doubling every 6 months, or 300 % annually [9].

Unfortunately for investors, they were all wrong. Actual Internet bandwidth growth has been closer to 100 % annually. The over-zealous forecasts assumed an exponential model with an extraordinarily high growth rate continuing into the future – "Moore's law on steroids" was the quip. However, the high early growth rate was fueled by millions of new Internet users coming on line in the 1990s. The forecast shown in Figure 25 (from a 1999 TFI study) made clear that the growth rate in first time users was declining and would decline in the future.

The high early growth rate from new users was amplified by the increase in bandwidth per user as people spent more time online and as their computers and applications grew more sophisticated. This factor, increasing roughly at the rate of Moore's law or about 57 % annually, also partially offset the inevitable fall-off in the growth rate from new users, but not enough

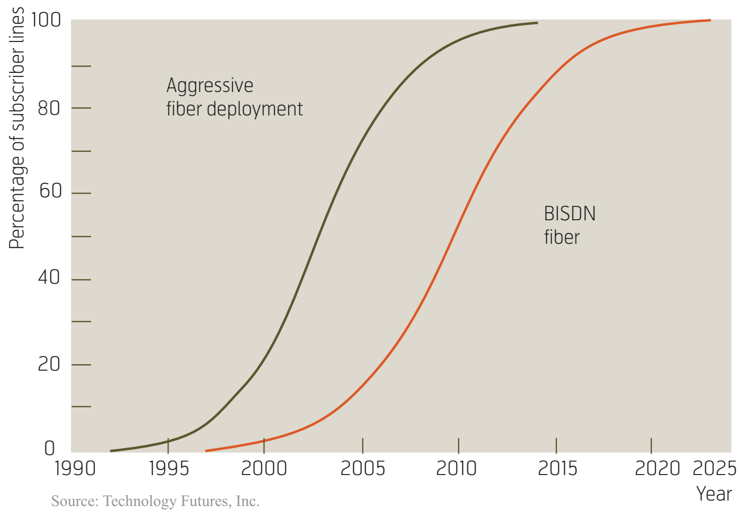

Figure 19 Alternative scenarios for distribution fiber in the US (1989 TFI Forecast) [15]

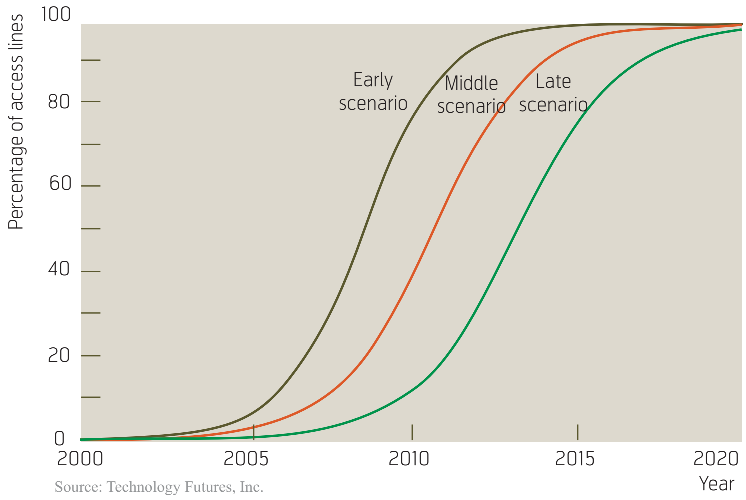

Figure 20 Alternative scenarios for distribution fiber in the US (2003 TFI Forecast) [16]

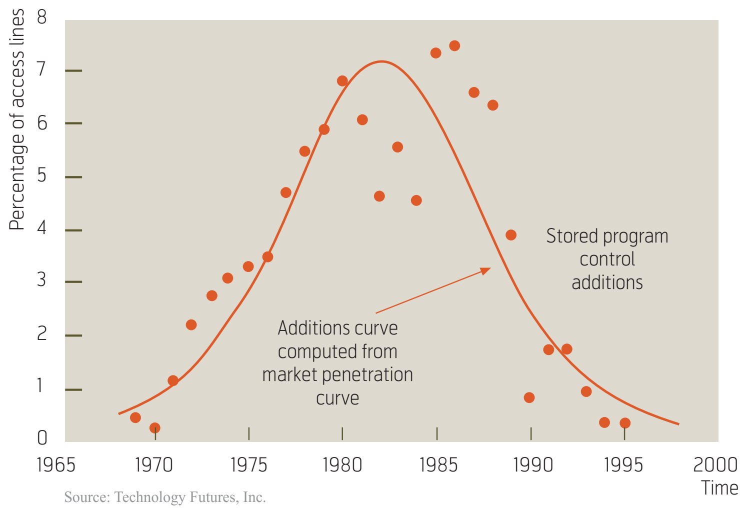

Figure 21 Additions of SPC access lines by local telephone companies

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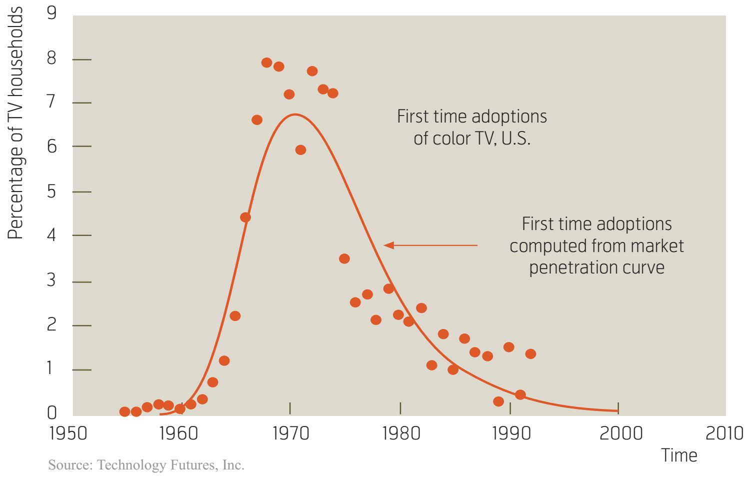

Figure 22 First-time adopters of color television

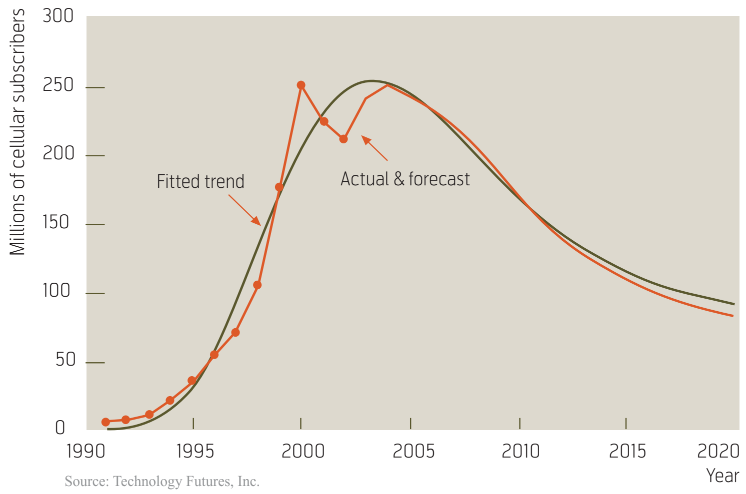

Figure 23 Worldwide first time cellular subscribers

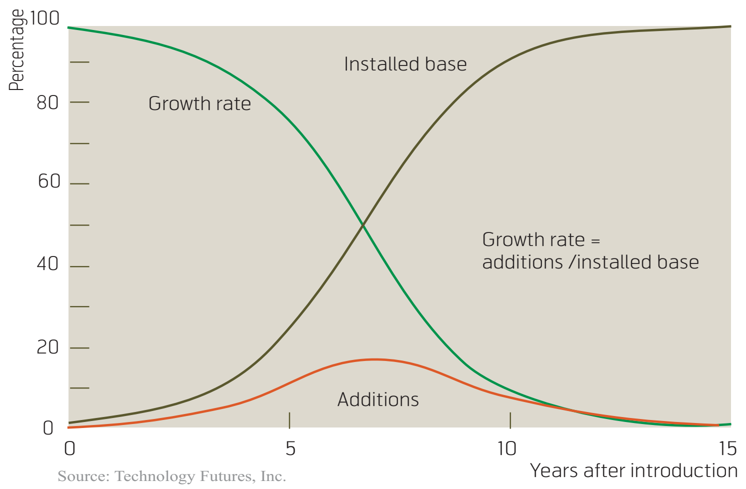

Figure 24 Percentage increase in new technology installed base (Fisher-Pry Model)

to sustain growth rates of 300 % and more, as shown in Figure 26 (also from the 1999 TFI study).[5]

Conclusions

We have shown a few representative examples of telecommunications technology forecasts. There are many more that tell much the same story. There are several points that we have not mentioned or that we should reemphasize:

Although the methods are simple there can be complications in practice: multiple substitutions, market segmentations, aggregation issues, linked substitutions, and resource constraints, to name a few. These can be handled with extensions to the models.

There remains considerable uncertainty, especially when the substitution or adoption has not started yet. Multiple scenarios are useful in addressing and conveying uncertainty.

A drivers and constraints analysis helps address key issues such as a technology's likely success, ultimate market, introduction time, and adoption rate.

Forecasting how fast a new technology will replace an old one is much easier than forecasting which of two new closely competing technologies will win. The latter relies more on qualitative methods and considerable luck. For example, we are reasonably certain that by 2015 most households in the industrialized world will be served by distribution fiber. But the technology choice for the final link is far from settled: VDSL on copper cable, fiber PONs (one of several varieties), wireless (again one of several varieties), coaxial cable, and electric power lines are all candidates.

Most of the examples here are from the US, but the methods have been used everywhere. The starting points, rates of substitution, ultimate penetration points, and technology choices vary, but the basic principles of technology adoption appear to be fairly universal.

The mathematical modeling is only a small part of the forecasting equation. Even largely quantitative forecasts like the ones shown here require substantial qualitative work. Forecasting is seldom a "turn-the-crank" process, and forecasting technology adoption is no exception.

---

5) *Another problem was poor analysis of the historical growth rate. Individual Internet service providers might experience an extremely rapid growth spurt and in the very early days of the Internet the growth rate was extraordinary. But average growth rates across the Internet and over the 1990s were more moderate.*

In summary, our experience with technology forecasting in telecommunications has been excellent and we continue to use the same basic approach and methods. The Five views gives us the big forecasting picture and the Fisher-Pry and Gompertz models give us the quantitative forecasts that our clients need. Combined with good judgment and knowledge of the industry, this relatively simple approach has usually outperformed industry wisdom and the guesses that often pass for market forecasts. Anyone whose future depends on technology markets will find technology forecasting extraordinarily useful both in gaining insight and understanding, as well as in decision making.

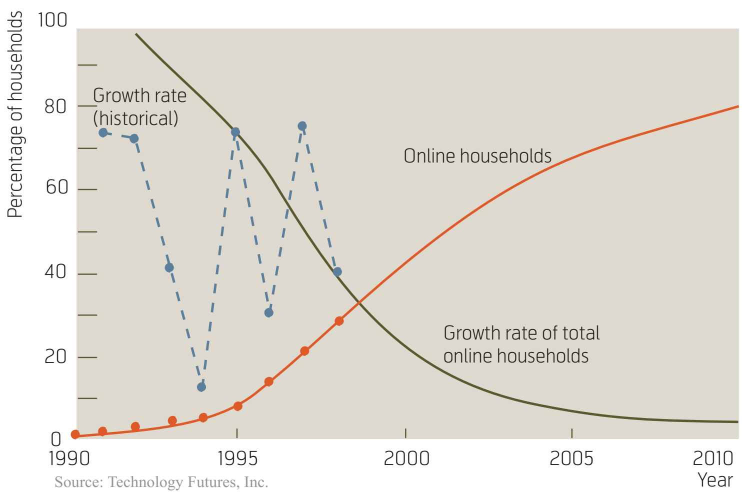

Figure 25 Growth rate in broadband subscribers (1999 TFI Study) (From 1999 TFI private client-sponsored study)

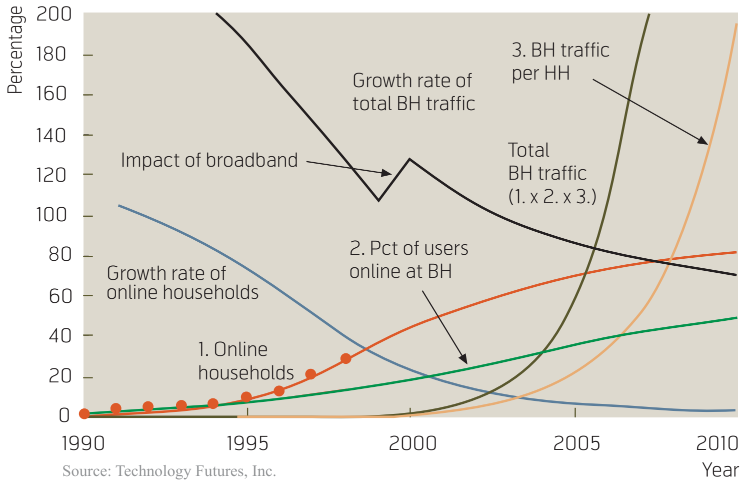

Figure 26 Bandwidth forecast accounting for decrease in online user growth rate (1999 TFI Study) (From 1999 TFI private client-sponsored study)

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Dr. Lawrence Vanston is an internationally recognized authority in the use of technology forecasting in the telecommunications and other high-tech industries. As president of Technology Futures, Inc., Dr. Vanston has been monitoring, analyzing and forecasting telecom technologies and services for more than 20 years. Subject areas include broadband access, VoIP, fiber optics, advanced video services, and wireless communications. An expert on the impacts of new technologies and competition on telephone networks, he often testifies before government agencies. In addition to enhancing planning and strategy, Dr. Vanston's forecasts are often used for estimating depreciation lives and valuations of telecom assets. Before joining Technology Futures in 1984, Dr. Vanston spent four years with Bell Labs and Bellcore in network planning. His academic achievements include an MS and PhD in operations research and industrial engineering, both from the University of Texas at Austin.

email: lvanston@tfi.com

A Senior Consultant with TFI since 1994, Mr. Hodges has authored numerous reports on telecommunications, including studies commissioned by the Telecommunications Technology Forecasting Group (TTFG), comprised of Bell Canada, BellSouth Telecommunications, Sprint-LTD, Verizon, and QWEST. Topics have included Internet access requirements, xDSL technologies, ATM/IP switching, fiber optics, video services, and wireless communications. Mr. Hodges is also an expert witness on telecom depreciation and valuation issues. Prior to joining TFI, Mr. Hodges spent 25 years with GTRE Telehone Operations (now Verizon) as a manager of both technical and financial areas.
Mr. Hodges is a member of the Institute of Electrical and Electronic Engineers (IEEE) and served as Vice-Chairman of its Technology Forecasting and Assessment Committee. He is also a senior member of the Society of Depreciation Professionals. Mr. Hodges holds a BS from Georgia Southern University in Industrial Management and Technology.

email: rhodges@tfi.com

Forecasting residential broadband demand with limited information
– A long-term supply and demand model

CARLO HJELKREM, KJELL STORDAHL AND JOHANNES BØE

The paper is a description of a long-term forecasting model bridging the gap between supply and demand. The demand side is described by choice probabilities, assessed as quantiative representations of several qualitative aspects. The supply side is represented by deployment. Linking supply and demand, supply elasticities may be derived. The model is fed with available information, using the HB@ segmentation.

Carlo Hjelkrem is a Senior Market Analyst in Telenor Networks

Kjell Stordahl is Senior Advisor in Telenor Networks

The safe harbour of utilizing historical information for forecasting purposes is lost when the new technology and services of DSL are introduced. Having little or no demand data, forecasts will face a great deal of uncertainty. In such cases traditional quantitative forecasting models, such as time series models and regression models are left in favour of e.g. scenario techniques and analogies. A group of quantitative forecasting models, which reuire little data, are diffusion models, often used for long-term forecasting of telecom accesses. However, such models describe a syntehsis of supply and demand, and cannot answer questions like what happens to demand when supply is increased.

The model presented is an attempt to bridge the gap between supply and demand through a simple mechanism. The demand side is described by quantitative representations of several qualitative aspects, while supply is represented by deployment.

Consisting of seven segments, the model utilizes the HB@ (Hybrid Broadband Access) segmentation of the Norwegian residential market. HB@ was a project that assessed the technical and financial realisation of different combinations of broadband technologies, such as VDSL (Very high data rate Digital Subscriber Line), HFC (Hybrid Fiber Coax, i.e. cable-TV and Internet modems), FWA (Fixed Wireless Access) and DTH/SMATV (Direct To Home/Satellite Master Antenna Television, i.e. satellite access). The segments are constructed on a combination of three different variables: population density, technologies available and major operators present. Here, the lower the population density, the fewer technologies available and the poorer the supply.

Linking demand to Internet access demand and feeding the model with all available information, the results clearly show that cable modems cannot maintain its dominant role over time, since deployment in Norway is limited. On the otehr hand, access technologies like ADSL and VDSL will obtain major market shares.

Although too early for a long-term model, checking of model performance shows that it has some desirable features.

1 What drives demand?

Before answering this, it would be appropriate to define broadband. Many definitions are used and a thorough discussion of the topic is out of scope for this article. We will simply follow the mainstream definition used by most market practitioners: Broadband in the residential market is local network access with capacity exceeding ISDN; i.e. over 128 kbit/s (256 kbit/s for "Turbo ISDN", offered on a small scale). Regarding today's residential market, this mainly means ADSL, cable modems and fiber to the home.

What drives demand, some short-term factors:

- Increasing Internet access penetration
- Transition to higher capacities: from PSTN/ISDN to ADSL, cable modems, etc.
- Fixed price
- Always On

What drives demand, some longer-term factors:

- Entertainment
- Larger applications
- TV/Video with better quality
- Price reductions

What limits demand, some factors:

- Limited investment and deployment
- Length of subscriber lines
- Price: many Internet surfers cannot defend the cost of a broadband access

2 The Norwegian Internet market

The Gallup Institute of Norway conducts a monthly survey on Internet access penetration of Norwegian households, see Figure 1.

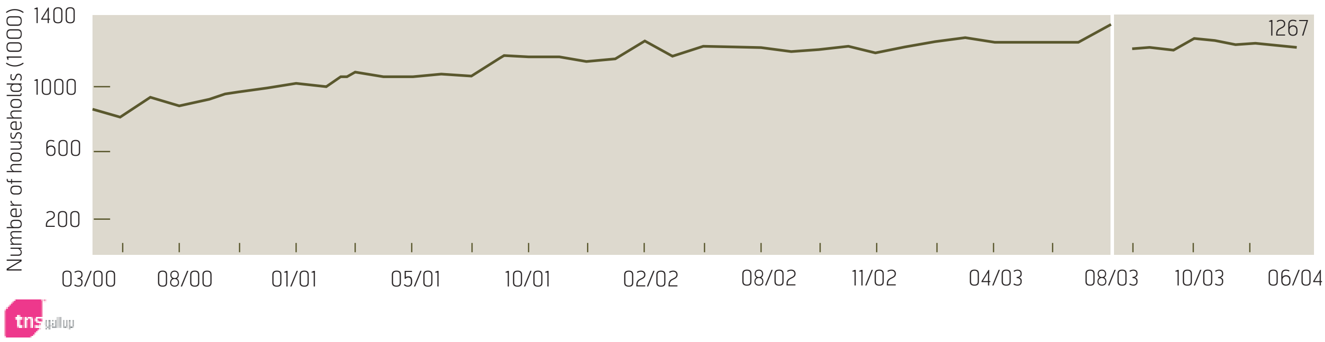

Figure 1 Gallup InterTrack: Monthly Internet penetration survey

As of August 2004, the survey indicates that 1.27 million households are connected to the Internet. With approximately 2 million households in Norway, this means a penetration of about 64 %.

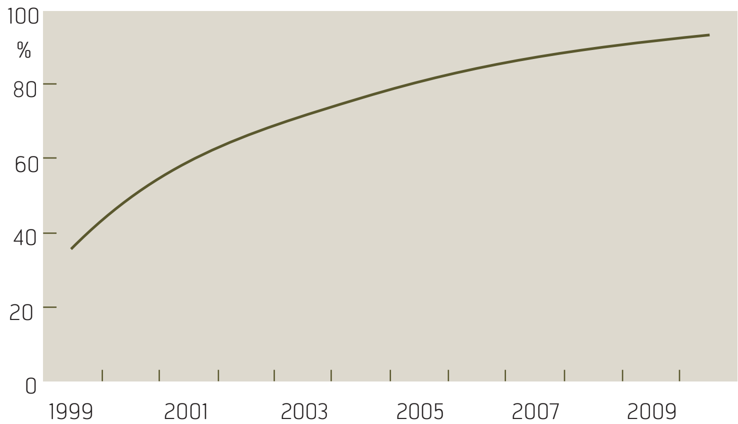

Figure 2 Possible forecast of future Internet penetration of Norwegian households

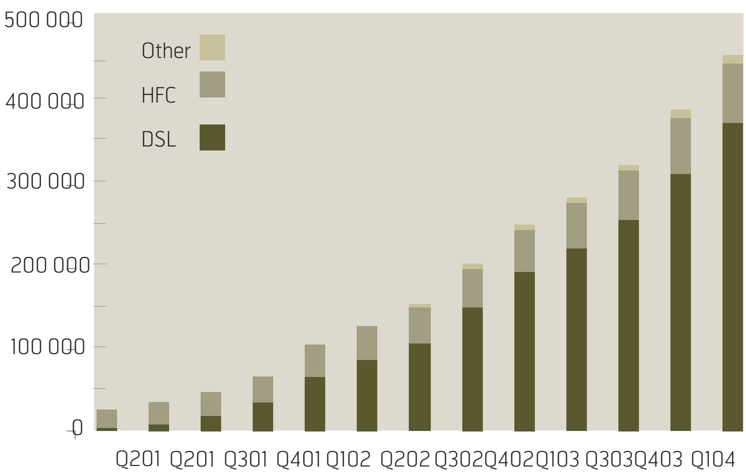

Figure 3 Quarterly demand for Broadband accesses in Norway (Business DSL access demand also included. As of Q1204 these were less than 43,000)

A possible forecast derived from a logistic diffusion model indicates future growth, see Figure 2.

Obviously, this growth must be supplied by available technologies. The crucial question is how much by old technologies, represented by PSTN/ISDN, and how much by the new technologies, represented by different broadband technologies.

Also we want to know what market shares can we expect between the different operators. And last, but not least: How does availability affect demand?

3 Broadband demand in Norway

The graph in Figure 3 shows that Cable modems had an early start, but is now surpassed by DSL. Other technologies are so far insignificant.

Telenor offers a variety of ADSL accesses, depending on up-/downstream speeds and download limitation. It would be too rigorous to list them all, but they are all in the range of:

- 704 kbit/s, no limit: NOK 349 – EUR 42
- …
- 2048 kbit/s, no limit: NOK 549 – EUR 66
  Competitors charge 10 – 20 % less

The installation charges vary, depending on whether campaigns are running, but full price is around NOK 1,000 (approx. EUR 120).

4 HB@ segmentation

HB@ (Hybrid Broadband @access) was a Telenor project that technically and economically evaluated different combinations of broadband technologies, investment plans and rollout plans. Technologies included

- VDSL (Very-high-data-rate Digital Subscriber Line)
- HFC (Hybrid Fiber Coax, i.e. cable TV and Internet modems)
- FWA (Fixed Wireless Access)
- DTH/SMATV (Direct To Home/Satellite Master Antenna Television, i.e. Satellite access)

In order to do this evaluation, the Norwegian residential market was segmented on the basis of

- competition
- geography
- demographics.

Three main segments were identified:

A: Areas with major CaTV networks (HFC > 1,000 subscribers)

B: Areas with large to medium urban settlements without major Cable TV networks (smaller CaTV may be present)

C: Areas with small urban settlements without CaTV and rural areas

Available statistics from Statistics Norway was used, following the definition of urban settlements:

- *An urban settlements is a collection of houses where at least 200 people live, and where the distance between the houses on a normal basis does not exceed 50 metres.*
- *However, for certain types of buildings the distance may be up to 200 metres, e.g. blocks of flats, industrial buildings and sports grounds.*
- *Clusters of at least 5 houses less than 400 metres outside the urban settlements are included into the urban settlements.*

Segment A represents the areas which first started supplying broadband accesses to the residential market. In fact, for a while broadband was associated with CaTV. Also, segment B represents densely populated areas considered attractive to Telenor and other operators. Segment C with its low population density is considered rather unattractive.

As may be seen from Table 1, the areas A, B and C are all divided into sub-areas.

A1 is the area of Telenor's largest competitor UPC[1)], a subsidiary of the Dutch based United Pan-Europe Communication. UPC offers "Triple Play" (Cable

					% of households in		
		Households	Area (km^2)	Households/km^2	Detached houses Farms	Chained houses Semi detached houses Terraced houses	Apartment buildings Dwellings on business premises
A1	UPC	375,000	355	1056	37	30	33
A2	Other CaTV	62,000	78	795	59	26	15
A3	Avidi	410,000	454	903	49	29	22
All of A	> 1000 subs	847,000	887	955	44	29	26
B1	> 300 inh	365,000	512	713	70	21	9
B2	1000<inh<3000	159,000	320	497	82	14	4
All of B		524,000	832	630	74	19	7
C1	200<inh<1000	127,000	353	360	84	12	4
C2	<200 inh	493,000	-		85	11	4
All of C		620,000	-		85	11	4

Table 1 HB@ segments

1) *While UPC was the largest competitor at the time of this segmentation, NextGenTel now keeps that position. NextGenTel is offering LLU.*

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TV, Telephony and Internet) at prices just below Telenor's, and is present in the major cities. About 40 % of their network is upgraded to supply Triple Play.

A3 is the area of Telenor Avidi, Telenor's own cable company. About 30 % of their network is upgraded to supply two-way communication.

The small segment **A2** comprises 25 different cable operators, each with over 1,000 subscribers. On their own, each of them is not considered big enough to finance an upgrading of their network, but in the future both UPC and Avidi may collaborate with them or even buy some of them. As of today, few are offering broadband services.

All in all, segment **A** covers about 43 % of the market and is the part where competition is expected to be the strongest.

B1 includes urban settlements with more than 3,000 inhabitants, but with no cable company of significance (smaller ones may be present). However, because of the population density, it is considered attractive both to Telenor and to their competitors.

Likewise, segment **B2**, with between 1,000 and 3,000 inhabitants, is considered sufficiently densely populated to be attractive to Telenor and at least one competitor.

Although no cable accesses to the Internet are offered, segment **B** is important due to its dense population. It covers 26 % of the market.

Entering segment **C1**, population density drops to below 1,000 and over 200. Only parts of this small segment bordering other segments are considered attractive to any operator of broadband services.

The rather large area **C2** is the area with households living too scattered to be attractive to any operator of broadband services.

Segment **C** is rather large and covers about 31 % of the households, and most of it is rural areas that will have to settle for old technology, unless public authority budgets say something else.

5 Supply and demand in the different segments

Having divided the residential market into the seven HB@ segments, we now need to know something about the distribution of households currently connected to the Internet, across the segments and across the different access technologies used. This will provide the model with a starting point.

Apart from the old technology of PSTN and ISDN, the technologies that HB@ worked on represent the relevant ones. For operational purposes, we have chosen the following groupings:

- PSTN/ISDN
- ADSL (Telenor)
- VDSL (Telenor)
- Cable Modem (HFC)
- Other

The last group is a mixture of different technologies, mainly LLU (ADSL/VDSL) and LMDS.

Regarding Cable Modem, subscriber information for the two A segments (A1, A3) is easily available. And so far, VDSL is a Telenor pilot in the A1 segment. For PSTN/ISDN however, we do not know the distribution. The approximation used is the relative number of households in each segment. The same is done for ADSL and Other.

The total number of households connected to the Internet is then forecast for each segment, using an adequate diffusion model, just the same way as we did for the whole market.

The next step is to distribute the overall forecast for each segment on the different technologies.

The forecasted growth in households connected to the Internet in each segment is the basis of "New Households with Internet Access".

For each of the technologies a choice probability is assessed on the basis of relative "market strength" or attractiveness. Available information on factors like customer service, efficiency of distribution channels, applications, marketing strategies, quality of service, price and others are "rated".

Then, the supply-side is connected by multiplying each Choice Probability by the corresponding deployment (supply), i.e. proportion of households with access to the different technologies. This yields the Potential Demand from New Households with Internet Access, allocated to the different technologies/ operators.

We then assume that a proportion of the households (e.g. 15 %) each year is in "change mode", either because they are moving to a new address or simply because they want to upgrade their access to a newer and faster technology. In the same way as for New

New households with Internet access

Tech choice:	Choice prob:		Deployment:
PSTN/ISDN	4 % declining from '04		100 % whole period
ADSL Telenor	18 % declining from '05		72 % increasing to 90 % in '04
VDSL Telenor	30 % increasing from '04	x	1 % increasing to 80 % in '06
Cable modem	30 % whole period		30 % increasing to 60 % in '05
Other	18 % whole period		25 % increasing to 80 % in '07

Old households with Internet access

Tech choice:	Choice prob:		Deployment:
PSTN/ISDN	4 % declining from '02		100 % whole period
ADSL Telenor	18 % declining from '02		70 % increasing to 90 % in '04
VDSL Telenor	40 % increasing from '04	x	1 % increasing to 80 % in '06
Cable modem	20 % whole period		30 % increasing to 60 % in '05
Other	18 % whole period		25 % increasing to 80 % in '07

Table 2 Forecast Model example, A1 segment

Households with Internet Access, all access technologies have their individual choice probability assessed and multiplied by their corresponding deployment, to yield Potential Demand from Old Households with Internet Access.

This link between deployment and Choice Probability makes it possible, within the frame of the model, to say something about how demand changes if investments are changed.

Summing Potential Demand from New Households with Internet Access and Demand from Old Households with Internet Access, this is in a last step restricted to deployment for each of the technologies in every segment. Thus, we go from Potential Demand to Forecast Demand. In this step, Potential Demand from one technology exceeding its supply is left with the old technology, i.e. PSTN/ISDN.

In the end, forecast demand is aggregated over all the seven segments to give the total market demand.

6 Some model results

As we can see from Figure 4, the results clearly show that cable modems cannot maintain the dominant role they played at an early stage, since deployment in Norway is limited. Additionally, cable operators are struggling against limited investment means. On the other hand, access technologies like ADSL and VDSL will obtain major market shares.

At model level, we may also estimate short term supply elasticities. Some examples have been calculated:

$$El_{ADSL}ADSL = + 0.47$$

$$El_{ADSL}VDSL = – 0.1$$

$$El_{ADSL}HFC = – 0.18$$

$$El_{ADSL}Other = – 0.35$$

$$El_{ADSL}Total = + 0.12$$

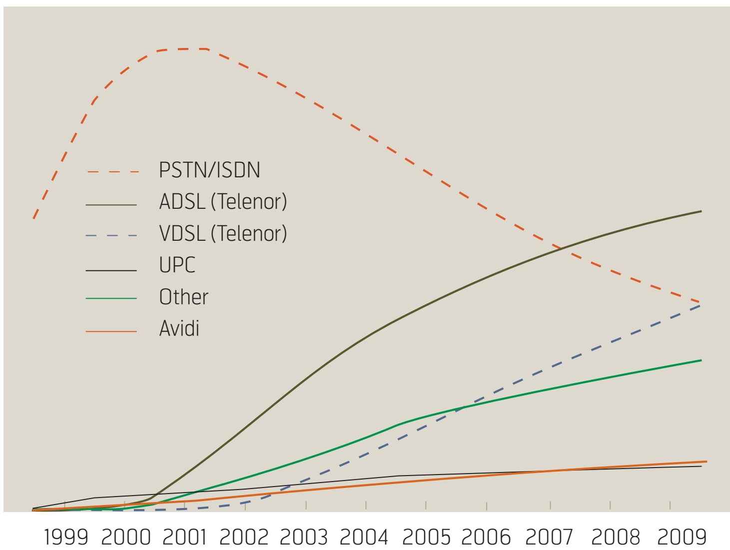

Figure 4 Forecast results

ISSN 0085-7130

Increasing ADSL supply (deployment) by 1 %, increases demand for ADSL from Telenor by 0.47 %, all other factors constant. This makes sense, since increasing deployment means new customers are given the opportunity to get an ADSL access.

At the same time, VDSL, HFC[2)] and LLU have their demand reduced, since ADSL is offered to customers who would potentially get their access from these technologies.

7 Model performance

Looking back, how well did the model do? In order to answer this, some criteria of model performance must be defined. We want it to behave close to any other quantitative forecasting model. Here we have looked at three measures of performance.

First, we have measured the ability to hit the actual observations over time, given by the percentage deviation between the forecasts and the actuals. See Table 3.

Over time we also want the model to avoid a tendency to forecast higher or lower than the actuals, see Score in Table 3. Score is defined as the number of forecasts higher than the actuals (+) and the number of forecasts lower than the actuals (–).

Also it is natural for a forecasting model to show increased uncertainty the longer the forecasting horizon. In Table 3, this is represented by RMSE – Root Mean Square Error:

RMSE (Root Mean Square Error) =

$$SQRT\left(\frac{\Sigma(Actual - Forecast)^2}{Number\ of\ observations}\right)$$

The forecast given in May 01 with a forecast horizon of one year is the forecast for the end of year 2001. The forecast given in May 01 with a forecast horizon of three years is the forecast for the end of 2003.

As we can see from Table 3, the forecasts for DSL, HFC and Other all have a tendency to improve over time. For example, the absolute value of the one year forecasting error for Other diminishes from a high 167 % in May 01 to 7 % in Aug 03. However, all the one year forecasts are given as input from short term models and thus are not a result of this model. Nevertheless, looking at the two and three year forecasting errors we see the same tendency (although not in all cases) and this reflects more of a fine tuning of the model as experience with market and model grows.

Observing the Score, DSL is over-forecasted on the one year horizon and under-forecasted on the three

	Forecast horizon	Forecast given									
		May 01	Aug 01	Nov 01	Apr 02	Sep 02	Jan 03	Apr 03	Aug 03	Score	RMSE
DSL	1 year	39 %	26 %	–12 %	34 %	12 %	2 %	–10 %	1 %	+6/–2	15 485
	2 years	–2 %	–7 %	–5 %	15 %	7 %				+2/–3	15 561
	3 years	–1 %	–4 %	–4 %						+0/–4	6 246
	Average	12 %	5 %	–7 %	25 %	10 %					
HFC	1 year	28 %	3 %	7 %	–4 %	–4 %	–11 %	–12 %	–10 %	+3/–5	5 755
	2 years	34 %	16 %	–3 %	19 %	–7 %				+3/–2	10 373
	3 years	45 %	33 %	21 %						+3/–0	23 707
	Average	36 %	17 %	9 %	7 %	–5 %					
Other	1 year	167 %	135 %	73 %	–25 %	–16 %	–16 %	–11 %	–7 %	+3/–5	8 439
	2 years	44 %	43 %	–16 %	–4 %	–19 %				+2/–3	12 425
	3 years	21 %	23 %	2 %						+3/–0	10 697
	Average	77 %	67 %	20 %	–15 %	–17 %					

Table 3 Model performance

2) *The example is from the A1 segment, with a major cable operator.*

year horizon. Again, all the one year forecasts are given as input from short term models and thus are not a result of this model. For the three year horizon we only have three observations, really a bit too few to evaluate the model. Similar conclusions may be drawn for HFC and Other.

In simple words, the RMSE measures the average of the forecast errors at each forecasting horizon. Normally, it should increase over time. While RMSE for HFC is clearly increasing with forecasting horizon, this is not the case for DSL and Other. However, with only three observations for the three year forecasting horizon, this is expected to change substantially as we gain more data.

So, the conclusion is that we do see some desirable model characteristics, but for a long term model it is really a bit early to tell. Time will show.

8 Summary

The model presented is a simple model aiming at describing the most important market mechanisms. It uses available information where possible, utilizing the HB@ segmentation, which also is a guide to understanding the competitive scene of the Norwegian Broadband market.

The model helps us forecast how much of the demand will be represented by PSTN/ISDN and how much will be represented by the new broadband technologies. Furthermore, it distinguishes between different broadband technologies, such as DSL, HFC and FWA, and indicates what market share Telenor may expect.

An important characteristic of the model is that it gives guidance to what role availability plays, through answering the question of what the expected change in demand is, when deployment is increased/ decreased.

Looking back at how the model has performed over the last three years, it shows some of the model characteristics of regular quantitative forecasting models.

Carlo Hjelkrem (45) is Senior Market Analyst in the Market Analysis Group in Telenor Networks where he is responsible for broadband access demand forecasting. Before joining Telenor Networks he worked for Bell Canada and Norwegian Telecom in various capacities. Carlo Hjelkrem holds a Master of Economics from the University of Oslo.

carlo.hjelkrem@telenor.com

For a presentation of Kjell Stordahl, please turn to page 2.

Johannes Bøe (43) is a Senior Advisor in the New Revenues Group in Telenor Networks. He is the former leader of the Market Analysis Group in Telenor Networks. Before joining Telenor Networks, he worked as a Forecast Analyst in Norwegian Telecom.

johannes.boe@telenor.com

Mobile market dynamics

KJELL STORDAHL, IRENA GRGIC GJERDE, RIMA VENTURIN, K.R. RENJISH KUMAR, JARMO HARNO, ILARI WELLING AND TIMO SMURA

Kjell Stordahl is Senior Advisor in Telenor Networks

Irena Grgic Gjerde is Research Scientist at Telenor R&D

Rima Venturin is Research Scientist at Telenor R&D

Jarmo Harno is Research Scientist at Nokia Research Center

K.R. Renjish Kumar is Research Scientist at Helsinki University of Technology

Although mature, the global mobile market is still foreseen to grow due to the potential of new markets, fixed-to-mobile substitution, and emerging technologies such as EDGE, 3G – WCDMA, CDMA. Predicting the evolution of such a market with respect to the number of subscribers, the way they will use the services, the amount of money they will spend on telecom services, their choice of technology and terminals development are some of the pivotal ingredients for designing robust business models and reacting effectively on the changes in the market. The forecasts presented in this article show the market dynamics with respect to some of the above topics. The focal market is the mobile market in Western Europe, and the development of the number of users and number of handsets in use related to different access technologies is forecast. The development of the mobile subscriptions per technology is described as well. The results presented in this article are achieved in the CELTIC Eureka project – ECOSYS [18], and are also using the forecasting techniques and models developed in the IST TONIC [14] and AC 364 TERA [15] projects.

1 Introduction

In recent years, the global mobile market has seen unprecedented growth in its subscriber base. Globally, the mobile subscribers overtook fixed-line subscribers in 2002 and now stand at around 1.5 billion. This growth is expected to continue in the future due to the new emerging mobile technologies and services in mature markets, and the potential of the emerging markets.

But the mobile market is also rather complex and dynamic due to several reasons – various technologies implemented in the network infrastructure, strong regulation, migrations towards 3G, new roles and actors playing in the market, hard competition between the actors, the myriad of services they offer to the users, who are requiring more and becoming steadily more aware of technological advances that can improve their everyday life. Predicting the evolution of such market with respect to the number of subscribers, the way they will use the services, the amount of money they will spend on (tele)com services in the future, their choice of technology and terminals development are some of the pivotal ingredients for designing robust business models and reacting effectively on the changes in the market. Forecasts on the above listed topics are very important for anyone dealing with economic and strategic issues, for example designing business models, planning a strategy or running a techno-economic analysis. More information on the relevance of forecasts for techno-economic evaluation of the rollout of different technologies can be found in [13]. Examples of techno-economic evaluations of mobile rollouts of new technologies and business cases can be found in ([2–4], [6], [8–9], [11]).

This article presents long-term forecasts for the mobile markets in Western Europe covering the period 2004 – 2012. In particular, the development of the number of users and number of handsets in use with respect to different access technologies, and the development of the mobile subscriptions per technology are focused on. Four major technologies were considered – 2G/GSM, 2.5G/GPRS, 2.75G/EDGE, 3G/WCDMA. When arguing for the trends in the forecasts of the market development, different issues were taken into account – technologies available in both core and access portions of the network, services foreseen to be offered and their expected usage, terminals evolution and their capabilities, and the natural development of society – population, consumers' buying power and average spending on telecom and content industries, etc. The 3G-rollout plans for different operators were discussed as well. Though the monthly subscription fee would remain the same independent of technology, the functionality and capacity ability increases along with new technology generations. This opens for offering new services and new ways of distributing the content, which in turn generate more traffic and require higher traffic capacity. These factors are consequently the key for higher revenue and higher ARPU.

The results presented in this article are achieved in the CELTIC Eureka project – ECOSYS [18], in the activity dealing with the market dynamics/forecasts for both fixed broadband and mobile industries. The EU projects IST 2000-25172 TONIC [14] and AC 364 TERA [15] were predecessors to ECOSYS, where the pillars of the forecasting model used to get the results presented in this article were developed. Another project, IST TONIC, has also used a similar approach and made long-term forecasts ([7], [12]).

ISSN 0085-7130 © Telenor ASA 2004

Ilari Welling is Research Scientist at Nokia Research Center

Timo Smura is Research Scientist at Helsinki University of Technology

The article is organised as follows: Before presenting the forecast results in Chapter 5, we first give a brief overview of the technologies considered for the forecast studies in the next chapter. Services for the 3G market, convergence issues and the fixed-mobile substitution are described in short in Chapter 3, followed by the reflections on the 3G rollout plans of the operators playing in the Western European markets in Chapter 4. Chapter 5 discusses the mobile handset issues. Finally, concluding remarks are presented in Chapter 7.

2 Technologies considered

Cellular, nomadic, broadcasting and proximity technologies were studied for the forecasts planning, but in this article we focus on the cellular technologies. Cellular technologies initially considered included the complete spectra – from the GSM and HSCSD, via GPRS and EDGE, towards UMTS/WCDMA, and further to the 4G. The four most significant of these technologies were considered forecasts. The other investigated technologies were not further focused on

Label	Technology	Description
2G	GSM	Global System for mobile communications (GSM) is a circuit-switched digital cellular technology standard primarily suitable for voice services. However, GSM also supports narrowband data service. GSM utilizes the FDMA/TDMA transmission technique and operates at 900, 1800 and 1900 MHz frequency bands. The 200 KHz frequency spectrum is divided into 124 frequencies, each of which is then divided into 8 time slots. GSM systems offer data rates ranging from 9.6 to 14.4 kb/s per slot. GSM introduced the concept of global roaming and short messaging services (SMS).
2.5G	GPRS	General Packet Radio Service (GPRS) is a packet-switched technology implemented over the existing GSM network; it operates in the same frequency bands and utilizes the same transmission techniques. Packet switching over multiple time slots makes GPRS spectrally efficient and enhanced data rates of up to 171 kb/s (theoretical) can be achieved. In practice, these rates may vary depending on the number of slots made available by the operators. GPRS is better than HSCSD in handling the bursty behaviour of data services. Voice services are still handled by the circuit-switched GSM part.
2.75G	EDGE	Enhanced data rates for GSM evolution (EDGE) is considered as an intermediate step in the evolution of the GSM family of technologies from GPRS to UMTS. EDGE differs from GPRS only in the access network, while the core network remains unchanged. Hence, an operator can easily upgrade its GPRS network to EDGE. It uses the 8-PSK modulation instead of the GMSK modulation used in GSM, thus achieving 48 kb/s per GSM time slot. EDGE provides better spectral efficiency than GPRS but it also requires higher radio signal quality (higher signal to noise ratio). This asks for more base stations to be added compared to those in the GSM networks. EDGE supports the four QoS classes adopted by 3GPP and promises data rates of up to 384 kb/s (for pedestrian) and 144 kb/s (for vehicles). EDGE and WCDMA are complementary technologies. Since EDGE and WCDMA share the same packet core network, many GSM operators tend to exploit the flexibility of both radio access solutions. Therefore, it is feasible to expect that most GSM operators will offer 3G services on a combined WCDMA/EDGE network, because EDGE can be seen as a business decision ensuring that operators can compete and defend existing investments and assets due to: · EDGE-enabled services can deliver new revenue streams, · No separate roaming agreements are required as EDGE is covered under GPRS roaming agreements, · EDGE stimulates growth of mobile multimedia services.
3G	WCDMA aka UMTS-FDD as defined by ITU-T in the IMT2000	Universal Mobile Telecommunications System-Frequency Division Duplex (UMTS-FDD) also called Wideband CDMA (WCDMA) is a packet-switched mobile technology standard specified by 3GPP (Release 99). Due to the lack of backward compatibility with 2G, 2.5G, and 2.75G technologies 3G networks and related services have suffered a slow deployment. WCDMA requires minimum 2x5 MHz channel bandwidth for a duplex transmission and provides a maximum data rate of up to 2 Mb/s. WCDMA supports approximately 98 to 196 voice calls over 2x5 MHz bandwidth and also supports the four QoS classes specified by 3GPP. WCDMA enables the provisioning of multimedia services over mobile networks.

Table 1 Cellular technologies considered for the forecasts

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	Data rate typical [kb/s]	Data rate maximum [kb/s]	Connection type	Generation label
TDMA	9.6	9.6	Circuit	2G
GSM	9.6	43,2	Circuit	2G
HSCSD (GSMf)	9.6-14.4	117	Circuit	2G
CDMAone	14.4	14.4	Circuit	2G
GPRS (GSMf)	20–40	117	Packet	2.5G
1xRTT (CDMA)	50–80	153	Packet	2.75G
EDGE(GSMf)	144	384	Packet	2.75G
WCDMA (FDD/TDD)	144	2000	Packet	3G
1xEV(CDMA-2000)	144	2000	Packet	3G
1xEV-DO ph1 (CDMA-2000)	600–1200	2500	Packet	3G

GSMf = GSM family

Table 2 Overview of the cellular technologies

in the forecasts due to either an insignificant market presence (e.g. HSCSD), or immaturity / early stage of development (e.g. 4G, MBWA), or non-predominant presence in Western Europe. For example, the 4G systems are not analysed here, since we anticipate that they will have a limited impact during the period 2004 – 2012, for which the forecasts have been made. One argument includes the fact that the allocation of 4G frequencies is not scheduled before 2007, and technological solutions for networks and terminals, as well as services are under research. It is a possibility that 4G systems will be introduced in 2010, but there are significant uncertainties connected to the introduction. Another example includes HSDPA air interface technology and MIMO systems that are rather interesting, but not considered in the forecasts due to the fact that they are still under development and many uncertainties are related to the potential technological solution. The third example includes an important technology omitted from our forecasts due to its negligible presence in Western Europe – the cdmaOne family of technologies (cdmaOne, CDMA2000 1xRTT, CDMA2000 1xEV-DO, CDMA2000 1xEV-DV) that have recently made inroads into the Eastern European markets. In addition, nomadic (WLAN, WiMax, etc.), broadcasting (DVB-H, DAB, etc.) and proximity (Bluetooth, Ultra-wideband) technologies were not considered in the forecasts presented here.

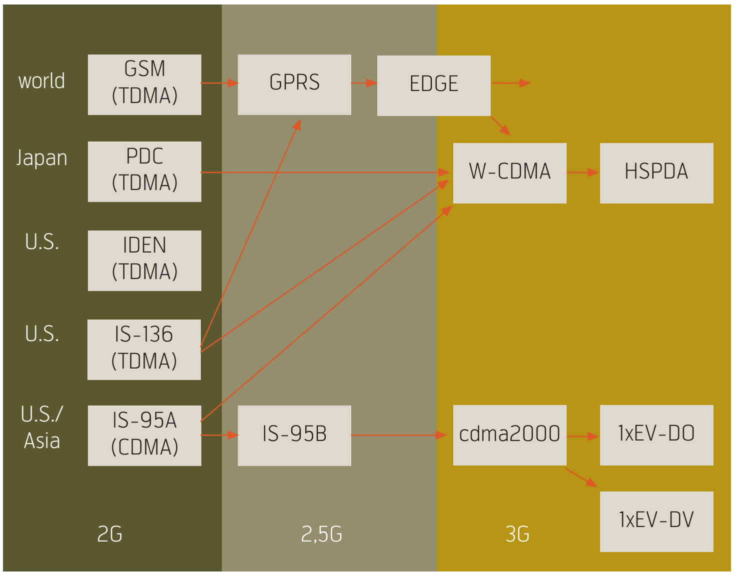

Figure 1 Evolution of 3G standards, from [17]

Four key mobile and wireless access technologies were considered for the forecast studies – 2G/GSM, 2.5G/GPRS, 2.75G/EDGE, 3G/WCDMA. These are briefly described in Table 1, along with a reflection on their evolution in the Western European markets. These markets are playing an important role in the development and presence of different mobile access technologies and services. More details on the other technologies mentioned above, which are not considered in these forecasts can be found in [1].

An overview of the major cellular technologies including the generation labelling, capacity and maximum data rate, as well as the switching paradigm is given in Table 2.

The evolution of different mobile technology standards is shown in Figure 1.

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3 Market considerations

Our assumptions on the future mobile market are briefly presented in this chapter. The services described are drivers for the demand for new system generations and may potentially create additional revenue. When making forecasts we did not develop forecasts on different market segments such as: Consumers, SME and Corporate. Some considerations about the ARPU are presented in this chapter, since the combination of the mobile forecasts and the ARPU helps get a revenue picture. Finally, a brief outline of fixed-to-mobile substitution topics is addressed as well.

3.1 Services

The advent of packet-switched mobile technologies has provided operators with new opportunities in offering new value-added services that in turn generate more revenue. For the revenue estimation it is essential to try to quantify and describe the character of the traffic generated by these services. Though several service classifications are feasible, e.g. with respect to the pricing schemes, QoS requirements, communication type (person-to-person, person-to-machine, etc.), requirements on the terminal capabilities (screen size, resolution, OS, etc.) and the classification, we focused on the 3GPP proposal [16]. The services are organised in nine groups (Information, Communication, Entertainment, Business, Finance, Education, Community, Telematics and Special services) based on several parameters including QoS requirements, business area, etc. Traffic generated by these services can be described for example using four QoS service classes (Conversational, Streaming, Interactive and Background) adopted by 3GPP [16].

3.2 Market segments and the ARPU

Most typical market segments are Consumer and Business, where business subscribers are usually defined as those who do not personally pay for the subscription. Since different segments have different usage and spending patterns in the mobile market, more coarse segmentations within these groups may ease a process of ARPU prediction. For example, the differentiators could be a company size (SME, corporate), type of business (e.g. transportation, industry, public services), age of consumers (youth, established, older people). Both subscription types and the set of services used may vary between segments. For example, many consumer segment customers may use pre-paid subscription types (may to some extent lead to the restriction of a subscribers' consumption), while this could be considered as an unusual situation for business subscribers. Another interesting aspect within the 3G-market could be the issue of "mixed" subscriptions. "Mixed" subscriptions imply that the user may use the services for both private and professional purposes, but his company pays the subscription. Special rules and policies could determine his usage, e.g. the permission to use a certain (specified) set of services, pre-programmed set of phone numbers, refund via a tax system, etc. Therefore, the proportion of different segments could vary between countries.

The statistics of ARPU figures for certain markets are usually based on country statistics, where the total mobile telecom revenues are divided by the total number of subscriptions. As the future ARPU estimations are extrapolations of the historic data, this leads to ARPU forecasts that are not necessarily the right basis for the ARPU prediction for the 3G case.

Firstly, as we are modelling the usage amounts and thus spending per person, the subscription base is not the right reference, since one should look at the real average revenue per user, including both monthly subscription fee and usage tariff. In many Western European countries people tend to have more than one subscription, making ARPU per subscriber clearly higher than ARPU per subscription. For example in Finland, the subscriber penetration is near the 75 % level of subscriptions [21].

Secondly, ARPU levels differ substantially between different types of operators. Levels differ in different market areas (Eastern Europe and Western Europe), but also from country to country. Even within one country one operator might have twofold ARPU compared to another. A high percentage of business customers and high data revenue proportions are correlating with a high ARPU level of the operator. Mobile Virtual Network Operators (MVNO) in many cases focus on the low-end consumer segment competing with low costs and low tariffs. For 3G operators, it is highly important to consider their profile relating to market segment and new data related services.

3.3 Fixed-to-mobile substitution

Another phenomenon that influences mobile revenues and demand is the so-called fixed-to-mobile substitution. The migration from fixed to mobile has an effect on the mobile user and on subscription evolution. In addition, the migration implies that the services (and the traffic generated by these services) traditionally present in the fixed network are actually being moved to the mobile networks. Explanations could be that the living pattern of the Western European population has changed significantly (available always and anywhere), the mobile market is positively regulated, stable and mature, and the prices have fallen dramatically from the first days of the mobile industries, terminals' capabilities got highly improved. In Western

Europe around 20 % of all voice calls originate from mobile networks. A 50 % increase in mobile originated voice calls could increase the network traffic by 150 % according to Nokia [19].

At the moment, the voice service is predominantly affected by this phenomenon – according to Analysys [10] around 65 billion minutes of voice traffic worldwide could migrate to mobile networks from landline by 2007. Frost & Sullivan [5] report a 5 % drop in landline minutes in Europe in 2003 only. Such a substitution is a cause for the major concern among the landline operators considering the fact that voice services constitute the majority share of revenue earned and will continue to be so in the near future.

4 Status and rollout plans for EDGE and WCDMA in Western Europe

In 2000, UMTS/WCDMA was introduced as "the next big thing" of the IT and telecom world. In Europe alone, a total of EURO 120 billions were invested in license costs and about the same amount in the network deployment. This makes 3G the technology with the biggest investment in the history of telecom industry. But today's picture is slightly more moderate – WCDMA deployment has not been so fast and successful as it was believed in 2000. There are severe uncertainties related to the 3G market dynamics. In order to make forecasts for the market development of EDGE and WCDMA, we surveyed the status of the EDGE and WCDMA deployment today, and also investigated the rollout plans that operators in Western Europe either have announced or are obliged to fulfil due to the regulatory pressure.

In Finland, TeliaSonera is the first operator offering EDGE/WCDMA packet data handover in a commercial network. It means that the customers can enjoy seamless continuation of 3G services while roaming between EDGE and WCDMA networks. The handover between WCDMA and GSM/GPRS/ EDGE is crucial for better end-user experience, and the key to success of the smooth introduction of WCDMA.

In Norway, the "beauty contest" took place in November 2000 and four licences have been awarded (Broadband Mobile ASA, NetCom GSM AS, Telenor AS and Tele 2 Norge AS). The minimum conditions were WCDMA coverage for 12 defined urban areas (approximately 40 % of the population) within five years from granting the licenses. Broadband Mobile and Tele 2 have withdrawn their licences. Tele 2 has plans to become MVNO using Telenor's WCDMA network. In September 2003 Hi3G Access Norway AS (Hutchison), has been awarded a licence to offer 3G services in Norway. However, the company has not yet started network deployment in Norway.

At the moment, Telenor is running both EDGE and UMTS commercially. These were launched in 2004. NetCom experienced some delays, and plans to launch EDGE in the first place in 1Q2005, followed by WCDMA at the same time. More details on the Norwegian case can be found in Box 1.

In Germany, the regulatory requirement has imposed the licensees to realise the coverage of 50 % of the population by the end of 2005. T-Mobile has announced that it will boost its coverage to 50 % of Germany's population by end of the 2004.

In UK the coverage obligation set by the regulator is 80 % of the population by the end of 2007. O2 announced the least ambitious 3G rollout plan, a coverage map showing that its 3G service would reach 80 % of the population by 2007, just fulfilling the regulatory requirement. Other UK WCDMA operators promised to provide a wider 3G coverage than O2. For example, in July 2004, Orange announced that its 3G network already covers 66 % of the population.

The National Regulatory Authority (NRA) in France revised the 3G network rollout obligations for Orange and SFR in 2004. The deadline for commercial service launch has been set for December 31, 2004. By this date, each operator must provide 3G services in at least 12 of the largest urban areas. By December 31, 2005 both operators are required to cover 58 % of the population. In addition, ART considers that the medium-term objective of providing 3G coverage to a majority of users must be upheld. The rollout obligations for the third French WCDMA licence holder, Bouygues Telecom have been relaxed, thus giving it more time to meet its license obligations.

In Italy the original rollout requirement was to cover regional capitals within 30 months and provincial cities within 60 months. Telecom Italia Mobile has adopted the same approach for its EDGE rollout as specified by the operator's WCDMA-license population coverage obligations in an attempt to overcome the shortage of 3G spectrums.

Sweden had the strictest coverage requirements (99.98 % of the population by the end of 2003). This requirement was alleviated and the infrastructure-sharing model was allowed. According to current regulation, the operators need to offer coverage for at least seven million people by December 31, 2004, eight million by the end of 2005 and eight and a half million by the end of 2006, while the whole popula-

Box 1 – 3G in Norway

		2005	2006	2007
Telenor	Total number of inhabitants	2,820,000	3,250,000	3,750,000
	Total geographical area [km^2]	15,100	35,000	75,500
NetCom	Total number of inhabitants	1,697,635	3,365,610	3,401,600
	Total geographical area [km^2]	1,996	45,749	50,046

Table 3 WCDMA rollout for Norway

Due to slow development in WCDMA deployment the Norwegian Government suggested in February 2003 that the minimum conditions for coverage and rollout frequency encompasses WCDMA coverage to 30 % of the population within six years in order to obtain the necessary interest for the available WCDMA licenses. The Government decided to tender the two free WCDMA licenses as soon as possible, and for the licenses to be distributed by auction. At the same time the Government suggested that the two remaining WCDMA licensees, Telenor Mobil AS and NetCom AS are given a 15 month postponement regarding the licenses' obligation on rollout requirements.

In order to facilitate the development of competition in the mobile market the Government also considers the possibility of mandatory national roaming between WCDMA networks. Roaming implies that mobile network operators agree to using each other's networks. As stated in the White Paper, demanding national roaming between different WCDMA networks will be considered when the rollout of WCDMA is accomplished according to the license conditions. A possible decree regarding national roaming will be issued in accordance with regulations in the forthcoming regulatory framework for electronic communications.

Both Telenor and NetCom consider EDGE as an important step to the WCDMA deployment. Telenor launched EDGE in September 2004, and by October eleven of the largest cities in Norway were covered. The plans are to cover the 35 biggest cities before the end of 2004. NetCom have not yet launched EDGE. NetCom is upgrading its network starting in Northern Norway. The final launch for EDGE in Oslo is expected March 2005. NetCom tried in August 2004 to reduce its concession requirements by offering EDGE to a broader population and to further reduce its initial WCDMA population coverage of 76.5 %. NetCom has announced commercial WCDMA launch in March 2005, but will start some trials for business customers in 4Q2004.

tion, 8.8 million people, must be covered by December 31, 2007.

According to Global mobile Suppliers Association (GSA) [20], EDGE is commercially launched in thirty-eight networks worldwide as of October 2004. A total of 114 EDGE network operators in 67 countries have committed to deploy EDGE. In Western Europe, EDGE is launched in Finland, Norway, Italy and (a trial) in the Netherlands.

When it comes to 3G, GSA defines a commercial WCDMA network as a network that meets all of the following criteria:

- Anyone can subscribe to a service (not a limited trial or selected customers only)
- WCDMA phones or terminals are available to users
- WCDMA phones are sold to subscribers (not only rented)
- The operator has made a public announcement
- The operator charges for the service

Some operators deploy only WCDMA. After a slow start of WCDMA deployments, a significant number of new networks have been launched in Europe and Asia offering services in 2003, and several launched in early 2004. In total 120 WCDMA licenses have been awarded in more than 40 countries.

As of October 2004 GSA reports of the 50 commercial WCDMA networks in 24 countries world-wide,

Figure 2 Overview of commercially launched WCDMA networks in Western Europe (October 2004)

ISSN 0085-7130 © Telenor ASA 2004

Handset (by access technology)	Description
GSM	This is a GSM-only handset
GPRS	This handset may support GPRS as well as GSM
EDGE	This handset may support GSM, GPRS and EDGE
WCDMA	This handset may support GSM, GPRS, EDGE and WCDMA

Table 4 Handset classification (by access technologies)

with 40 of these in 14 West European countries (Figure 2).

As already mentioned, the analysis of rollout plans is important for argumentation built in the predictions for EDGE and UMTS subscriber penetration. For example, the UMTS subscriber penetration is highly dependent on the coverage development.

The rollout analysis in Western Europe shows that all incumbent operators with a high market share are involved in providing or deploying UMTS services. Some of them will also deploy EDGE providing data services to a broader customer base.

5 Mobile handsets

The development and the presence of mobile handsets have played a central role in the rollout of services in the past. They assured not only success but contributed to the failures, latest experienced within the 3G market.

New and advanced mobile data services require numerous functionalities to be included into handsets. Their usage depends on the capabilities of the handsets. These issues imply that the evolution of the handsets is an important factor to be considered when predicting the success of future mobile services.

Similar to services, handsets can also be classified by different criteria – by functionality, by the access technology they support, etc. We focused on the functionalities and the supported access technology, and recognised four main groups of handsets (Table 4). Note however that the subscribers who own these handsets may not necessarily be using all the technologies embedded in them. Therefore, it is not straightforward to devise a clear picture of the actual subscriber numbers for each access technology.

More details on the functionality of these four groups of handsets along with the popular names for the handsets are given in Table 5.

As we see from Table 5 the handsets have evolved from the basic voice phones to the advanced phones supporting various access technologies and functionalities necessary for new mobile data service provisioning. Major analysts anticipate for example that smart phones will be the leading handset type in Western Europe, and that the USIM will be much more significant in the next 3–5 years. For example, Yankee Group predicts that smart phones will have the majority share of sales in Western Europe by 2008 owing to lower costs and supply-side migration to WCDMA. It also predicts that all handsets sold in 2007 will have Java and colour displays while Bluetooth- and camera-enabled handsets will be close to 70 % and 80 % respectively in 2008. Push over Cel-

Access Technologies	Functionalities				
	Voice Phone	WAP Phone	Feature phone	Smart phone	Convergence Phone
	Voice & SMS	WAP browser, polyphonic ringtones, color	Speaker phone, MMS, camera, Java, MP3, email client, IM Client, M-wallet, PTT, Presence, PIM	OS-based, touch screen, QWERTY keyboard, video player, memory card, video conferencing	PDA, WLAN interface, DVB-H
2G/GSM	x				
2.5G/GPRS	x	x	x	x	x
2.75G/EDGE	x	x	x	x	x
3G/WCDMA	x	x	x	x	x

Table 5 Handset classification as considered in the ECOSYS

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lular (PoC) handsets are expected to constitute 90 % of the total by 2008.

In Western Europe, the use of multi-SIM devices will decrease according to Strategy Analytics, while the multi-device segment will show an increase with nearly 10 % of users having a second handset by the end of 2008. The number of users by access technology would follow the natural evolution of the GSM family of technologies, i.e. an increase in the user numbers for GPRS-enabled handsets followed by an increase in EDGE-enabled handsets and ultimately leading to WCDMA-enabled handsets. Strategy Analytics expect approximately 45 % of all users in Western Europe to have WCDMA-enabled handsets by the end of 2008.

6 Mobile forecast modelling

Before going into the details of particular forecasts and results, we discuss the presumptions of the long-term modelling. The forecasts presented here are made for the main technologies described in Chapter 2 – 2G/GSM, 2.5G/GPRS, 2.75G/EDGE, 3G/WCDMA. Recall that the other technologies were not taken into account due to their negligible presence in Western Europe in the period considered, or their immaturity. Usually long-term forecasts are developed based on rather long time series. However, most of the mobile technologies are rather new and no historical data are available. Sufficient data are available on GSM, but we lack the historical data for the technologies introduced just recently.

Furthermore, the market considered is the whole of Western Europe. Though the picture of each particular market may reveal some peculiarities – and the picture would differ for the large country market (e.g. France, Germany) and for the small country market (Scandinavian countries) – we made a homogeneous picture that reflects the Western European market as a total. This view has been used as a basis for the forecasts. Mobile market information has been gathered from a lot of different sources. Project partners in the CELTIC project ECOSYS have collected up-to-date data of the mobile evolution. Other important sources have been consultant reports from OVUM, Jupiter, Forrester and Strategy Analytics. However, their forecasts have not been used, but ECOSYS has developed its own forecasts. Finally, the services, market segmentation, the fixed-to-mobile substitution phenomenon, and rollout plans of various operators have been taken care of when modelling the forecasts. The handset evolution, as described in Chapter 5, has been an important element when modelling the forecasts presented in this chapter. Recall that we distinguish between four types of handsets:

- GSM handset has no possibility using technologies other than GSM;
- GPRS handset supports GPRS as well as GSM;
- EDGE handset supports GSM, GPRS, and EDGE;
- WCDMA handset supports GSM, GPRS, EDGE and WCDMA.

The handset forecasts for the different technologies are called technology forecasts. This means that the market share for the GPRS technology is equal to the market share for the GPRS handsets, and the same is valid for the penetration.

So far, it is observed that the number of handsets in use is very close to the number of mobile subscribers. Very few subscribers have two handsets. In other words, the technology forecasts based on the handsets are very close to the mobile subscriber forecasts. However, the concept subscriber related to a technology/handset is not precise when he has more than one handset.

On the other hand, many subscribers have more than one subscription. It may be a combination of post- and prepaid subscriptions, and the subscriber may very well have one handset but different SIM cards (different subscriptions). Some of the subscribers also have an active subscription and in addition a subscription which mainly is not used.

Also, the issues of WLAN hot spots, and the strategic question whether the mobile or fixed network operators will go for such a solution is highly dependent on many factors, such as the focal market, company organisation and vision, competition picture, etc. In the ECOSYS project, we have plans to investigate the so-called convergence case, where we assume that fixed and mobile networks support the traffic coming from either fixed or mobile terminals, and the services are provided independently of the underlying network infrastructure, but depending on the context (location, terminal capabilities, personal preferences, etc.). In such cases the WLAN needs to be considered along with the cellular technologies, which is not the case for the forecasts presented in the following.

6.1 Forecasting methodology

As already mentioned, the analysis is mainly based on mean values from the Western European market. The models can be improved by making forecasts for particular (homogeneous) groups of European countries or by making forecasts for each Western European country. Then more dedicated information such as rollout speed, coverage of various technologies, demographics, prices etc. appropriate for the different countries will be used.

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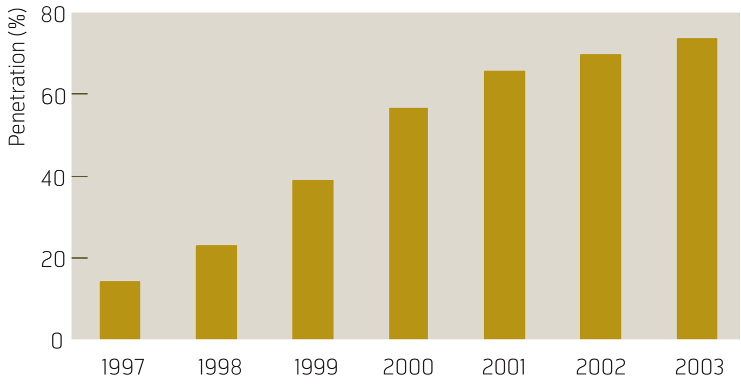

Figure 3 Penetration of mobile handsets in Western Europe 1997 – 2003

The first step is to develop a forecasting model for the total number of mobile handsets in use. As commented earlier, the number of handsets in use is very close to the number of subscribers. The model does not differentiate between the customers' segments (i.e. who is paying for the subscription), or usage of services, or ARPU, but only the terminal capabilities.

Predictions of the evolution of market shares between different mobile technologies are then developed based on a set of Logistic forecasting models. Migrations between the GSM, GPRS, EDGE and WCDMA technologies are handled.

Finally, the mobile penetration forecasts for the technologies are found by multiplying the total forecasts with the market share forecasts for the technologies.

6.2 Mobile forecasts

6.2.1 Handset penetration

The mobile handset penetration, which is very close to the subscriber penetration, in the period, 1997 – 2003, is shown in Figure 3.

Since GSM was introduced in Europe and common standards and roaming were in place early, it has witnessed a remarkable increase in the number of mobile subscribers. The Nordic countries had a significant demand even before 1997, because of early deployment of the Nordic Mobile Telephone System (NMT) at the beginning of the 1980s. However, the Western European market got a significant push only after GSM was introduced in 1992.

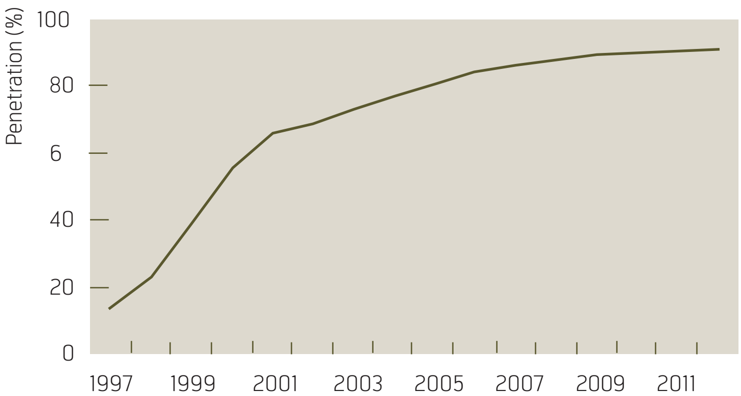

Figure 4 Mobile handset penetration forecasts for Western Europe

After the prepaid cards were introduced the penetration got even deeper. The penetration shown in Figure 4 considers all customers without differentiating between business and consumer market segments. The shape of the mobile subscriber evolution follows an S-shaped curve, pointing at diffusion models as the right alternative for modeling the forecasts. A four parameter Logistic model has been used. The long-term saturation is set to 93 %. The question is of course at what time young boys and girls will get their own mobile handsets, and how many persons will never have a mobile handset. Some arguments advocating for the 93 % saturation level are:

- Young children (younger than 5 – 6 years) will seldom have a mobile handset;
- Some people will always hesitate to buy a mobile handset;
- Very old people (older than 80 – 85 years) will not be able/willing to use the handset.

One could naturally argue that the saturation level can be either lower (on the mean Western Europe basis) or higher. For example, the saturation level could be lower if the starting age of having a mobile handset moves to 8 – 10 years. We can point it out in a Norwegian case. In 1999, eight year old children were not included in statistics since only few of them had a mobile, but by 2004 every fourth eight year old child in Oslo has a mobile handset. In addition, the fact that as much as 90 % of all 12 year olds and 100 % of youngsters aged 16 – 21 have mobiles nowadays, contributes to the expectation of 93 % saturation level for the Western Europe on average. Another argument supporting the saturation level being higher than 93 % is that the youngsters who are already accustomed to the mobile usage and handsets, in 10 years will be in the working segment of the population with their own income, and the people with mobile handsets who are now older than 70 – 75 years will be in the group of very old people. In addition, the question is how long will the last sceptics reject mobile technology given for instance new services and values that the mobile can bring to them (e.g. *e*Bank, *e*Learning, *e*Wallet).

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Though the multi-device penetration is important to consider, we assume that subscriber penetration is very close to the mobile handset penetration. Figure 4 shows the mobile handset penetration forecasts for the Western European market in the period 2004 – 2012.

The next step is to make market share predictions for each technology: *Plain GSM, GPRS, EDGE* and *WCDMA*.

As already pointed out, historical data are rather important for making forecasts, and we use them here as a starting point. Figure 5 shows the evolution of plain GSM penetration in Western Europe.

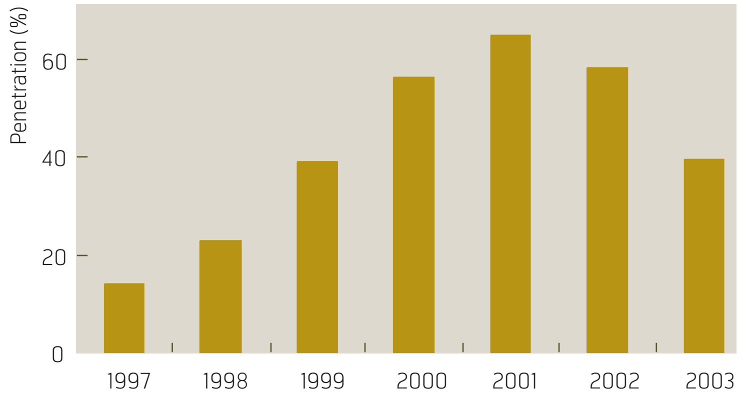

Figure 5 GSM handset penetration in Western Europe 1997 – 2003

The figure shows that the number of users of plain GSM has started to fall, e.g. comparing 2002 and 2003 results. In the modeling approach, it is more interesting to investigate the market share evolution where we study the relative share that a certain technology has on the market. The market share for GSM is reduced from nearly 100 % in 2001 to about 55 % in 2002. The GPRS is now capturing significant market shares from GSM. The question is how long will the GSM handsets be on the market. In addition, the EDGE system is now introduced in many Western European countries, while it is expected that also the WCDMA will be introduced in many of the countries by the end of 2004. Therefore, plain GSM will in the next years lose its market share significantly. One important factor is the lifetime of the handsets, which is currently about three years but is expected to decrease further. When a customer needs a new handset there is a high probability that the customer chooses a handset with the new technology if the subscription fee remains the same.

Based on historical evolution and knowledge, a Logistic four parameter model is applied to model the forecasts for the sum of GPRS + EDGE + WCDMA. The plain GSM forecasts are found by taking the difference between 100 % and the accumulated penetration for the new technologies. The forecasts are shown in Figure 6.

The market share for plain GSM is anticipated to decrease significantly in the coming years. Different countries will phase out the system at different times. It is therefore difficult to predict at what point the system will be eliminated from the Western European market. However, the current development indicates that there is reason to believe that after 2007 the number of plain GSM subscribers will be very limited (less than 2 %). As pointed out, one important reason is the short lifespan of the handsets.

The most important mobile system in the coming years will be WCDMA or UMTS. After a slow start, caused by high license fees in many European countries, the lack of handsets with adequate capabilities and other problems, WCDMA is now deployed in some of the Western European countries.

The presentation of the status and rollout plans for the EDGE and WCDMA for a selection of Western European countries (ref. Chapter 4) indicated rather aggressive rollout plans that may support the expectations for the UMTS launch in 2004/2005.

The WCDMA system is superior to the preceding mobile systems, especially because of its functionality and capacity. The investments in the 3G (licenses and systems) are rather heavy, and the operators want to get a significant return on their investment as fast as possible. A set of different factors such as the market, the functionality, new and enhanced services, content possibilities, the tariffs, and competition between the other mobile systems – will influence future penetration. We used a four parameter Logistic model to forecast the future market share for WCDMA.

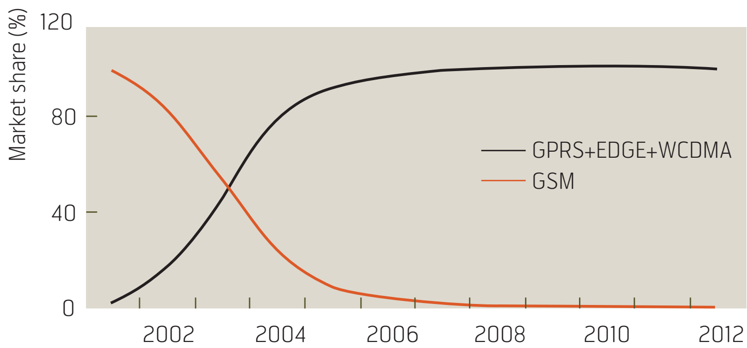

Figure 6 Market share forecasts for GSM handset and the sum of GPRS, EDGE and WCDMA handset for Western Europe

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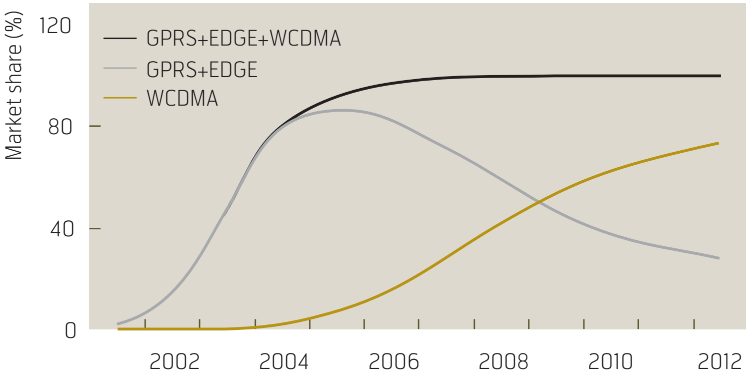

Figure 7 Market share handset forecasts for WCDMA, GPRS + EDGE, GPRS + EDGE + WCDMA for Western Europe

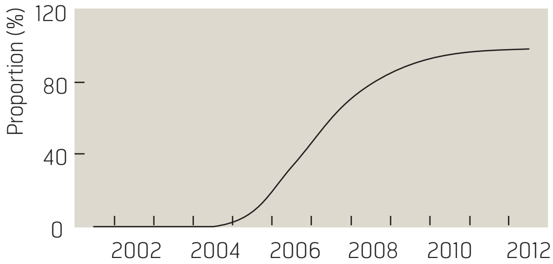

Figure 8 Forecasts of EDGE handset proportion of EDGE + GPRS handsets

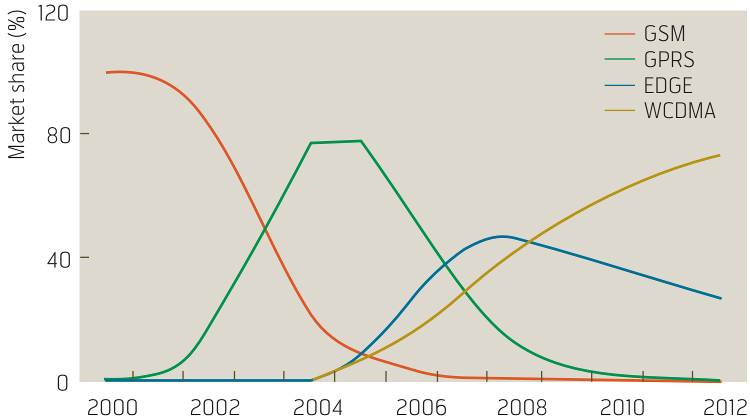

Figure 9 Market share forecasts for GSM, GPRS, EDGE and WCDMA handsets for Western Europe

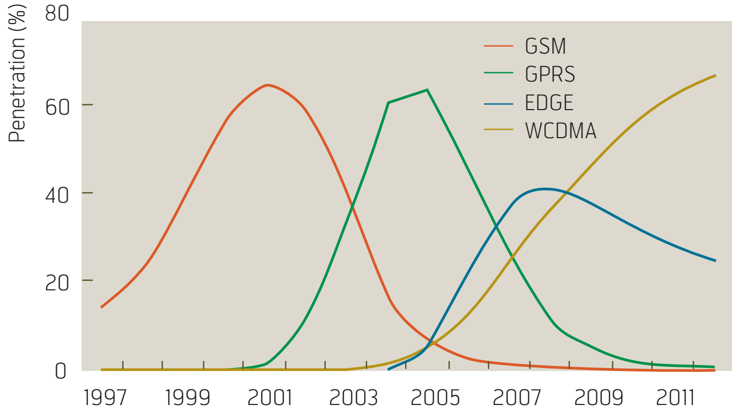

Figure 10 Handset (technology) penetration forecasts for GSM, GPRS, EDGE and WDCMA for Western Europe

The market share forecasts for WCDMA, GPRS + EDGE, GPRS + EDGE + WCDMA are shown in Figure 7.

The figure shows that GPRS and EDGE are losing their position to WCDMA in the long run. WCDMA is predicted to have about the same market share as GPRS + EDGE at the end of 2009. Here, the proportion of the GPRS and EDGE includes the uncertainty regarding the lack of historical information and the exact facts on the strategic decisions operators will make. In case many decide to go for the EDGE as the natural step towards UMTS, the EDGE share could be somewhat stronger than what is shown in the current forecasts.

When discussing the proportion of the market presence between the EDGE and GPRS, it is useful to recall that both of them are the members of the GSM family – 2.5G and 2.75G, respectively. EDGE uses the same platform as GPRS, but offers higher capacity and supports customers' demands for services that need higher bandwidth and QoS. The EDGE system is more effective than GPRS and the investments in upgrade are not very high. Some European countries are now installing EDGE, e.g. in Norway it has been commercially available since 3Q2004. The question is how fast the system will be implemented in the other Western European countries. Handsets with EDGE and GPRS functionality are already available on the market, but due to the stronger capabilities of the EDGE system one can expect the GPRS handsets to be phased out after some years.

Figure 8 shows how the proportion of EDGE handsets increasees compared to the EDGE and GPRS total (GPRS+EDGE). It defines the market share evolution for EDGE and GPRS.

An overview of the market share forecasts for all four technological solutions, i.e. GSM, GPRS, EDGE and WCDMA is shown in Figure 9.

The figure shows that GSM will lose significant market shares in the coming years. GPRS will reach its maximum level at the end of 2006. The WCDMA technology is predicted to be the dominating technology in Western Europe from the end of 2008.

As a result of the market share forecasts and the total mobile handset forecasts, the penetration forecasts for each technology are found by multiplying the mobile handset forecasts by each market share forecast. The technology penetration forecasts are shown in Figure 10. The figure reflects the penetration forecasts for all of the considered technologies. GPRS will in a year or two reach the same penetration level as GSM had in 2001, and it is interesting to note that an "early" introduction of WCDMA compared to EDGE seems to reduce the maximum penetration of EDGE.

6.2.2 Subscription forecasts

A rather simple forecast model has been developed for the mobile subscription forecasts. It is assumed that the long-term saturation for the subscriptions is 115 %. The saturation level for the subscribers was 93 %. It is assumed that the number of additional subscriptions is proportional to the penetration of each technology. The subscriptions are divided into three classes:

- GSM
- GPRS+EGDE
- WCDMA

Since GPRS and EDGE are quite similar and use the same network platform, it is expected that these technologies will constitute a common subscription class.

The resulting penetration development is shown in Figure 11. The figure shows that the subscription penetration reaches nearly 110 % in 2012. Since the subscription penetration is evolving continuously in the period 2001–2012, the WCDMA subscription penetration is expected to reach the peak level of GPRS + EDGE in 2012/2013.

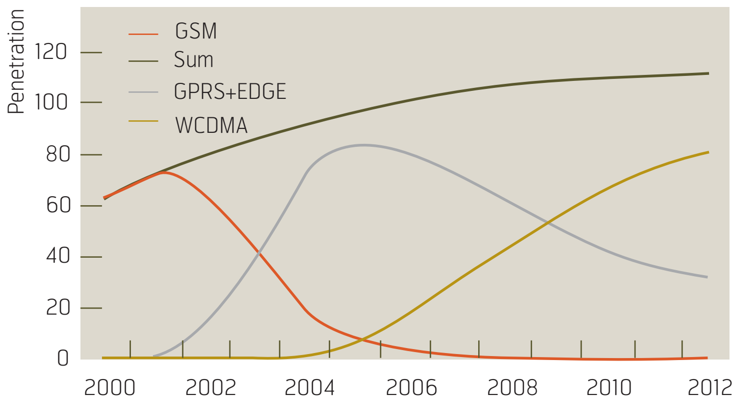

Figure 11 Mobile subscription forecasts for GSM, GPRS, EDGE and WCDMA for Western Europe

7 Conclusions

Long-term mobile forecasts have been developed for the Western Europe as a whole. The forecasts are made for handsets and subscriptions and segmented in Plain GMS, GPRS, EDGE and WCDMA (UMTS) technologies. While historical data for GSM are available, only limited demand data exist for the new technologies – GPRS, EDGE and WCDMA. A reason for this is simple – these technologies were not present in the market long enough – GPRS has been on the market for about two years, while EDGE and WCDMA are being introduced now. Important elements in the forecasting input are techno-economic evaluations of the technologies, rollout plans to the operators, handset technologies and handset lifetime. Additional uncertainties bring the variation in EDGE and WCDMA rollout plans in the different Western European countries.

The long-term forecasts show that GMS handset penetration will be quite low in 2007. The GPRS technology is taking over followed by EDGE, which uses the same platform. The WCDMA technology enters the market based on significant rollout and launch in 2004. The handset (in use) penetration as a mean for Western Europe is about 70 % in 2002 and is expected to reach 90 % in 2010.

The Western European long-term forecasts show the future evolution of the new mobile technologies EDGE and WCDMA. The results are used as input to techno-economic evaluation of mobile business cases and rollout strategies. New forecasts, limited to specific country groups or countries, will be developed as input to the different techno-economic analysis. These forecasts will reduce the uncertainty to some extent, because of the possibility to include more precise information like rollout plans and other type country specific information.

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For a presentation of Kjell Stordahl, please turn to page 2.

Irena Grgic Gjerde received her BSc, MSc and PhD degrees in the field of Electrical Engineering, area of Telecommunications, from the Faculty of Electrical Engineering and Computing at the University of Zagreb, Croatia in 1996, 1999 and 2003, respectively. Since 1998 she has been employed by Telenor R&D as Research Scientist. Her current interests include business modelling, techno-economic analysis, SLAs and negotiation, and forecasting. She has been involved in numerous international projects (IST, EURESCOM, CELTIC) and is the author/co-author of more than 40 publications.

email: irena-grgic.gjerde@telenor.com

Rima Venturin received her BSc and MSc degrees in the field of Electrical Engineering, area of Telecommunications, from the Faculty of Electrical Engineering and Computing at the University of Zagreb, Croatia, in 1992 and 1995, respectively. She has been employed by Telenor R&D as Research Scientist since 1996 and has been working with techno-economic analysis, business modelling and network planning since 1998. She has been involved in numerous international projects (IST, EURESCOM) and is the author/co-author of several publications. At the moment she is Research Manager for the Business Assessment group.

email: rima.venturin@telenor.com

K.R. Renjish Kumar has been Research Scientist/PhD student at the Networking Laboratory, Helsinki University of Technology since January 2003. Prior to this, he worked with Siemens ICM, Singapore as R&D Engineer for over a year and with Cognizant Technology Solutions for over two years as programmer analyst. He received his Masters degree in Computer Science from the National University of Singapore (2001) and Bachelor of Engineering degree in Electronics and Communications from the National Institute of Technology in Suratkal, India (1997). His research interests include techno-economic issues in mobile communications, IP QoS and TCP performance issues.

email: renjish@netlab.hut.fi

Jarmo Harno received his MSc degree in Mathematical Analysis from the University of Helsinki in 1983. After working in the SW industry he joined Nokia in 1987, and has worked as systems analyst and manager in R&D, Quality Assurance and Product Management. He started as a senior research scientist on techno-economics with Nokia Research Center in 2001. Doing research on the future telecom technologies and service concepts, he has also taken part in the EU IST framework co-operation project TONIC (2001–2002), especially the mobile business case, investigating the 3G UMTS services combined with WLAN deployment. In the co-operation project ECOSYS on "Techno-economics of integrated communication systems and services" started in 2004 under the EUREKA's CELTIC initiative, he has been leading the work package for "Mobile and wireless network economics beyond 3G". Mr. Harno has authored/co-authored several international journal articles and conference presentations, and has also some international patents on telecom technology and services.

email: jarmo.harno@nokia.com

Ilari Welling received his MSc degree in Telecommunication Engineering from the Helsinki University of Technology in 1996. He joined the Nokia Research Center in 1995, where he has been studying techno-economic aspects of telecommunication networks and is currently leading the research group focusing on this topic. Recently he has been working on the EU project TONIC and is currently leading the CELTIC project ECOSYS, which concentrates on techno-economic modelling.
Mr. Welling has authored/co-authored several international journal articles and has presented papers at conferences in the field of telecom techno-economics. He was also co-author of the book "Broadband Access Networks: Introduction strategies and techno-economic evaluation" (Chapman&Hall, 1998).

email: ilari.welling@nokia.com

Timu Smura (26) received his MSc (Tech) degree from Helsinki University of Technology in 2004. He is currently working as a research scientist and carrying out his post-graduate studies at the Networking Laboratory in Helsinki University of Technology. His research interests include competition in the telecommunications industry, operator business models and strategies, and techno-economics of communication networks.

email: timo.smura@hut.fi

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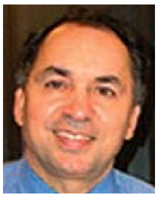
Modelling and forecasting the growth of wireless messaging

MOHSEN HAMOUDIA AND TOWHIDUL ISLAM



Mohsen Hamoudia is Head of Strategic Marketing at the Corporate Solutions Division of France Telecom, Paris

Towhidul Islam is Assistant Professor of Marketing at the University of Guelph, Ontario, Canada

There is a crucial need for telecommunications operators to forecast new products such as wireless messaging. SMS is the most popular form of wireless messaging and the lessons learned from its evolution can be transferred to more advanced forms of wireless messaging, such as MMS, Mobile Instant Messaging (IM) and Wireless Email, which are positioned as the next wave of growth.

To meet this challenge, we evaluate in this study the performance of an adequate modelling approach [1] based on Innovation Diffusion Models, i.e. the Linearised Gompertz Model using the Pooling Single Generation Multi-Country Data. This approach is evaluated for the SMS market which for most operators represents at least 80 percent of data revenue in 2003. The approach could be extended later when data will be available to MMS and Wireless Email markets using the Multi-Generation Diffusion Models.

1 Introduction

With over 400 billion messages sent worldwide in 2003, SMS is the most popular form of wireless messaging. Despite the wide variety of SMS applications that exist, 90 percent of text messaging still comprises of person-to-person communications. However, the lessons learned from SMS can be transferred to more advanced form of P2P messaging, such as MMS, mobile Instant Messaging (IM) and Wireless e-mail, which are positioned as the next wave of growth.

In terms of their functionality, three standards of Wireless Messaging can be distinguished:

- *SMS* (Short Message Service) enables mobile phone users to send short plain-text messages to other mobile phone users. For most operators, SMS contributed to between 84 and 97 percent of data revenue in 2001.
- *EMS* (Enhanced Message Service) enables mobile phone users to send longer text messages, plus simple graphics and sounds, to other mobile phone users
- *MMS* (Multimedia Message Service) enables mobile phone users to send formatted text messages of any length, plus graphics, photos, and audio and video content, to other mobile phone users and e-mail users.

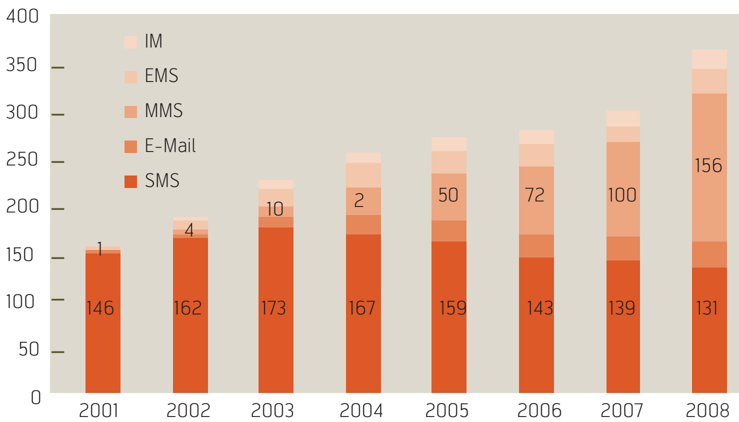


Figure 1.1 Wireless messaging in Europe (active users in millions). These forecasts are based on a survey and market study

Many studies have shown that SMS progressively will be replaced by MMS mainly, but also by mobile email. Figure 1.1 [2] shows that the number of SMS users in Western Europe peaks in 2003 and the decrease starts in 2004. In the same period, the MMS market will grow dramatically.

2 Forecasting the SMS market development using the Innovation Diffusion Models

The objective of this part is to give a brief overview of the most important forecasting models based on the Growth Curves and Innovation Diffusion Models concepts concerning the growth of markets and products such as the SMS market.

In curve fitting models, the SMS market trend is extrapolated by calculating the values of the parameters of some function that is expected to characterize the growth of the SMS market over time. The estimated coefficients of some curve fitting models can be performed by using the least squares method.

The following are the main and most common curve fitting models used for forecasting the growth of variables such as the SMS market:

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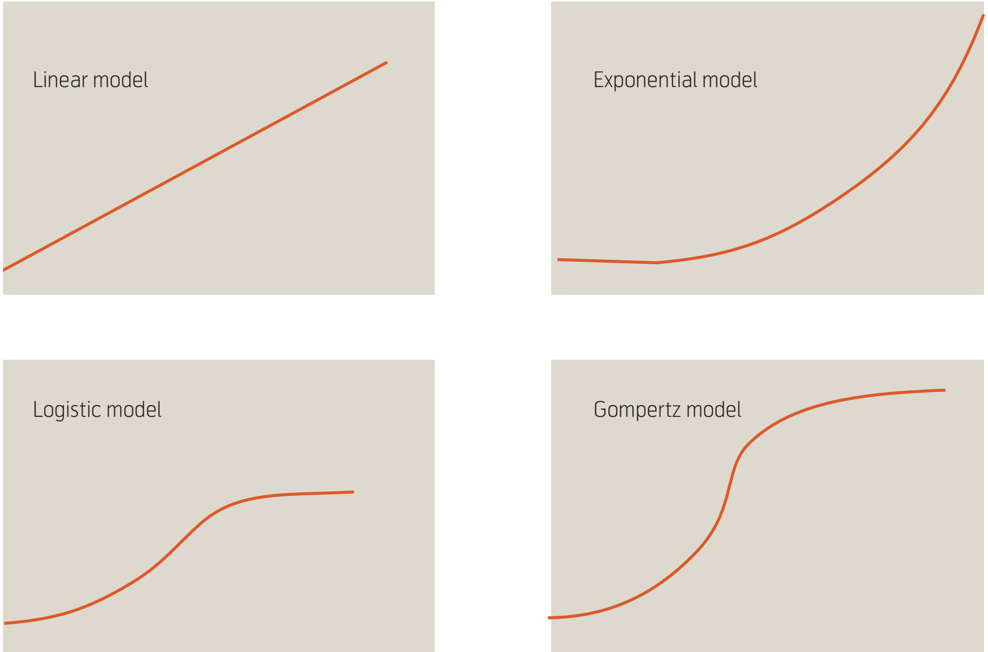

Figure 2.1 Curve fitting examples

Linear: $Y_t = a + bt$ (2.1)

Parabolic: $Y_t = a + bt + ct^2$ (2.2)

Exponential: $Y_t = ae^{bt}$ (2.3)

Simple Logistic: $Y_t = \frac{M}{1 + ae^{bt}}$ (2.4)

Gompertz: $Y_t = M(a)^{bt}$ (2.5)

where

Y_t is the cumulative SMS market at time t,

a, b, c, are parameters to be estimated,

M is a parameter describing the saturation level of the SMS market.

The *Logistic* and *Gompertz* curves differ from the *Linear*, *Parabolic* and *Exponential* curves by having a saturation level. This saturation level can be estimated in the model or fixed.

However, in the case of the SMS market, its sensitivity to socio-economic, price and competition variables makes these basic growth curves inappropriate. Then it is necessary to consider extensions of these models. For example, for the Logistic model (2.4) we can extend it as below:

The *Extended Logistic*: In this model proposed by Bass [3], the Innovation coefficient captures the propensity to adopt the SMS due to the influence of mass media, and the imitation coefficient captures the adoption due to word of mouth, i.e. to conform with the behavior of the remainder of the customers.

The *Non-Symmetric Responding Logistic* (NSRL): This model proposed by Easingwood [4], tend to make the simple Logistic more flexible or responsive.

	France	Germany	Italy	Netherlands	Spain	Switzerland	UK
1998	3,899	5,788	6,780	988	1,650	795	7,015
1999	7,652	13,455	13,490	3,108	4,790	1,211	14,500
2000	9,710	17,880	19,470	4,857	8,010	2,088	18,951
2001	13,420	22,454	26,700	6,193	10,035	3,065	24,103
2002	19,560	29,800	29,852	7,493	14,500	3,740	29,887
2003	24,700	34,844	31,700	8,120	17,800	4,100	34,500

Table 3.1 SMS adoption in Europe

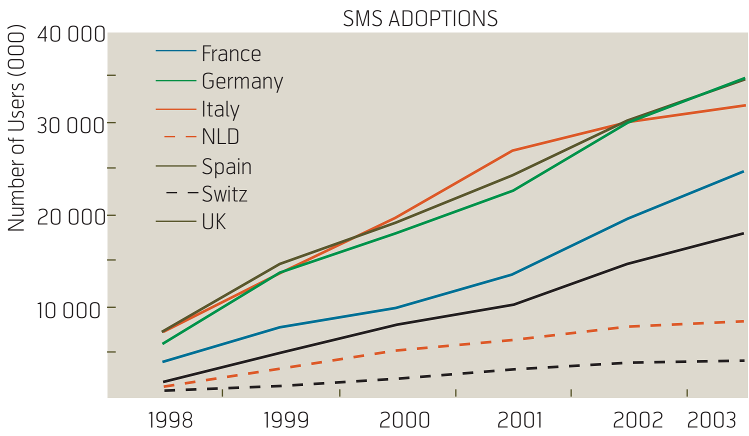

Figure 3.1 The SMS adoption in Europe

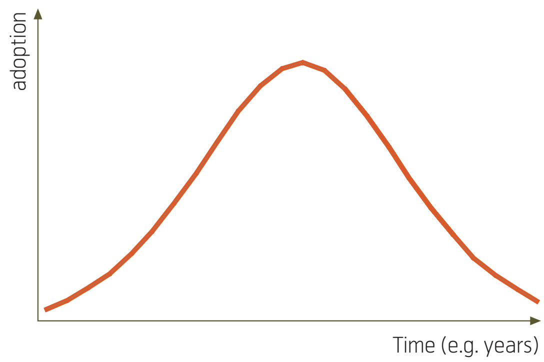

Figure 3.2 The SMS adoption profile

The *Local Logistic*: This model [5] and [6] bases its forecasts on the recent available observation, rather than fit a global curve to all the available data.

In the case of the Gompertz model, we will consider more suitable and more accurate specifications (cf. part 4 below).

3 Description of data

The data set on number of SMS users is listed in Table 3.1 and Figure 3.1. These data are a synthesis of the following sources: Idate (France), Ovum and Strategy Analytics (UK). The data for 2003 were estimated by the authors (using either a GAGR growth rate for the 1998–2002 period or estimate from other sources).

We have considered only *active users* (i.e. users who send at least five messages monthly). SMS data aggregates and includes all types of SMS (SMS games, SMS text, news and traffic alerts over SMS) used in each country.

The analysis of the observations shows a bend in trend, i.e. this excludes time series options.

The data set includes yearly observations from 1998 to 2003, i.e. short data. This excludes model estimation using only a single country data. The more suitable framework for modeling short data series is pooling multi-country data as suggest by Islam, Fiebig and Meade [7].

4 Modelling and forecasting the SMS market growth

4.1 Pooling Single Generation Multi-Country data

We have estimated the SMS data of seven countries using Innovation Diffusion Model, i.e. linearised Gompertz [7] using short data pooling approach.

4.2 The Linearised Gompertz Model

$\ln(Y_{ct} / Y_{ct\text{-}1}) = \phi \ln mc - \phi \ln Y_{ct\text{-}1} + \varepsilon\, ct$

where

Y_{ct} is the cumulative number of adopters of SMS of country c and time t,

ϕ is the growth rate, common for all the countries,

m_c is the market saturation level of country c,

$\varepsilon\, ct$ is an error term corresponding to country c and time t.

We have considered and estimated two pooling models using Linearised Gompertz, i.e. the *Fixed Effect* and *Cross Sectionally Varying* (CSV) models.

4.2.1 The Fixed Effect Model

In this case, the market saturation (i.e. *mc*) for each country is estimated, but the slope or growth coefficient (i.e. f) is common across all the countries

4.2.2 The Cross-Sectionally Varying (CSV) Model

In this case

- the market saturation *mc* for each country depends on a number of covariates, whereas slope or growth coefficients (i.e. ϕ) is common across all the countries;
- the covariate considered here is the number of digital cellular connections. The Cross-Sectionally Varying (CSV) saturation estimates becomes $mc = b_0 + b_1 * \textit{Digital Cellular Conn.} + e_c$. Here b_0 is market saturation intercept and b_1 determines the relationship between market potential and digital connection. e_c is the error term.

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4.3 The forecasting performance

The forecasting performance of models could be measured by RMSE (Root Mean Square Error), APE (Absolute Percentage Error) or MAPE (Mean Absolute Percentage Error). We choose the MAPE in this study to compare the performance as it has been widely used in comparable studies in the past and is easily interpretable.

The forecasting performance of both models is similar and only the performance of the fixed effect model is presented for brevity. The models have been estimated with two to four years data only.

The CSV model was estimated with only a single covariate, i.e. number of digital connections. We are working on revising these market saturation estimates by incorporating additional variables such as income, price, etc.

As we are estimating a model with only six years data (i.e. a very small sample size), we have also investigated the plausibility of market saturation estimates. If the market saturation estimates are lower than last sample observation, the suitability of the model will be in doubt.

In all the cases, the ratio of saturation estimates and last sample observation is greater than 1 and ratios (market saturation/last obs. in the sample) are summarized in Table 4.2.

We have also checked the plausibility of parameter estimates. The estimates of CSV model parameters are summarized in Table 4.3 and Figure 4.1. The parameter estimates have the correct sign and magnitude. The estimates have changed slightly over time due to short data and have reached a stable level, see Figure 4.1 in year 2003.

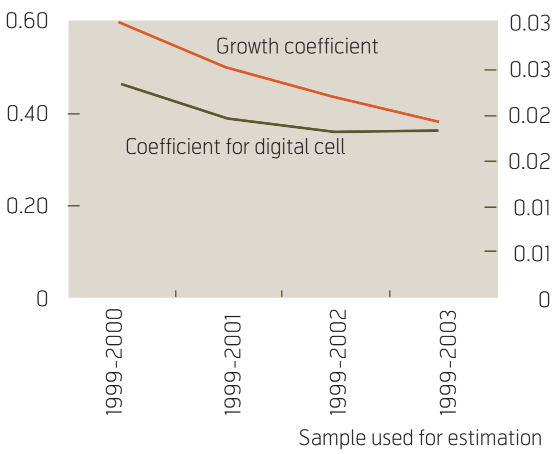

Figure 4.1 The stability of market saturation and growth coefficients (CSV model)

Countries	1 year ahead MAPE	2 years ahead MAPE	3 years ahead MAPE
Germany	9.1	20.1	24.7
Italy	5.9	11.6	16.1
Netherlands	4.9	11.5	21.3
Spain	7.4	10.3	25.5
Switzerland	20.2	45.6	47.1
UK	11.9	22.1	34.5
France	21.2	39.6	48.7

Table 4.1 Forecasting performance

Countries	Fixed Effect	CSV
Germany	1.13	2.47
Italy	1.19	1.72
Netherlands	1.35	1.13
Spain	1.19	1.44
Switzerland	1.07	1.69
UK	1.12	1.61
France	1.02	1.32

Table 4.2 Ratio of saturation estimates and last observation

Sample		Estimates	t-ratio
1999 – 2003	intercept	3.3153	38.78
	B_Digital Cell	0.0182	6.91
	Growth Coeff.	0.3867	12.51
1999 – 2002	intercept	3.5097	29.44
	B_Digital Cell	0.0181	19.65
	Growth Coeff.	0.4417	10.67
1999 – 2001	intercept	3.9158	28.74
	B_Digital Cell	0.0195	15.44
	Growth Coeff.	0.5071	9.82
1999 – 2000	intercept	4.7917	28.12
	B_Digital Cell	0.0232	15.53
	Growth Coeff.	0.6068	8.07

Table 4.3 The estimates of market saturation coefficients of CSV model

ISSN 0085-7130

5 Conclusion and further work

Among four classes of 29 models [8] we have used Gompertz Diffusion Model. The CSV pooling model seems to be adequate for the fast developing SMS market. The estimates of saturation levels and parameter estimates are plausible. The MAPE statistic shows that the forecasting performances are accurate in most of the cases.

The next step will be the use of the Multi-Generation Diffusion Model for the MMS market growth. As indicated in part 1 [2], SMS and MMS are the most important markets in the Wireless Messaging market in Europe and worldwide. So it is very crucial to build forecasts for these markets.

The MMS services were launched in 2002 in the main European markets. So, when data will be available, we will run the Multi-generation, Multi-country diffusion model (see Figure 5.1). This approach will allow adoption switching from earlier technologies, i.e. the SMS technology, to the new technology, i.e. MMS and IM.

The multi-generation modeling based on the Norton and Bass Model [9] can be modified to model multi-country short data using the approach suggested by Islam and Meade [10] as follows:

$$SMS_{ct} = f(m_{1c}, p_a, q_a) + \varepsilon_{1ct}$$

$$MMS_{ct} = f(m_{1c}, m_{2c}, p_d, q_d) + \varepsilon_{2ct}$$

where $\varepsilon_{1ct} \sim N(0, \sigma^2_{1c})$ and $\varepsilon_{2ct} \sim N(0, \sigma^2_{2c})$

m_{1c} is the SMS market saturation for country c.

m_{2c} is the incremental MMS market saturation for country c.

p_a and p_d are the coefficient of innovations of SMS and MMS respectively. These coefficients will capture the early growth of the technology.

q_a and q_d are the coefficient of imitations of SMS and MMS respectively. These coefficients will capture the long-term growth of the technology.

ε_{1ct} and ε_{2ct} are the error terms and σ is the variance.

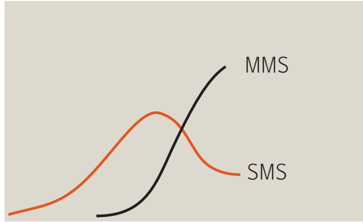

Figure 5.1 Multigeneration diffusion of innovations

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Mohsen Hamoudia joined France Telecom Group in 1993. Since 2001 he has been Head of "Strategic Marketing" at the Corporate Solutions Division, Paris. Before this, he was Head of the "Traffic Forecasting" Division at France Telecom Long Distance, Head of the "Network Customized Solutions" Division at the Domestic Network, Head of the "New Services" Division, at Ile-de-France & Paris area Network. Before joining France Telecom Group, he was Director (1988–1992) of "Marketing Information Systems" at Atos Group, Paris, and Forecasting Manager in Air Inter-Air France Group (1984–1987) and Researcher in "Operational Research" at University of Paul Sabatier, Toulouse (1979–1983). Mohsen Hamoudia is also Associate Professor in "Forecasting Techniques" at the ESDES-Business School of Lyon since 2000, at ISM Paris since 1989, and at ESC-Toulouse (Business School of Toulouse) since 1990. He received his PhD in Industrial Economics from University of Paris Pantheon Sorbonne, and his MBA in Mathematics and Statistics from University of Toulouse, and his MBA in Econometrics from University of Paris Pantheon Sorbonne.

mohsen.hamoudia@francetelecom.com

Towhidul Islam is Assistant Professor of Marketing at the Department of Marketing and Consumer Studies, University of Guelph, Ontario, Canada. He has an MSc in Telecommunications Engineering, an MBA from Dhaka University, a DIC (Diploma of Imperial College), and a PhD in Management Science (1996) from Imperial College, University of London. He previously held research and teaching positions at the University of Sydney, Australia, and Dalhousie University, Canada. His current research is on diffusion of innovations, behavioral issues in household level trial and repeat purchases and the impact of missing information on consumer product choices. He has published in Management Science, European Journal of Operational Research, Journal of Forecasting, International Journal of Forecasting, Journal of the Operational Research Society, Journal of Productivity Analysis, and Technological Forecasting and Social Science.

islam@uoguelph.ca

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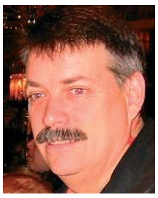
The demand for Voice over IP – An econometric analysis using survey data on willingness-to-pay

PAUL RAPPOPORT, LESTER D. TAYLOR, DONALD KRIDEL AND JAMES ALLEMAN[1)]

Paul Rappoport is Associate Professor of Economics at Temple University

The focus in this paper is on what can seem the logical final chapter for consumers in the "convergence" of the computer and telecommunications industries, namely, the residential market for VoIP (Voice over Internet Protocol) services. Although at present this market is quite small, a number of companies (Vonage, AT&T, and Qwest, for example) foresee it as potentially large, and are investing accordingly.[2)] The purpose of the present exercise is to take a sober look at the market for VoIP by using data on willingness-to-pay from a representative survey of US households, to provide estimates of the underlying price elasticity of demand for 'best-effort' VoIP services, as well as initial estimates of the size of the 'best-effort' VoIP market.[3)]

Lester D. Taylor is Professor of Economics and Professor of Agricultural and Natural Resources at the University of Arizona, Tucson



Donald Kridel is Associate Professor of Economics at the University of Missouri, St. Louis

1 Introduction

VoIP is a common term that refers to the different protocols that are used to transport real-time voice and the necessary signaling by means of Internet Protocol (IP). Simply put, VoIP allows the user to place a call over IP networks. "Best-effort" VoIP is the provisioning of voice services using broadband access (cable modem or DSL). It is referred to as 'best-effort' because service quality and performance cannot be guaranteed by the provider. The traditional voice telephony system meshes a series of hubs together using high-capacity links. When a call is placed, the network attempts to open a fixed circuit between the two endpoints. If the call can be completed, a circuit that stretches the entire length of the network between the two endpoints is then dedicated to that particular call, and cannot be used by another until the originating call is concluded.

The basic architectural difference between traditional telephony and IP telephony is that an IP network such as the Internet is inserted between the telephony endpoints, typically central offices. IP networks are packet-switched, as opposed to circuit-switched traditional telephony. Unlike circuit-switched networks, packet networks do not set up a fixed circuit before the call begins. Instead, the individual voice packets are sent through the IP network to the destination. Each packet may traverse an entirely different path through the network; however, the conversation is reassembled in the correct order before being passed on to the VoIP application. The "glue" that ties together the PSTN (Public Switched Telephone Network) with the IP network is known as an IP gateway. IP gateways perform many of the traditional telephone functions such as terminate (answer) a call, determine where the call is to be directed, and perform various administrative services such as user verification and billing before passing the call on to a receiving IP gateway. The receiving IP gateway, which may also be interconnected with the PSTN, dials the destination and completes the call.[4)]

Pricing a new service is mostly a trial and error process, and the pricing of Best-Effort VoIP service is obviously no exception. Judging from the number of recent press releases, financial analyses, and articles written on VoIP, estimation of market size, consumer interest, and willingness-to-pay for VoIP services is a hot subject. A recent Goldman Sachs telecom services report notes that, as the VoIP threat evolves, it should not be viewed as catastrophic by the incumbent local exchange carriers (ILECS).[5)] *Business 2.0* published a story "Beware the VoIP Hype" in its December 9, 2003 issue describing a mismatch between expectations of investors and realities of the market. The author of that story noted that "… the big winners are likely to be the established companies that are already profitable and can afford to spend money on research and development and marketing. Most companies are not making money off the technology."[6)]

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1) *The authors thank Dale Kulp, president of Marketing Systems Group for access to the CENTRIS omnibus survey.*

2) *For a comprehensive look at VoIP providers see http://VoipWatch.com*

3) *'Best-effort' refers to VoIP plans that provide voice services over the Internet. This offering requires potential customers to have or be willing to have a broadband connection. 'Primary line' quality VoIP is provided by a service provider who owns or controls the infrastructure between the MTA (telephone enabled DOCSIS modem) and the gateway.*

4) *http://www.cse.ohio-state.edu/~jain/cis788-99/ftp/voip_products/. IP gateways may be a computer type of connection at the termination/origination of the call.*

5) *Goldman Sachs, Telecom Services: Wireline/Broadband Competitive Analysis, April 16, 2004.*

6) *Business 2.0 http://www.business2.com/b2/subscribers/articles/0,17863,534155-2,00.html*

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Before turning to technical details, it is useful to note just what it is that VoIP represents. Unlike some services that have emerged out of the electronic revolution, VoIP does not involve a new good *per se*, but rather a new way of providing an existing good at possibly lower cost and in a possibly more convenient manner.[7)] The good in question, of course, is real-time voice communication at a distance. The word *possibly* is to be emphasized, for voice communication is a mature good in a mature market, with characteristics that for all practical purposes are now those of a commodity. The ultimate potential market for VoIP, accordingly, is simply the size of the current voice market plus normal growth. Hence the evolution of VoIP is pretty much strictly going to depend upon the efficiency *vis-à-vis* traditional telephony with which VoIP vendors can provision this market.

To our knowledge, the present effort, which builds upon a previous study of the demand for broadband access using models of willingness-to-pay [Rappoport et al. (2003c)], is the first to focus on the modeling of VoIP services. The analysis in this paper makes use of data from an omnibus survey conducted in March and April, 2004, by the Marketing Systems Group of Ft. Washington, PA,[8)] in which respondents were asked questions concerning their willingnesses-to-pay (WTP) for VoIP services. In the study of broadband access just referred to, price elasticities for broadband access were developed using extensions of a generally overlooked procedure suggested by Cramer (1969). The same analysis has been used in this study. *Inter alia*, price elasticities for VoIP are obtained that range from an order of –0.50 for a fixed price of $10, to –3.00 for a fixed price of $70.

In addition to the range of elasticities just mentioned, the principal findings of the paper are:

1) Market drivers include the distribution of total telephone bills (local and long distance); the distribution of WTP and the distribution of broadband access to the Internet.

2) The market size for best-effort VoIP is small. For example, at a price of $30 a month, the estimated consumer market size is 2.7 million households.

3) Households with access to the Internet, especially with broadband access, have a higher willingness-to-pay for VoIP services.

The format of the paper is as follows. The next section begins with a short descriptive presentation of factors that underlie the demand for VoIP services. Section III provides the underlying theoretical framework that guides the analysis; Section IV discusses the data used in the analysis; Section V discusses the calculation of the price elasticities for best-effort VoIP services derived from kernel-smoothed cumulative distributions of willingness-to-pay; while the modelling of the willingness-to-pay is presented in Section VI. Market-size simulations are presented in Section VII. Conclusions are given in Section VIII.

James Alleman is Professor in the College of Engineering and Applied Science at the University of Colorado

II Descriptive analysis

The analysis of the demand for VoIP services can be viewed as the conjunction of the three forces or factors. These include the distribution of total telephone bills; the probability that a household has or is interested in getting broadband access to the Internet; and the household's willingness to pay for VoIP service. Figure 1 displays the distribution of telephone bills (local and long-distance). Of interest here is the assumption that a household's interest in VoIP – and hence willingness-to-pay – depends on the household's total telecommunication expenditures. Thus, households with large telephone bills will presumably be more interested in VoIP than households with a smaller telephone bill. The fall-off in telephone expenditures after $50 shown in this figure suggests that the potential size of VoIP may be limited by the number of households that have monthly telephone bills greater than $50.

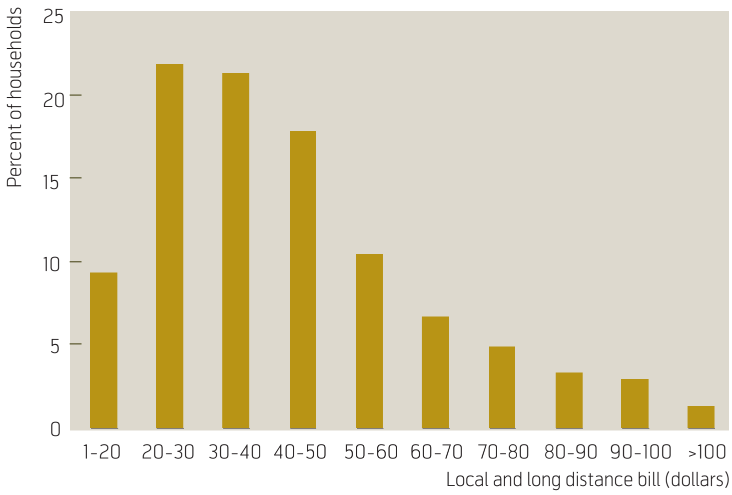

Figure 1 Distribution of total telephone bill

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7) *Cellular telephone provides an apt contrast with VoIP, for while cellular, too, represents an alternative way of providing real-time voice communication, it also allows for such to take place at times and places not available to traditional fixed-line telephony, hence in this sense is a genuine new good.*

8) *www.m-s-g.com*

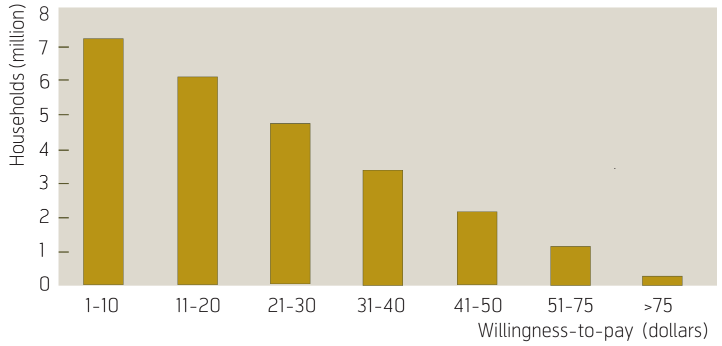

Figure 2 Distribution of willingness-to-pay for VoIP (households with broadband access)

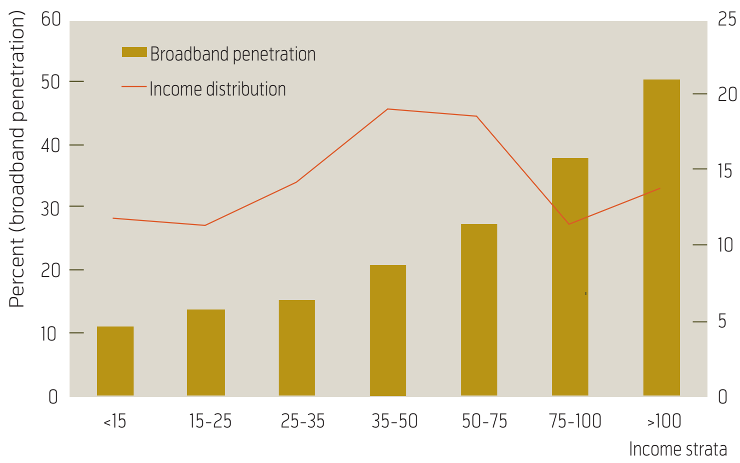

Figure 3 Demand for broadband as a function of income

Figure 2 shows the distribution of willingness-to-pay for VoIP for households that already have broadband access to the Internet. Since these are the households that would seem to have the most potential for migrating to VoIP, the prospective size of the VoIP market suggested by the numbers in this distribution would appear to be pretty modest. At a "price" of $40 per month, the indicated size of market (as measured by the number of households with WTP greater than $40) is seen to be about 2 million households, while at $10 a month (which would almost certainly not be remunerative), the number is only 7 million.

Figure 3 examines the relationship between the distribution of income (left scale) and the broadband penetration rate (right scale). Since broadband access is presumed to be a requirement for best-effort VoIP, the strong positive relationship that is indicated to hold between broadband penetration and income makes it clear that the distribution of income (especially the upper tail) is an important determinant of the potential VoIP market.[9]

III Theoretical considerations

We begin with the usual access/usage framework for determining the demand for access to a network, whereby the demand for access is determined by the size of the consumer surplus from usage of the network in relation to the price of access.[10] Accordingly, let q denote usage, and let $q(p,y)$ denote the demand for usage, conditional on a price of usage, p, and other variables (income, education, etc.), y. The consumer surplus (CS) from usage will then be given by

$$CS = \int q(z,y)dz. \tag{1}$$

Next, let π denote the price of access. Access will then be demanded if

$$CS \geq \pi, \tag{2}$$

or equivalently (in logarithms) if

$$\ln CS \geq \ln \pi. \tag{3}$$

Alleman (1976, 1977) and Perl (1983) were among the first to apply this framework empirically. Perl did so by assuming a demand function of the form:[11]

$$CS = \int_p^\infty Ae^{-\alpha p} y^\beta e^u dz, \tag{4}$$

where y denotes income (or other variables) and u is a random error term with distribution $g(u)$. Consumer's surplus, CS, will then be given by

$$CS = \frac{Ae^{-\alpha p} y^\beta e^u}{\alpha}. \tag{5}$$

With net benefits from usage and the price of access expressed in logarithms, the condition for demanding access to the telephone network accordingly becomes:

$$\begin{aligned} P(\ln CS \geq \ln \pi) &= P(a - \alpha p + \beta \ln y + u \geq \ln \pi) \\ &= P(u \geq \ln \pi - a + \alpha p - \beta \ln y), \end{aligned} \tag{6}$$

[9] *The relationship between WTP and income will be examined in Section V below.*

[10] *See Chapter 2 of Taylor (1994).*

[11] *Since its introduction by Perl in 1978 in an earlier version of his 1983 paper, this function has been used extensively in the analysis of telecommunications access demand [see, e.g. Kridel (1988) and Taylor and Kridel (1990)]. The great attraction of this demand function is its nonlinearity in income and an ability to handle both zero and non-zero usage prices.*

where $a = \ln(A/\alpha)$. The final step is to specify a probability distribution for consumer surplus, which, in view of the last line in equation (6), can be reduced to the specification for the distribution of u in the demand function for usage. An assumption that u is distributed normally leads to a standard probit model, while an assumption that u is logistic leads to a logit model. Empirical studies exemplifying both approaches abound in the literature.[12)]

The standard procedure for estimating access demand can thus be seen in terms of obtaining information on the consumer surplus from usage by estimating a demand function, and then integrating beneath this demand function. In the present context, however, our procedure is essentially the reverse, for what we have by way of information are statements on the part of respondents in a survey as to the *most* that they would be willing-to-pay for a particular type of VoIP service. This *most* accordingly represents (at least in principle) the maximum price at which the respondent would purchase that type of service. Thus, for any particular price of VoIP, VoIP will be demanded for WTPs that are this value or greater, while VoIP will not be demanded for WTPs that are less than this value. Hence, implicit in the *distribution* of WTPs is an *aggregate demand function* (or more specifically, *penetration function*) for VoIP service. In particular, this function will be given by:

$$\begin{aligned} D(\pi) &= \text{proportion of WTP's that are greater than or equal to } \pi \\ &= P(WTP \geq \pi) \\ &= 1 - CDF(\pi), \end{aligned} \tag{7}$$

where $CDF(\pi)$ denotes the cumulative distribution function of the WTPs. Once CDFs of WTPs are constructed, price elasticities can be obtained (without intervention of the demand function) via the formula (or empirical approximations thereof):

$$Elasticity(\pi) = \frac{d \ln CDF(\pi)}{d \ln \pi}. \tag{8}$$

IV Data employed in the analysis

As noted, information on willingness-to-pay for VoIP service was collected from an omnibus national survey of about 8000 households in April and May, 2004, by the Marketing Systems Group (MSG) of Philadelphia. The omnibus survey, Centris[13)], is an ongoing random telephone survey of US households. Each of the participants in the surveys utilized here was asked one (but not both) of the following two questions regarding their willingness-to-pay.

a) What is the most you would be willing to pay on a monthly basis for a service that provides unlimited local and long distance calling using your computer?

b) What is the most you would be willing to pay on a monthly basis for a service that provides unlimited local and long distance calling using your computer with Internet connection at a cost of $20 per month?[14)]

The first question was asked of those households that currently have broadband access, while the second version was asked of those households that did not have broadband access.

V Calculation of price elasticities

We now turn to the calculation of price elasticities in line with expression (8) above. The most straightforward way of doing this would be to define the elasticities as simple arc elasticities between selected adjacent points on the empirical CDFs. Unfortunately, however, because the survey-elicited WTPs tend to bunch at intervals that are multiples of 5 dollars, the values that emerge from this procedure are highly unstable, and accordingly of little practical use. To avoid this problem, elasticities are calculated using a kernel-based non-parametric procedure in which the "pileups" at intervals of 5 dollars are "smoothed out."

Since kernel estimation may be seen as somewhat novel in this context, some background and motivation may be useful. The goal in kernel estimation is to develop a continuous approximation to an empirical frequency distribution that, among other things, can be used to assign density, in a statistically valid manner, in any small neighborhood of an observed frequency point. Since there is little reason to think that, in a large population, "pileups" of WTPs at amounts divisible by $5 reflect anything other than the convenience of nice round numbers, there is also little reason to think that the "true" density at WTPs of $51

12) *Empirical studies employing the probit framework include Perl (1983) and Taylor and Kridel (1990), while studies using the logit framework include Bodnar et al. (1988) and Train, McFadden, and Ben-Akiva (1987). Most empirical studies of telecommunications access demand that employ a consumer-surplus framework focus on local usage, and accordingly ignore the net benefits arising from toll usage. Hausman, Tardiff, and Bellinfonte (1993) and Erikson, Kaserman, and Mayo (1998) represent exceptions.*

13) *www.Centris.com*

14) *$20 was selected since dial-up prices were approximately $20.*

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WTP	With Broadband	Without Broadband
\$70	-2.86	-2.96
60	-3.02	-2.47
50	-2.78	-3.01
40	-1.76	-1.56
30	-1.07	-1.05
20	-0.73	-0.76
10	-0.55	-0.60

Table 1 VoIP elasticities based on WTP kernel-smoothed CDF

or \$49 ought to be much different from the density at \$50. The intuitive way of dealing with this contingency (i.e. "pileups" at particular discrete points) is to tabulate frequencies within intervals, and then to calculate "density" as frequency within an interval divided by the length of the interval (i.e. as averages within intervals). However, in doing this, the "density" within any particular interval is calculated using only the observations within that interval, which is to say that if an interval in question (say) is from \$40 to \$45, then a WTP of \$46 (which is as "close" to \$45 as is \$44) will not be given weight in calculating the density for that interval. What kernel density estimation does is to allow every observation to have weight in the calculation of the density for every interval, but a weight that varies inversely with the "distance" that the observations lie from the center of the interval in question.

For the analytics involved, let $\hat{g}(x)$ represent the density function that is to be constructed for a random variable x (in our case, WTP) that varies from x_1 to x_n. For VoIP WTP, for example, the range x_1 to x_n would be 0 to \$700.[15] Next, divide this range (called the 'support' in kernel estimation terminology) into k sub-intervals. The function $\hat{g}(x)$ is then constructed as:

$$\hat{g}(x_i) = \sum_{j=1}^{N} \frac{K(\frac{x_i - x_j}{h})}{Nh}, \quad i = 1, \ldots, k. \tag{9}$$

In this expression, K denotes the kernel-weighting function, h represents a smoothing parameter, and N denotes the number of observations. For the case at hand, the density function in expression (9) has been constructed for each interval using the unit normal density function as the kernel weighting function and a 'support' of k = 1000 intervals.[16]

From the kernel density functions, VoIP price elasticities can be estimated using numerical analogues to expression (8).[17] The resulting calculations, undertaken at WTPs of \$70, \$60, \$50, \$40, \$30, \$20, and \$10 per month, are presented in Table 1.[18] The estimated elasticities are seen to range from about –3.0 for WTPs of \$60–70 to about –0.6 for WTPs of \$10. Interestingly, the values in column 1 (for households that already have broadband access) for the most part mirror those in column 2 (which refer to households that do not). Since this appears to be the first effort to obtain estimates of price elasticities for VoIP, comparison of the numbers in Table 1 with existing estimates is obviously not possible. Nevertheless, it is of interest to note that the values that have been obtained are similar to existing econometric estimates for the demand for broadband access to the Internet.[19] More will be said about this below.

VI Modeling willingness-to-pay

An interesting question is whether willingness-to-pay, which in principle represents areas beneath demand curves, can in turn be "explained" in terms of the determinants of demand, that is, as functions of

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15) *This is for the households with broadband access. For those households without broadband access [i.e. for households responding to Question (b)], the range is from 0 to \$220.*

16) *Silverman's rule-of-thumb,*

$\hat{h} = (0.9) min[std.dev., interquartile\ range/1.34](N^{-1/5})$,

has been used for the smoothing parameter h. Two standard references for kernel density estimation are Silverman (1986) and Wand and Jones (1995). Ker and Goodwin (2000) provide an interesting practical application to the estimation of crop insurance rates.

17) *The kernel-based elasticities are calculated as "arc" elasticities using points (at intervals of ± \$5 around the value for which the elasticity is being calculated) on the kernel CDFs via the formula:*

$$Elasticity(x) = \frac{\Delta CDF(x)/CDF(x)}{\Delta WTP(x)/WTP(x)}.$$

Thus for \$70, for example, the elasticity is calculated for x (on the kernel CDFs) nearest to 75 and 65.

18) *Since Question (b) postulates an access cost of \$20, the WTPs for households without broadband access are assumed to be net of this \$20.*

19) *See e.g. Rappoport, Taylor, Kridel, and Serad (1998), Kridel, Rappoport, and Taylor, (1999), Kridel, Rappoport, and Taylor (2002a), Rappoport, Taylor, and Kridel, (2002b), Rappoport, Kridel, Taylor, Duffy-Deno, and Alleman (2003a) and Rappoport, Taylor and Kridel (2003b).*

price, income, and other relevant factors. To explore this, we return to the expression for consumer surplus in equation (5), which we now express (in logarithms) as:

$$\ln CS = f(p, y, x, u), \quad (10)$$

where p, y, x, and u denote the price of usage, income, a variety of socio-demographic and other characteristics, and an unobservable error term, respectively. Since information on y and x is available (but obviously not vendor prices for VoIP) from the Centris survey, expression (10) can be estimated as a regression model with lnWTP as the dependent variable. However, before this can be done, the fact that some of the WTPs are zero – which creates an obvious problem in defining the dependent variable – has to be dealt with.

Two solutions emerge as possibilities. The first solution is to use WTP as the dependent variable in place of lnWTP (in which case zeros are clearly not a problem), while the second solution is simply to eliminate all of the observations with zero WTPs from the sample. We have opted for the second solution. However, we do this as part of a two-stage procedure, in which, in the first stage, a discrete-choice probit model is estimated that explains zero and non-zero values of WTP. The inverse of a "Mills ratio" is then constructed from this model and used as a "correction" term in a second-stage model, in which the logarithms of non-zero values of WTP are regressed on a set of dummy variables representing income and various socio-demographic factors.[20] The "independent" variables that are available to the analysis include income (measured in terms of income intervals); gender, age, education, and region of residence; satellite, cable, Internet, telephone, and cellular bills; forms of Internet access (including no access), and the number of cellular telephones.[21] The statistical relationships should almost certainly be positive between WTP for VoIP and income and education, but probably negative for age.[22] Obviously, a strong positive association should prevail between VoIP WTP and a household's telephone bill.

The results for the first-stage probit models are tabulated in Tables 2 and 3. Table 2 refers to households that already have broadband Internet access in some form, while Table 3 refers to households that have either dial-up service or no Internet access at all. The results, though weak statistically,[23] are in keeping with the expectations just noted, especially with respect to the size of telephone bill. The effect of income is non-linear and positive, as is education, while age (especially for households that do not already have broadband access) is negative.[24] It is interesting that DSL and wireless Internet access, but not cable-modem access, are seen to be important for households that already have broadband access, [25] which suggests that households view VoIP, at this point anyway, primarily in terms of conventional telephony.

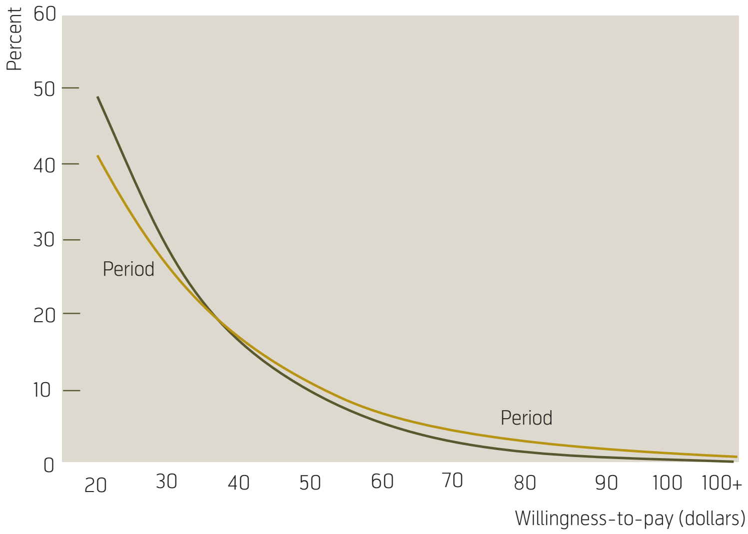

Figure 4 Shifts in willingness to pay for VoIP over time

20) *Although a value of zero is certainly a valid response to questions concerning willingness-to-pay, to put zero and non-zero values on the same footing in constructing CDFs would seem to entail the assumption that penetration rates would be 100 % at VoIP prices of zero. Obviously, this need not be the case. By specifying a first-stage model that explains the likelihood of a household having a non-zero WTP, and then incorporating this information as a "correction" in a second-stage model that explains the magnitude of (non-zero) WTP, penetration is thereby determined only with respect to those households that value VoIP positively.*

21) *Definitions of the variables are provided in the appendix.*

22) *We say this because of a finding in our earlier study of the demand for broadband access [Rappoport et al. (2004)] of a strong negative relationship between age and the WTP for broadband access.*

23) *That the results are generally weak statistically is evident in the paucity of p-values that are less than 0.10 and the fact that linear probability models (i.e. regression models with zero-one dependent variables) yield R2s that are of the order of 0.07. The strong importance of the dummy variable denoting whether the household was surveyed in April as opposed to March may well reflect the increased awareness of VoIP by households.*

24) *For income, the left-out category is income less than 15 K, for education, the left-out category is less than high-school graduate, and for region, the left-out category is west.*

25) *Because broadband access is a prerequisite for VoIP, readers are cautioned to view these relationships as simply ones of association.*

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Variable	Coefficient	Standard Error	Chi-Square	Pr > Chi-Sq
Intercept	0.3855	0.4257	0.86	0.3537
Gender	-0.0159	0.0704	0.05	0.8211
dinc2	0.2890	0.1464	3.90	0.0483
dinc3	-0.1518	0.1367	1.23	0.2668
dinc4	0.0084	0.1117	0.01	0.9399
dinc5	-0.0043	0.1062	0.00	0.9676
dinc6	0.1907	0.1243	2.35	0.1251
dinc7	0.0506	0.1145	0.20	0.6586
dinc8	0.2307	0.2429	0.90	0.3421
dinc9	-0.0859	0.1956	0.19	0.6605
Lnage	-0.1523	0.0962	2.50	0.1137
HS	0.1050	0.1540	0.46	0.4954
Somecoll	0.0551	0.1560	0.12	0.7240
Collgrad	0.2000	0.1549	1.67	0.1967
Gradschl	0.1721	0.1764	0.95	0.3293
Tech	-0.0800	0.2650	0.00	0.9758
Northeast	0.1014	0.1041	0.95	0.3304
Northcentral	-0.0898	0.1055	0.73	0.3944
South	0.0719	0.0940	0.59	0.4441
Satbill	-0.0002	0.0016	0.01	0.9228
Cablebill	0.0005	0.0011	0.18	0.6698
Internetbill	0.0005	0.0017	0.08	0.7749
Telephonebill	0.0016	0.0009	3.16	0.0757
Cellbill	0.0003	0.0005	0.25	0.6179
Cablemodem	0.1193	0.1418	0.71	0.4002
DSLmodem	0.2361	0.1458	2.62	0.1054
Wireless	0.7369	0.4676	2.48	0.1151
#cellphones	0.0489	0.0328	2.23	0.1354
dapril	-0.3881	0.1240	9.80	0.0017

Number of observations: 1395
Number of WTPs > 0: 777
Number of WTPs = 0: 618

Table 2 VoIP probit model for non-zero willingness-to-pay. Households with broadband access

The first stage results suggest that the size of the telephone bill and whether a household has broadband access emerge as the key determinants of interest in (and willingness-to-pay for) VoIP telephony services. Since the effects of income and age are highly correlated with broadband demand[26] it is not surprising that these demographics enter into the first-stage equations. The dummy variable for April was included to test whether WTP changes when households have the ability to obtain more information on VoIP services. Other things being equal, we would expect the WTP function to shift "clockwise" as households are exposed to more information on VoIP service: It is becoming harder to miss the Vonage banner adds! This shift is illustrated in Figure 4. Period 2 is the most recent period.

The estimated coefficients, standard errors, t-ratios, and p-values for the second-stage models are tabulated in Tables 4–6. The dependent variables in these models are the logarithms of the (non-zero) WTPs. The independent variables include all those that appeared in the first-stage models, plus the first-stage "Mills ratios" (LnMillsVoIP).[27] Table 4 contains the second-stage model for households that already have broadband access, while Table 5 contains the same for the households that do not. An equation using a merged sample for the two groups is given in Table 6.

The results for the second-stage models, for the most part, parallel those for the first-stage models. Statistical significance is generally weak,[28] the effects of income and education are positive, and the effect of age is negative. VoIP WTP for both groups of households is positively related to telephone expenditures, but the effects, especially for households already with broadband access, are not as strong empirically as might have been expected. The Mills ratio is positive, but of little importance statistically.[29] The importance of the telephone bill and the Internet bill is stronger for households with broadband access. This result is expected for "best-effort" VoIP, as we would expect households with broadband access to be better

26) *See discussion in Rappoport, Taylor and Kridel (1999), Kridel, Rappoport, and Taylor (2002a), Rappoport, Taylor, and Kridel (2002a).*

27) *The Mills ratio, it is to be noted, corrects for the fact that, because the second-stage model can be interpreted as the conditional expectation of WTP, given that WTP is greater than zero, the error-term in this model is "drawn" from a truncated distribution, and therefore does not have a mean of zero. The Mills ratios are accordingly calculated according to the formula $n(\pi i)/N(\pi i)$, where πi denotes the predicted value (in the first-stage probit equation) of the probability that respondent i has a non-zero WTP and $n(\pi i)$ and $N(\pi i)$ represent the standard normal density and cumulative distribution functions of this event. For a derivation and discussion, see Chapter 6 of Maddala (1983).*

28) *Reference here is to t-ratios and p-values for individual variables and coefficients. Low R-squares with cross-sectional survey data of the type being employed are normal.*

29) *Unlike the usual procedure in two-stage models of this type, which is to include the Mills ratio as it stands, the logarithm is used instead. Use of the latter makes little difference with regard to fit and own significance, but does cause an increase in significance of several of the other independent variables.*

Variable	Coefficient	Standard Error	Chi-Square	Pr > Chi-Sq
Intercept	0.9803	0.3316	8.74	0.0031
Gender	-0.0759	0.0540	1.97	0.1604
dinc2	0.0317	0.1081	0.09	0.7697
dinc3	0.0241	0.0933	0.07	0.7960
dinc4	0.0788	0.0784	1.01	0.3148
dinc5	0.1484	0.0782	3.60	0.0578
dinc6	0.1310	0.1019	1.65	0.1987
dinc7	-0.0161	0.1073	0.20	0.8809
dinc8	0.1445	0.1569	0.85	0.3573
dinc9	-0.0438	0.1469	0.09	0.7657
Lnage	-0.2427	0.0749	10.49	0.0012
HS	0.0324	0.1070	0.09	0.7617
Somecoll	-0.0974	0.1117	0.76	0.3833
Collgrad	-0.1177	0.1115	1.11	0.2912
Gradschl	-0.1837	0.1350	1.85	0.1738
Tech	-0.3466	0.2028	2.92	0.0875
Northeast	0.0324	0.0864	0.14	0.7073
Northcentral	-0.0610	0.0788	0.60	0.4392
South	-0.0179	0.0741	0.06	0.8095
Satbill	-0.0002	0.0011	0.03	0.8541
Cablebill	-0.0011	0.0010	1.14	0.2851
Internetbill	-0.0009	0.0018	0.29	0.5901
Telephonebill	0.0026	0.0008	11.45	0.0007
Cellbill	0.0004	0.0005	0.41	0.5224
Dialup	0.1196	0.0972	1.51	0.2185
#cellphones	0.0354	0.0289	1.51	0.2198
dapril	-0.4481	0.0835	28.80	<0.0001

Number of observations: 2302
Number of WTPs > 0: 1145
Number of WTPs = 0: 1157.

Table 3 VoIP probit model for non-zero willingness-to-pay. Households without broadband access

Variable	Coefficient	t-ratio	Pr > |t|
Intercept	3.0181	8.02	<0.0001
Gender	-0.0749	-1.16	0.2452
dinc2	0.2657	0.80	0.4250
dinc3	0.0658	0.30	0.7646
dinc4	-0.0584	-0.57	0.5673
dinc5	0.1280	1.33	0.1845
dinc6	0.1300	0.58	0.5609
dinc7	0.1843	1.64	0.1024
dinc8	0.1205	0.38	0.7065
dinc9	-0.3638	-1.93	0.0543
Lnage	-0.2350	-1.22	0.2240
HS	0.2430	1.27	0.2031
Somecoll	0.3511	2.14	0.0323
Collgrad	0.3717	1.42	0.1573
Gradschl	0.2498	0.99	0.3241
Tech	0.0132	0.05	0.9619
Northeast	0.0037	0.03	0.9785
Northcentral	-0.1321	-0.94	0.3471
South	0.1478	1.32	0.1878
Satbill	-0.0002	-0.15	0.8823
Cablebill	0.0008	0.80	0.4231
Internetbill	0.0046	3.03	0.0025
Telephonebill	0.0361	1.98	0.0481
Cellbill	0.0001	0.27	0.7857
Cablemodem	-0.0900	-0.43	0.6681
DSLmodem	0.0305	0.10	0.9225
Wireless	0.7256	0.95	0.3439
#cellphones	0.0077	0.13	0.8979
dapril	0.3923	0.89	0.3727
lnMillsVoIP	0.6842	0.47	0.6377

$R^2 = 0.1584$ d.f. = 747

Table 4 VoIP regression model for willingness-to-pay. Households with broadband access

positioned to fully use VoIP services. The strongest results, quite clearly, are the ones for the merged sample in Table 6, especially regarding the effects of income, age, and telephone expenditures.[30)]

VII The potential market for VoIP

As noted in the introduction, VoIP is not a new good *per se*, but rather provides a new way of supplying an existing good. Its success, consequently, is going to depend upon whether VoIP vendors can supply acceptable quality voice telephony at costs that are lower than those of the traditional carriers. VoIP is not a "killer-app" whose "explosion on the scene"

30) *The format for this equation is to allow for the two subgroups of households (i.e. those already having broadband access and those without) to have separate intercepts and separate coefficients on type of Internet access. All other coefficients are constrained to be the same.*

Variable	Coefficient	t-ratio	Pr > |t|
Intercept	4.2961	6.70	<0.0001
Gender	-0.0378	-0.47	0.6377
dinc2	0.1201	1.11	0.2663
dinc3	0.1400	1.47	0.1408
dinc4	0.0594	0.54	0.5873
dinc5	0.1917	1.23	0.2190
dinc6	0.2204	1.41	0.1596
dinc7	0.0799	0.77	0.4394
dinc8	0.1768	0.95	0.3447
dinc9	-0.1900	-1.36	0.1733
Lnage	-0.3856	-1.72	0.0849
HS	-0.1064	-1.01	0.3118
Somecoll	-0.1301	-0.98	0.3257
Collgrad	0.0317	0.22	0.8260
Gradschl	0.0072	0.04	0.9717
Tech	-0.2294	-0.59	0.5531
Northeast	0.1347	1.57	0.1158
Northcentral	-0.0062	-0.07	0.9451
South	0.0611	0.88	0.3772
Satbill	0.0017	1.77	0.0762
Cablebill	0.0005	0.34	0.7338
Internetbill	0.0002	0.08	0.9340
Telephonebill	0.0013	0.67	0.5033
Cellbill	0.0009	1.67	0.0976
Dialup	-0.2913	-1.73	0.0834
#cellphones	-0.0196	-0.50	0.6195
dapril	0.1925	0.47	0.6393
lnMillsVoIP	0.3807	0.34	0.7328
$R^2 = 0.1157$ d.f. = 1144			

Table 5 VoIP regression model for willingness-to-pay. Households without broadband access

Variable	Coefficient	t-ratio	Pr > |t|
Intercept	3.5419	14.34	<0.0001
Gender	-0.0468	-1.17	0.2415
dinc2	0.1385	1.65	0.0987
dinc3	0.1189	1.60	0.1089
dinc4	0.0185	0.31	0.7585
dinc5	0.1687	2.81	0.0049
dinc6	0.1379	1.80	0.0720
dinc7	0.1595	2.24	0.0249
dinc8	0.1230	1.01	0.3107
dinc9	-0.2427	-2.29	0.0222
Lnage	-0.2699	-4.08	<0.0001
HS	-0.0221	-0.26	0.7926
Somecoll	0.2484	0.29	0.7719
Collgrad	0.1059	1.25	0.2128
Gradschl	0.0306	0.31	0.7580
Tech	-0.1170	-0.68	0.4940
Northeast	0.0639	1.06	0.2908
Northcentral	-0.0271	-0.46	0.6478
South	0.0939	1.79	0.0743
Satbill	0.0012	1.54	0.1248
Cablebill	0.0008	1.27	0.2043
Internetbill	0.0028	2.55	0.0107
Telephonebill	0.0157	2.85	0.0044
Cellbill	0.0004	1.43	0.1535
dvoip2Dialup	0.0364	0.88	0.3789
dvoip1Cablemodem	-0.1844	-1.93	0.0533
dvoip1DSLmodem	-0.1022	-1.00	0.3154
dvoip1Wireless	0.3806	1.23	0.2191
#cellphones	-0.0208	-1.06	0.2888
dapril	0.4647	4.27	<0.0001
lnMillsVoIP	0.1839	0.78	0.4332
dvoip1	0.0502	0.58	0.5612
R2 = 0.1140 d.f. = 1921			

Table 6 VoIP regression model for willingness-to-pay. All households

will fuel a whole new industry. The voice telephony market is an old market, and the growth of VoIP is for the most part going to have to be at the expense of existing vendors.[31] The purpose of this section is to take a sober look at what VoIP vendors might accordingly reasonably expect as an initial potential market.

Despite the relatively weak statistical relationship that was found in the preceding section between a household's WTP for VoIP and the size of the household's telephone, rationally this has to be a key consideration, for we should not expect a household to demand VoIP unless doing so leads to a reduction in

31) While the discussion here is couched in terms of new companies versus old, the argument is really with regard to technologies. If VoIP should in fact turn out to be superior in terms of quality and cost in relation to traditional circuit-switched technology, then existing telecommunication companies will have to adjust accordingly, which they almost certainly will do, rather than go the way of the dodo bird. The end result might be that traditional telcos simply transform themselves into full-scale Internet service providers.

the cost of voice communication. Not unreasonably, therefore, the potential market for VoIP can be viewed as consisting of those households for which both its telephone bill and WTP for VoIP are greater than price of the service. Potential markets employing this criterion using information from the Centris survey have accordingly been constructed for three different VoIP prices, namely 50, 40, and 30 dollars. The resulting households that are estimated to be candidates for demanding VoIP are presented in Table 7.

Price	Households
$50	810,000
40	2,170,000
30	2,700,000

Table 7 Potential market for VoIP

These numbers are small by any assessment, and stand in marked contrast with various estimates that have been promulgated by industry analysts. There are approximately 23 million households with broadband access in the US, and to some, this is the size of the potential market for VoIP. However, if one simply looks at willingness-to-pay for VoIP that is greater than zero, the potential market drops to approximately 7 million households. A then closer look at the willingness-to-pay function suggests that at a price of $30, the market size is less than three million households. There is room for some growth, especially if the number of households with broadband services grow. Nonetheless, the total size of the "best-effort" VoIP market is likely to remain at best modest.[32)]

VIII Conclusions

This paper has analyzed the consumer demand for best-effort VoIP service using information on willingness-to-pay for VoIP that was collected in early March and April, 2004, in an omnibus survey of some 8000 households. A theoretical framework has been utilized that identifies willingness-to-pay with consumer surplus from usage, which both allows for willingness-to-pay to be modeled as a function of income, education, and other socio-demographic factors, as well as the construction of a market demand function. The results of the exercise suggest that the demand for VoIP service is elastic (i.e. has an elasticity greater than 1 in absolute value) over the range of prices currently charged by VoIP service providers. The distribution of total telephone bills, the probability that a household has broadband access and the household's willingness to pay for VoIP service are used to simulate potential market size for various prices of VoIP service. In all simulations, the potential market size is estimated to be small.

Since the elasticities of the exercise are constructed from information elicited directly from households, and thus entail the use of contingent-valuation (CV) data, the seriousness (in light of the longstanding controversy surrounding the use of such data) with which our elasticities are to be taken might be open to question.[33)] However, in our view, the values that we have obtained are indeed plausible and warrant serious consideration. Added credence for our results, it seems to us, is provided by the fact that, with VoIP service, we are dealing with a product (voice telephony) with which respondents are familiar and already demand, unlike in circumstances (such as in the valuation of a unique natural resource or the absence of a horrific accident) in which no generally meaningful market-based valuation can be devised.

It is interesting to note that our estimated elasticities suggest that at a price around $30 demand shifts from inelastic to elastic. Vonage, the largest of the best-effort VoIP providers, recently announced a price reduction to $30 for all new and existing customers.[34)]

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32) *It is for these reasons that a number of large cable providers have opted to downplay best-effort VoIP in their telephony strategies and focus on providing basic telephony services over their IP-based network. Initial estimates for cable providers of the market size for IP-based telephone services are 20 % of the current RBOCs market.*

33) *The critical literature on contingent valuation methods is large. See the NOAA Panel Report (1993), Smith (1993), Portnoy (1994), Hanneman (1994), Diamond and Hausman (1994), and McFadden (1994). On the other hand, particularly successful uses of CV data would seem to include Hammitt (1986) and Kridel (1988).*

34) *See http://www.citi.columbia.edu/voip_agenda.htm. See also http://www.vonage.com*

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Appendix: Definitions of variables

Gender	1 = male; 0 = female
dinc2	Income between $15,000 and $24,999
dinc3	Income between $25,000 and $34,999
dinc4	Income between $35,000 and $49,999
dinc5	Income less than $50,000
dinc6	Income greater than $50,000
dinc7	Income between $50,000 and $74,999
dinc8	Income between $75,000 and $99,999
dinc9	Income of $100,000 or more
Lnage	Logarithm of age of head of household
HS	High school graduate
Somecoll	Some college
Collgrad	College graduate
Gradschl	Graduate School
Tech	Technical school
Northeast	Northeast Census region
Northcentral	North Central Census region
South	South Census region
Satbill	Self reported household satellite bill
Cablebill	Self reported household cable bill
Internetbill	Self reported household Internet bill
Telephonebill	Self reported household local and long distance telephone bill
Cellbill	Self reported household wireless bill
Cablemodem	1 if household is connected to the Internet via cable modem
Dslmodem	1 if household is connected to the Internet via DSL
Wireless	1 if household has a wireless (cell) phone
#cellphones	Number of cell phones in the household
dapril	Dummy variable for April, 2004
Dialup	1 if household access the Internet via dial-up connection
lnmillsvoip	Logarithm of the inverse mills ratio
dvoip1	Dummy variable for households that have broadband access to the Internet
dvoip2dialup	Dummy variable for households that have only dial-up access to the Internet
dvoip1cablemodem	Dummy variable for households that cable-modem broadband access to the Internet
dvoipdslmodem	Dummy variable for households that DSL broadband access to the Internet
dvoipwireless	Dummy variable for households that have wireless broadband access to the Internet

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Paul Rappoport is an Associate Professor of Economics at Temple University. He has over 25 years of experience in forecasting and data analysis, modeling and statistical assessment, with a specialization in applied telecommunications demand analysis. Dr. Rappoport has written extensively on choice models where he has analyzed network effects and route specific demand. His current research focuses on deriving price elasticities from estimates of a consumer's willingness to pay using survey data; the construction of network (internet) metrics; specifying and modeling business broadband; forecasting demand, measuring the nature of network externalities under conditions of increased competition and modeling the demand for best practice Voice-over-IP.
Paul Rappoport is a Senior Fellow at Columbia University's Center for Tele-Information and a Senior Consultant to Global Insight. He received his PhD from The Ohio State University in 1974.

email: prapp4@comcast.net

Lester D. Taylor received his BA with highest distinction from the University of Iowa in 1960 and his PhD from Harvard University in 1963. He is Professor Emeritus of Economics and Professor Emeritus of Agricultural Economics; Demand Analysis, Econometrics, and Economics of Regulated Industries at the University of Arizona, Tucson, USA. Dr. Taylor joined the faculty of the Department of Agricultural and Resource Economics in 1991. He also has an appointment in the Department of Economics, where he has been Professor since 1972. Prior to Arizona, he held positions at Harvard University and the University of Michigan.
His research interests have centered on consumer demand, econometrics, and the economics of regulated industries. Other interests include capital theory and the interface between psychology and economics. He was a senior staff economist at the Council of Economic Advisers in 1964-65 and spent 18 months in 1967-68 with the (then) Harvard Development Advisory service as an advisor to the Ministry of Planning of the Government of Colombia.
Dr. Taylor has been Associate Editor of 'The Review of Economics & Statistics' and on the Editorial Board of 'The Journal of Consumer Research' and 'Inernational Journal of Grey Systems'. He has published a long list of papers and books, and for the past 25 years his published research has focused heavily on the telecommunications industry.
Dr. Taylor has conducted business consulting for companies such as Telefonica de Argentina, Telekom Austria, Telecom Italia, Southwestern Bell Telephone Co., and many more. He has been a consultant to OPSIS in Venezuela, to Techniön University in Israel, to California Energy Commision and to the Ministry of Planning in the Kingdom of Saudi Arabia.

email: ltaylor@bpa.arizona.edu

Donald Kridel is Associate Professor of Economics at University of Missouri, St. Louis, where he has been teaching since 1993. Prior to joining the faculty at UM-St.Louis, Kridel was Director-Strategic Marketing at Southwestern Bell (now SBC) where he had held various positions since 1982. He publishes in the area of applied econometrics and regularly addresses industry and academic groups on telecommunications demand analysis. Kridel earned his PhD in economics from the University of Arizona.

email: kridel@umsl.edu

James Alleman is a Professor in the College of Engineering and Applied Science, University of Colorado – Boulder and a Senior Fellow at the Columbia Institute for Tele-Information (CITI), Graduate School of Business, Columbia University, where he was Visiting Professor (2001–2002). Previously Dr. Alleman was the Director of the International Center for Telecommunications Management at the University of Nebraska at Omaha; Director of Policy Research for GTE; and an economist for the International Telecommunication Union in Geneva, Switzerland. He conducts research in the area of network economics and finance.
Dr. Alleman founded Paragon Service International, Inc., a telecommunications call-back firm, and he has been granted patents on the process widely used by the industry. He holds BA and MA degrees from Indiana University, and a PhD in Economics from the University of Colorado.

email: James.Alleman@Colorado.edu

ISSN 0085-7130 © Telenor ASA 2004

Understanding residential Internet service adoption patterns in the UK

ALASTAIR ROBERTSON, DIDIER SOOPRAMANIEN AND ROBERT FILDES

Alastair Robertson is a research fellow at Lancaster University Management School

Didier Soopramanien is a lecturer at Lancaster University Management School

Robert Fildes is Professor at Lancaster University Management School

New research at Lancaster University Management School in the UK focuses on the development of ICT models that explain residential Internet service adoption and usage. In this paper, the authors apply both human characteristics and product attributes to the problem of Internet service adoption choice and estimate the choice structure using UK based household survey data. In general it is found that the application of both types of data to the problem of service choice leads to a modelling strategy that gives systematically varying price and income elasticity estimates at the consumer segment level.

Researchers are continually looking at new and better forecasting models that will allow them to gain a better understanding of how and why consumers adopt new technologies. Research at Lancaster University Management School focuses on understanding better the structure of residential Internet choice. Internet choice structure is analysed using a discrete choice model that embodies both human characteristic and product attribute data. The benefit of this approach is that it is possible to determine how the factors of choice vary between dial-up and broadband services. A further benefit of the procedure is that consumer segmentation issues can be address that allow for the estimation of segmental price and income elasticity effects. A conditional logit model is estimated using residential survey data from the UK, and this model reveals that price and income elasticity effects vary systematically by consumer segment.

1 Introduction

Understanding the factors that drive residential Internet adoption is an important step towards forecasting Internet adoption rates and levels. It is becoming increasingly important for market planners, government and telecoms professionals alike, to have and use consumer behavioral information so that forecasts may be employed that account for a more realistic number of market factors. In a special issue of the *International Journal of Forecasting* on telecommunications forecasting, Fildes (2002) discusses the complexities arising from the deregulation of the telecoms industries that complicate the processes of market modeling. Fildes (2002) also highlights the risk associated with poor forecasting techniques that lead to over-investment and oversupply of products (i.e. WAP telephony) and discusses the need for more research into forecasting techniques where limited data are available. For fast developing markets like the Internet, novel forecasting strategies must be developed, tested and successfully implemented. This article shows how consumer behavioral patterns may be used to understand residential Internet adoption patterns, clearing away some of the unknowns of the market place.

The Internet is a relatively new product in terms of residential adoption. Despite its origins spanning back to military and academic use during the 1960s, residential usage only became a realistic proposition in western communities during the late 1980s when home computing costs became a relatively minor part of household income. During the early 1990s, the popularity of the Internet soared internationally with the introduction of easy to use graphical interfaces that have simplified web use considerably (Cracknell, Mujamdar and Patel, 2002). As this new information source gained popularity new and innovative services, such as online banking and shopping, became available that further enhanced the user experience. As Internet services developed, questions were raised in respect of the Internet's ability to function with ever increasing demands being placed upon it as web designers began using more complex graphical interfaces designed to give the Internet user a more satisfying experience. This resulted in the generation of new and faster modem designs. In the UK, general home access began with 14.4 kb/s (kilobytes per second) modems that used standard copper wire telephone lines to connect to the Internet. From 1994 onwards, the user experience was enhanced further by the introduction of 28.8 and 33.6 kb/s modems that reduced download wait times substantially although this was soon to be superseded by 56 kb/s modems that became the standard for nearly five years. Although ISDN became a realistic alternative to standard dial-up services, this innovation never won any serious market share from dial-up services in the UK and tended to remain in the domain of home business users. Of course, we have to bear in mind that broadband services, at a typical speed of 512 kb/s, compete strongly with dial-up services and enhance the user experience further still by allowing the user to remain online twenty-four hours a day, seven days a week without interfering with incoming telephone calls, and the increased bandwidth gives a

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more seamless and faster operating environment. The UK has two main residential broadband delivery mechanisms, cable access and ADSL. Although both have limited coverage due to technological constraints, these data delivery mechanisms will be capable of offering services to some 87 % of households in the UK as of the summer 2004. British Telecom, the sole wholesaler of ADSL connections, aims to have 99.7 % of UK households broadband capable by the summer of 2005. As of April 2004, 52 % of homes in the UK have Internet access and 15 % use broadband services.[1)]

The discussion in the previous paragraph highlights that the Internet has provided a platform that has required a great deal of technological change to support its evolution. Mishra et al. (2002) suggest that the rapid development of technology markets has resulted in shorter product lifecycles because of increased competitiveness in the market place which forces firms to re-develop and upgrade their technologies constantly if they are to survive. To become a market leader, the firm must understand the potential of future technological innovation via forecasts of the technological change itself or by forecasts of the duration that its established products will remain financially viable to the market. Developments already seen in the Internet suggest rapid technical change will continue. For example, nearly 100 % of Japanese households presently have broadband coverage via ADSL. Recently also, Yahoo launched its new 26 Mb/s service in Japan that is connected via ADSL and is available to 80 % of households at a monthly subscription cost of just £20. With Internet bandwidth this wide, a new range of data hungry subscription services, such as video on demand, are now possible. But what these facts highlight is that this "super-broadband" will become available in the UK, which naturally leads to the question, how well will it be received by households? The aim of this paper is to show how survey data can be used to increase our understanding of residential Internet adoption patterns and how these patterns may vary between dial-up and broadband services. In addition, different consumer segments have differing attitudes to adoption, a fact that affects both government regulators and market planners as they consider the implications of new technological innovations and their forecasts of future uptake.

The organisation of this paper is as follows. Section 2 introduces the need to understand Internet markets better through the use of household surveys and discusses prior research where this methodology has been successfully applied using US centric data. It also discusses how the resulting data may be used to estimate predictive models, in this case the logit choice model, which measures the consumer's "latent" Internet utility. Section 3 describes the data collected during the first half of 2003 on UK residential Internet adoption patterns and also provides the results of an Internet choice model that captures the dynamics of consumer choice between the alternatives of no Internet service, dial-up service and broadband service. The final section offers conclusions and avenues for further research.

2 Previous research on Internet demand

This paper is based on prior research conducted by Kridel, Rappoport and Taylor (2002) that depicts the use of surveying as a method of capturing consumer level information when time series market level data is limited. Their research, which is US centric, assesses the demand for high-speed cable modem services and uses a very large consumer survey database (n = 32,000) from which they estimate consumer behaviors. The authors identify a number of factors that are found to be important in the choice of whether to adopt cable modem services. Specifically, they focus on income, age, educational attainment, household size and geographic location as the choice factors with price analyses included also. The idea that income is an important determinant of choice is not controversial as the demand for many products or services is known to be affected by this economic variable. As income increases, it would be expected that the demand for cable modem services would also increase. Age is also important when dealing with consumers at the individual level as older generations tend to have lower propensities to adopt hi-tech products and services, although it probably would not be wise to ignore the effect of the wealthy "silver surfers" depicted by Cracknell, Mujamdar and Patel (2002). These individuals are becoming a strong adoptive force in the UK's Internet revolution as they have the time to learn the complexities of computing and the income to purchase Internet services. Households with higher educational backgrounds tend to have a higher propensity to adopt information and communication technology in general as these individuals may have higher valuations of the usefulness of these products and services, perhaps induced by their previous educational training. A further factor that Kridel et al. (2002) use to predict Internet adoption is household size. This is perceived to impact the likelihood of a household adopting cable modem ser-

1) *Source: OFCOM, www.offcom.org.uk, April 2004. Report title: The Ofcom Internet and Broadband Update.*

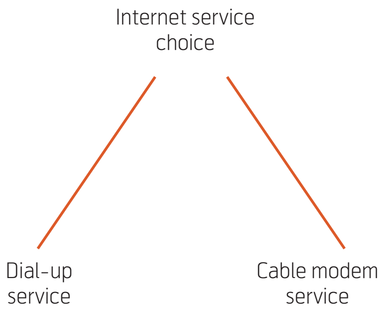

Figure 1 The two-way Internet choice structure

vices as this variable captures the presence of children, a factor known to exert a positive influence on the choice of whether to adopt residential Internet services (Kraut et al. 1996). This naturally arises as parents wish their children to have the educational benefits that computers and Internet services offer. Several strands of the literature suggest that technological innovations tend to be adopted by "technophiles". This implies that assessing the level of technological adoption of households should have some predictive capacity in assessing the demand for other technological innovations like the Internet. Busselle et al. (1999) and Kridel, Rappoport and Taylor (1999) analyse the relationship between Internet availability and technology in the home and find a strong correlation between the number of technological devices in the home and Internet adoption/usage.

The predictive model employed by Kridel, Rappoport and Taylor (2002) estimates the binary Internet choice model that is shown in Figure 1 using data on individuals that have residential Internet access. Underlying this choice structure is the concept of consumer utility that assumes that consumers will always maximize utility subject to constraints such as income. Kridel et al. propose equation 1 that captures this maximization behavior.

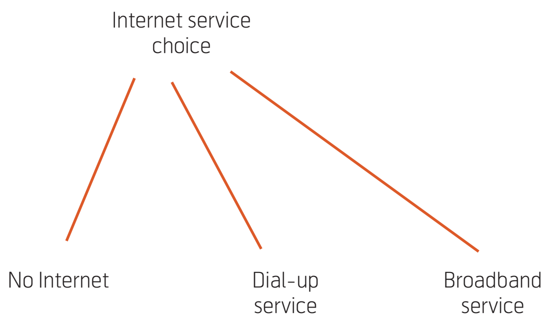

Figure 2 The three-way Internet choice structure

$$Prob(\text{high-speed access} \mid x) = P(\epsilon n - \epsilon y > Vy - Vn) \quad (1)$$

where the V elements are the observed utilities for having high speed access (y = yes) or not (n = no). In this equation *Prob(high-speed access | x)* is the conditional probability that high-speed access will be chosen over the dial-up alternative given the level of x that is a vector of product attributes (price) and the socio-economic consumer variables that have been discussed. In this case the following choice model is estimated,

$$Prob(\text{high-speed access} \mid x) = 1 / (1 + \exp(-x\beta)) \quad (2)$$

where β is a vector of parameters to be estimated from the data that relate to the product attributes and consumer decision variables. Kridel et al.'s model yields the following conclusions. Income and educational attainment have a positive effect on the adoption of high-speed services. As age increases, the propensity to adopt generally declines but as household size increases so does the likelihood of finding high-speed services in the household. The effect of cable modem price was found to be significant in the choices made and the own-price elasticity of demand was estimated to range from –1.08 to –1.79 with a cross-price effect of 0.15 suggesting a strong "substitution effect" between dial-up and cable modem services.

The Kridel et al. (2002) paper also highlights the usefulness of embodying both human characteristic type data with product attributes as a useful way of summarizing the effects of these factors on product choice. This paper follows their research methodology but extends the research on several dimensions. On the first dimension, it extends the number of human characteristics and socio-demographics used to estimate the choice model by including the number of available technologies in the home as a predictor of Internet service adoption. On the dimension of choice, the model is also extended to become a model with three mutually exclusive choices as is shown in Figure 2. In this model consumers may choose not to adopt Internet services at all, or have only dial-up services or finally choose to adopt broadband services. Since three choices are available, the model attempts to capture the differential behavioral dynamics of choice between dial-up and broadband services, although this does not always accomplish the best results due to the increased likelihood of multicollinearity among the socio-demographic variables as will be discussed later in this paper. The final new dimension that this study provides is that it is one of the first studies of its kind that focuses on the importance of both human characteristics and product attributes in the UK context.

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This research applies McFadden's conditional logit model of choice (Greene, 2000) to estimate the model parameters. On a theoretical note, the conditional logit model is limited by an underlying assumption that suggests the error terms be homoscedastic (sometimes called Gumbel distributed). When this assumption is satisfied, the conditional logit model will estimate cross-price elasticity effects that are constant across all alternative choices. This is commonly referred to as the independence of irrelevant alternatives (IIA) and becomes more problematic the more substitutable products become. To illustrate, the IIA assumption of the conditional logit model assumes that a decrease in the monthly subscription price of broadband will have a constant effect for users of the dial-up service and those who do not use the Internet. However, it is highly likely that the change in the subscription price will have a differential impact for users and non-users of the Internet respectively. This highlights the need to test whether the IIA assumption holds in the data. STATA 7, the statistical package used to estimate the model, provides the Hausman specification test that may be employed to test the homoscedasticity assumption. Should the Hausman test reject the null hypothesis of homoscedasticity then alternative discrete choice models should be employed that allow for the relaxation of the IIA assumption.

3 The data

The data used to estimate the three-way choice model was collected during the first half of 2003. The survey was initially piloted using market research students at Lancaster University Management School who were required to survey family and friends on their ICT habits. This yielded a total of 1916 responses from across the UK. After cleaning this first data set, only 525 remained for the analysis that is presented here. The data set was expanded further by posting the survey to 5000 households in the locality of Lancaster in the North-West of England and Brighton and Hove in the South-East of England. Households were selected using the British electoral register that was supplied by an organization called *UKinfo* that captures all registered voters over the age of 18. Only one survey was sent per household. The postal survey returned 830 responses of which 761 remained for estimation use post cleaning. Combined with the student collection 1286 responses are used in this analysis. The survey was very extensive asking respondents 73 questions relating to computer and Internet adoption, ISP subscription price and service type, perceptions toward ICTs, online shopping behavior and socio-demographic details at both the individual and household level. The dataset contained bias due to non-response error and this was overcome by weighting the data using known British averages on computer and Internet adoption, age distribution, educational attainment and gender.

4 Discussion of results

This section shows charts of the relevant factor effects that are found to impact on Internet service adoption. Chart 1 begins this process by looking at the effect of the number of existing technologies in the home on the likelihood of adopting Internet services. Essentially, this variable attempts to measure whether households with a higher propensity to adopt technology in general will also have a higher propensity to adopt Internet services as discussed by Busselle et al. (1999) and Kridel et al. (1999). Each household respondent was asked to choose from a list of 14 technologies that they have in their home. The list of 14 technologies presented to the respondents to select from was given as microwave oven, video recorder, DVD player, video camera, digital camera, games console (e.g. play station, Xbox), electronic personal organizer, answer machine, mobile phone, fax machine, satellite dish, cable TV, CD player, MP3 or minidisk player. For the purposes of this research four levels of household technology adoption are defined as: technologies 0 to 3, technologies 4 to 6, technologies 7 to 9 and technologies 10 to 14. Chart 1 shows the effect that this variable has on the adoption of Internet services. Here it is clearly seen that households with no Internet services have a rightward skewed distribution with regard to technology adoption whereas both dial and broadband service respondents tend to have distributions that are skewed leftward with the broadband distribution being more intense. This suggests that prior technology adoption and acceptance does seem to have strong predictive power on whether a household adopts Internet services, and this effect consistently changes across households from those that have only limited household technologies to those which are technophiles. Educational attainment is also shown to be a strong predictor of Internet service adoption. This is shown in Chart 2. As can readily be seen, households that do not have residential Internet services tend to come from less educated backgrounds. Both dial-up and broadband using households have strong rightward skewed distributions, but it can also be seen that broadband households tend to be more highly educated than dial households, although the relationship is not monotonic. This is evidence toward the hypothesis that households with higher educational attainment tend to value Internet services more than those from households with lower educational attainment. This may be due to the educational process itself that trains students to use information and communication products more effectively.

The effect of the presence of children on household Internet adoption is thought to be positive for two potential reasons. Firstly, parents wish their offspring to accrue educational benefits from computers and the Internet. The second potential reason is that children can act as educators of adults in computer matters as they tend to be educated in computing from junior school upwards (Kraut et al. 1996). This additional training increases the valuation that parents have toward computers and the Internet in general. This is shown in Chart 3. Here, only 11 % of non-Internet using households suggested children were present in the household. This number rises dramatically for dial services to 24 % and then to 31 % for broadband service. Why dial and broadband service should vary so much is unclear but it is possible that some parents may choose broadband over dial service because it frees up the phone line. More qualitative

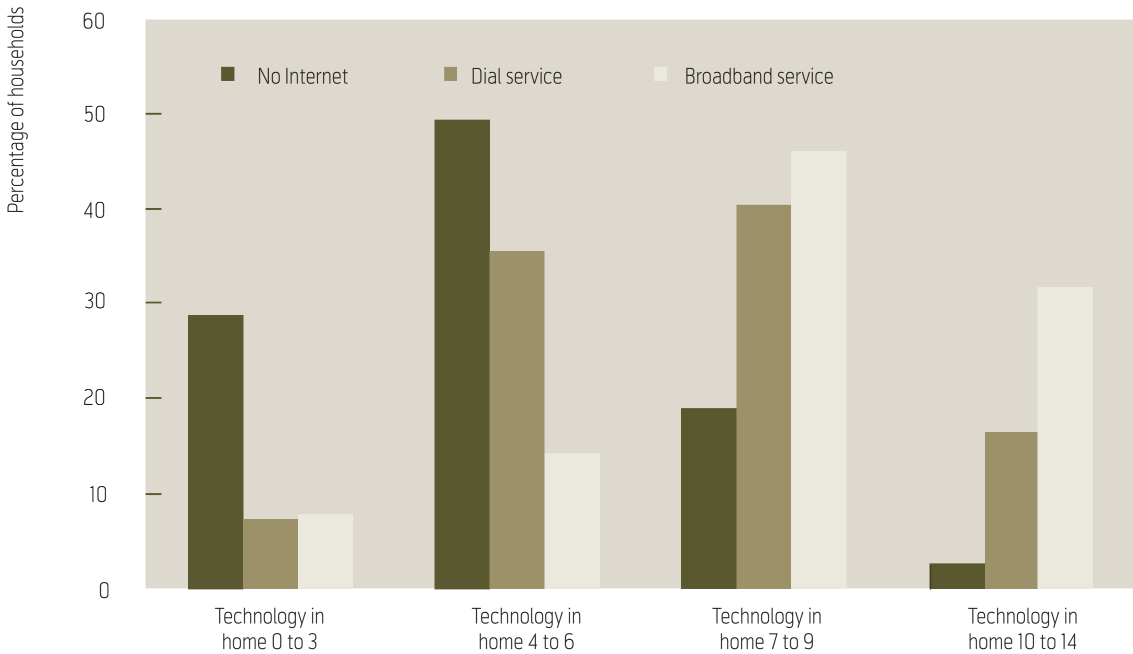

Chart 1 The effect of household technology acceptance on Internet service adoption

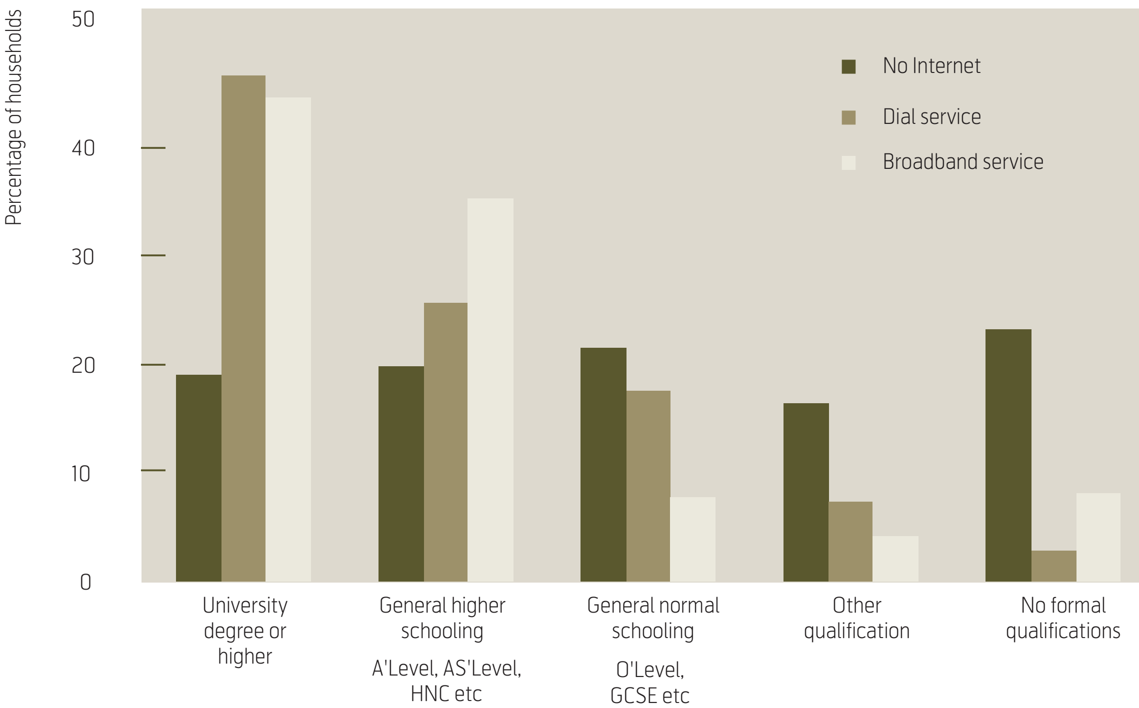

Chart 2 Effect of educational attainment on Internet adoption

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research is required in this area to get a clearer understanding of this effect. Needless to say, the presence of children does act as a predictor of Internet service adoption. It should be noted that the number of adults in the household was also tested as a potential predictor of Internet service adoption and although a reasonably strong pattern was observed, the pattern was highly correlated with household disposable income. This is to be expected given that the number of wage earning adults in the household will tend to increase household income. For modeling purposes, this results in multicollinearity between these variables that makes interpretation of the results at best difficult. In light of this, the effect of the number of adults on residential Internet adoption is dropped from the analysis and the only statistical solution to this problem would be to increase sample size.

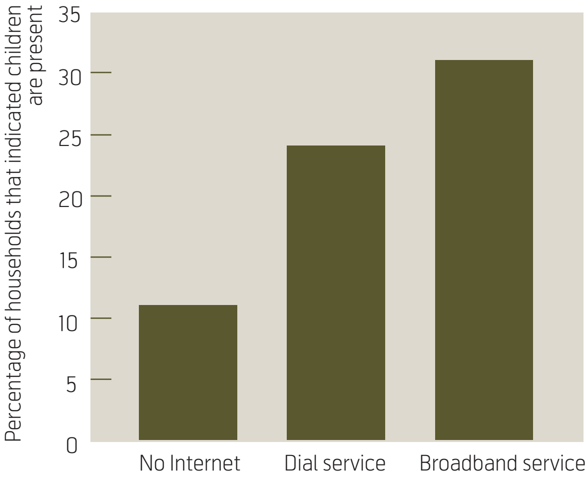

Chart 3 The effect of children on residential Internet adoption

The effect of household disposable income on Internet service adoption is shown to be positive in Chart 4. Respondents were asked to state the approximate household income, less income tax, national insurance and pension schemes and then to choose the appropriate income range. The chart shows that households without Internet services tend to have lower incomes than those with Internet services but that the difference between dial and broadband services is actually quite small. Earlier research conducted for this study suggested that income is a particularly strong factor in the choice of whether to purchase a computer as it is a relatively expensive item to purchase in the first place but once purchased the economics of choosing Internet services is less financially orientated as the costs are considerably reduced and most computers are shipped with modems preinstalled.

Internet service pricing varies systematically between dial-up service and broadband service as would be expected. At the time of the survey, for dial services, respondents paid on average £7 per month. For broadband this rose to £23. Both values are in line with OFCOM's independent estimates.

6 The conditional logit model of Internet service adoption

It was discussed earlier the importance of testing for violations of the IIA property. In this case the Hausman test supports the use of the conditional logit model at the 5 % level of significance. The nested alternatives model is to be considered in subsequent research. The conditional logit model was estimated in STATA 7 using maximum likelihood. There were incomplete responses in some cases also, hence only 1217 cases were used to estimate the results that are given in Table 1. In this model only three continuous variables are used; dial services price, broadband price and disposable income. All other variables are entered dichotomously. For example, technology level 2 (see section 4 for description of the variable) for either dial services or broadband is 1 if the household is found to have four to six of the listed technologies and 0 otherwise. Each set of categorical variables has a reference category and the resulting coefficients are compared to this. Overall the model performs well with a pseudo R^2 of 0.3528 suggesting a good general fit. The model converged after five iterations.

Table 1 contains 5 sections. The first section shows the effect of prices on the choices; both coefficients are negative which indicates that as the price of either service falls the adoption probabilities for that service should rise. The probability values (see P-values)

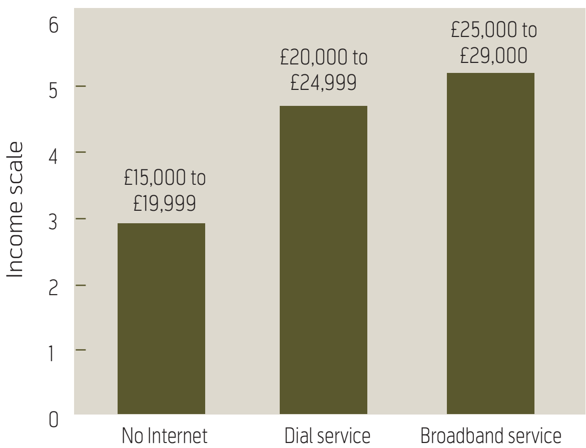

Chart 4 The effect of household disposable income on residential Internet adoption

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Variable	Coefficient	P-values
Dial price	-0.034	0.005
Broadband price	-0.086	0.000
Impact effect of factors on dial services		
Technology level 2	1.91	0.001
Technology level 3	5.54	0.000
Technology level 4	19.57	0.000
General higher schooling A-level, AS-level, HNC etc.	0.35	0.000
General normal schooling O-level, GCSE etc.	0.25	0.000
Other qualification	0.18	0.000
No qualifications	0.05	0.000
Children	1.87	0.001
Impact effecs of factors on broadband services		
Technology level 2	1.07	0.869
Technology level 3	7.73	0.000
Technology level 4	47.04	0.000
General higher schooling A-level, AS-level, HNC etc.	0.49	0.009
General normal schooling O-level, GCSE etc.	0.10	0.000
Other qualification	0.12	0.000
No qualifications	0.13	0.000
Children	2.53	0.000
Effects of factors on general Internet services		
Household disp. inc.	0.0759	0.013
Geographic control impact effect		
Lancaster	0.58	0.000
Brighton	0.48	0.013
N = 1217; Log likelihood: -885.9; Psuedo R^2 = 0.353		

Table 1 Conditional logit coefficients

show that these relationships are significant at 1 %. Clearer detail on the strength of effect of price on this market is given later in the text. The next section of the table shows how the factors that have been described affect dial service adoption. To assist in the understanding of how each factor affects product adoption quantitatively the coefficients are reported as impact effects.2) In this case the technology effects are positive and statistically significant at 1 %. The magnitude of the effects increase as the number of technologies in the home rises (the reference category is very low tech households, level 1). The value for technology level 2 is 1.9 and suggests that households with three to six of the listed technologies are almost twice as likely to adopt dial-up services as those from the lowest technology group. The impact effects increase sizably as technology levels increase. Households from technology level 3 are 5.5 times more likely to adopt dial-up services than very low technology households, whereas the very highest technology households are almost 20 times as likely. Overall, this suggests that households that adopt technologies in general are more likely to adopt dial services as would be expected. In terms of educational attainment the tabulated impact effects compare to those households that are degree qualified or above and therefore the impact effects are less than one and become smaller as educational attainment declines. All of the impact effects are statistically significant at 1 %. Those households that have at least one member that has general higher schooling are a third as likely to adopt dial-up services as those from the highest educational attainment category, and those with general normal schooling are a quarter as likely. Households with no formal qualifications are considerably less likely to adopt dial-up services as those from the very highest qualified households. Households that have children present are almost twice as likely to adopt dial services as compared to those without and this finding is statistically significant at 1 %.

For broadband in section 3 of Table 1, a similar picture emerges but for some effects the patterns are stronger than for dial-up services. The technology level 2 impact effect is statistically insignificant, which is different from the dial service result. The magnitude of the effect is close to 1 and this implies that no quantitative difference emerges between the two lowest technology categories. The highest two technology categories are significant at 1 % and give larger effects than the dial equivalents. Technology level 3 households are 7.7 times more likely to have broadband as lower tech households (including level 2). Technology level 4 households are 47 times more likely to have broadband services than those from the lowest tech households. Given the increased magnitude of the effects of technology on broadband over dial-up, it can be suggested that the role of prior technology adoption on broadband uptake is greater than for dial-up service. This provides further evidence of factor effects being more important earlier in the product lifecycle and is also supported by research conducted by Busselle et al. (1999). It may be expected in the years to come that these values will

2) *For example, in the logit model, the estimated technology level 2 coefficient is 0.648 and the impact effect is therefore exp(0.648) = 1.9.*

Segment 1	Very low income household, no formally qualified individuals reside in the household and household has few technology items *Adoption estimates from model: No Internet: 96.7 %, Dial service: 2.2 %, Broadband service: 1.1 %*
Segment 2	High income, moderately educated households but with low propensity to adopt technologies. Typically retired or nearing retirement *Adoption estimates: No Internet: 74.4 %, Dial service: 20.3 %, Broadband service: 5 %*
Segment 3	Average household with children. Average income, qualified at school to a moderate level and has a moderate propensity to adopt technologies *Adoption estimates: No Internet: 64.5 %, Dial service: 33.7 %, Broadband service: 1.8 %*
Segment 4	Highly educated households that have a high income and a high propensity to spend income on new technologies *Adoption estimates: No Internet: 4.4 %, Dial service: 67.4 %, Broadband service: 28.2 %*

Table 2 Household segment descriptions

decrease in time as broadband services reach more households. For educational attainment the result is not as clear as for dial services. Although all categories with less than a degree level education are less likely to choose broadband services the pattern is not as consistent as for dial services. This is quite likely to be a function of sample size as the broadband cohort amounts to only 120 cases in the weighted data with only a very small number of adopters residing in the more poorly educated categories. Households that have at least one member that has general higher schooling are half as likely to adopt broadband as highly educated households. The remaining educational attainment categories are approximately a 10th as likely to adopt broadband services as those households with highly educated members. Households with children are 2.6 times as likely to have broadband services as those without, a result that is statistically significant at 1 %; this suggests that the effect of children on broadband service adoption is marginally stronger than it is for dial services. This result confirms the findings in Chart 3 and again supports the hypothesis that the importance of factors such as demographic variables can change over the product lifecycle.

The 4th section of Table 1 shows that income is entered into the model to measure the effect of this variable across Internet adoption, rather than defining this effect on both dial and broadband services separately. This approach was adopted more for statistical necessity rather than by choice as multicollinearity effects were observed between household disposable income of broadband and a number of variables, but particularly broadband price. The income variable is statistically significant at 5 % and shows that as household disposable income increases, so should the propensity to adopt Internet services. Further discussion on the effect of income on Internet adoption is provided later in this paper. The final section in the model estimates the impact effects of two location control variables, Brighton and Lancaster, on general Internet adoption. Both variables are statistically significant to at least 5 % and suggest that Lancaster households are 3/5th as likely to have Internet connectivity as those households from the student collection (the comparison category) and half as likely if the household comes from Brighton. This result is not surprising as the student collection over-represents more highly educated households with higher than average incomes.

The conditional logit model is used to compute choice elasticity effects for dial price, broadband price and household disposable income whilst controlling for the other human characteristic effects. This is accomplished by assuming that specific and unique household segments exist based on the socio-demographic characteristics estimated in the model. The descriptions of the segments addressed here are shown in Table 2. In this case four segments are produced and for each segment it is possible to estimate own and cross-price elasticities that vary systematically by segment.

The segmental elasticities are calculated using sample enumeration techniques at the means of the data and the resulting estimates are given in Table 3. For the dial-up service, the own price elasticity ranges from -

	Dial Service		Broadband Service	
	Own-Price	Cross-Price	Own-Price	Cross-Price
Segment 1	-0.22	0.00	-1.8	0.01
Segment 2	-0.17	0.06	-2.0	0.13
Segment 3	-0.15	0.11	-2.2	0.03
Segment 4	-0.08	0.016	-1.5	0.58

Table 3 Segmental elasticity table

ISSN 0085-7130

	Income Elasticity
Segment 1	0.27
Segment 2	0.23
Segment 3	0.20
Segment 4	0.01

Table 4 Income elasticity table

0.08 for high utility Internet users to –0.22 for the very lowest utility group. This suggests that dial-up adoption service is price inelastic. This is not surprising as the pricing structure of the dial service in the UK is highly complex (see Taylor, 2002; Fildes, 2002) due to varying metered and non-metered services that are offered by 300 plus ISPs and these variations are not captured by price measure used.

The broadband own-price elasticity ranges between –2.2 and –1.5. The value of –2.2 represents the case for the average family with children and –1.5 represents the case for technology loving, wealthy households that are highly educated. The estimates are higher in magnitude to those given by Kridel et al. who report an own-price high speed Internet elasticity range of –1.08 to –1.79 for the US, although their results are not based on segmental analysis. The cross-price elasticities indicate that expected downward shifts in broadband price will have a larger draw effect from dial-up services for segment 4 users than for any other segment, which implies that this segment will be the first adopters of broadband. For segments 1 and 3 the draw effect from dial to broadband service is negligible and only moderate effects for segment 2 are observed. Research by Kridel et al. reports an average cross-price effect of 0.15.

The segmental income effects are reported in Table 4 and indicate that Internet and broadband adoption is income inelastic for both high and low ICT utility groups but more significantly so for those in the high ICT utility group. For the very low ICT utility groups, the income elasticity is larger than for other groups and suggests that income plays an important role in general Internet adoption for this group of Internet users.

7 Conclusions and avenues for further research

This paper shows how survey data can be used to give clearer insights into residential technology markets when market level data availability is limited. The empirical results show that adoption patterns in the Internet service market can be explained by socio-demographic variables such as educational attainment, household disposable income and the presence of children. Other human characteristics are also found to be important in this market such as the propensity for households to adopt technologies. This paper also shows that for the most part, these effects vary across the product lifecycle. For example, the impact of technology acceptance was found to vary systematically between dial-up and broadband service adoption with the impact being greater on the broadband product. This would suggest that any newer product offering that supercedes the current broadband product should be marketed toward "hi-tech savvy" households. Educational attainment is also found to be important in our understanding of the residential Internet market as more highly educated households tend to value ICT products more than those with lower levels of education. The presence of children in the household acts as a strong predictor of Internet adoption with the effect appearing to be marginally stronger for broadband than for dial services. The prices of the Internet service products are also found to be strong predictors of adoption and the estimated elasticities show that the broadband market is particularly competitive, which is not surprising given that over 100 ISPs now supply this product in the UK.

A number of avenues for further research became apparent during the research process. It was found that highly educated individuals are more likely to adopt and use ICT services as a result of their education, and this implies that research should be focused toward understanding this effect better. Is it simply that introducing households to ICT products and training individuals well in their use would increase the likelihood of them adopting ICT products, or is it something more to do with the types of individuals that take on higher education that have a higher propensity to do so? A qualitative analysis seems appropriate in this case as this may have important ramifications for researchers wishing to understand better the causes of the digital divide, as well as telecoms market planners aiming to ensure high levels of uptake for their company's products. For researchers, both in industry and government, it is important to develop general industry ICT forecasts so that planning initiatives may be undertaken that meet the objectives of both, whether this be in direct marketing effort or policy making. Research currently being undertaken at Lancaster University Management School is testing methods that will apply the probability output of the logit model and incorporate them into new-product diffusion models that forecast the broadband adoption paths under a variety of market scenarios including multi-generational modeling and more experimentally by producing the adoption forecasts at the segment level. This latter approach remains unexplored in the academic literature as far as we are aware. It would also be useful to track a group of households in time so that time dynamic behavioral effects could be explored, for example the effects of increased product familiarity on price elasticity. Again, research at Lancaster is now beginning that hopes to meet this objective.

A future difficulty that will arise in the study of Internet markets is the increasing complexity in the pricing of the data delivery services (see Taylor, 2002, for further discussion of this point). During the survey period the pricing of broadband in the UK was straightforward. Households would receive the connection with unlimited online time with no download limits and few bandwidth variations. This has since changed. Since many broadband households use their connection for bandwidth intensive usages, such as music downloads, stress on the networks forced many ISPs to limit download capacity by price. This implies that the future calculation of accurate price elasticities would need to control for these effects and this would take a much larger scale survey to accomplish, particularly if the values are required by market segment, desirable from the point of view of the telecoms market planner.

Acknowledgements

The authors are grateful to the ESRC (award number R42200124401) and the Pump Priming Research Funding Scheme at Lancaster University and the Small Research Grant Scheme at the Lancaster University Management School for funding this research.

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ISSN 0085-7130 © Telenor ASA 2004

Alastair Robertson is a research fellow at Lancaster University Management School and his research interests are supported by the Economic and Social Research Council's post-doctoral fellowship scheme. He joined the school in 2000 to undertake a PhD in Management that focuses on the re-development of new-product forecasting methodologies that combine both human characteristics and product attributes to yield forecasts at the consumer segment level.

email: a.w.robertson@lancaster.ac.uk

Didier G.R. Soopramanien is a lecturer in Management Science at Lancaster University Management School, UK. He joined the department of Management Science in 2002 after completing a PhD in Economics at Lancaster University. His main research interests are in the area of applied consumer behaviour, branding, Internet and ICT technologies adoption and usage, the economic development process of small states and the measurement and development of value added for online grocery retailing. He also supervises PhD students in the area of marketing, customer relationship management (data mining) and corporate credit scoring.

email: d.soopramanien@lancaster.ac.uk

Robert Fildes is Professor of Management Science in the School of Management, Lancaster University and Director of the Lancaster Centre for Forecasting. He has published widely in forecasting and planning. For ten years from 1988 he was Editor-in-Chief of the International Journal of Forecasting and was President of the International Institute of Forecasters, 2000–2004. His research interests are concerned with the comparative evaluation of different forecasting methods and the implementation of improved forecasting procedures in organisations. Current forecasting projects are in the design of forecasting support systems (funded by industry and government) and in automatic methods to select the most accurate forecasting method. For many years he has worked with BT on telecoms forecasting projects and also spent nine months with Bell Communications.

email: r.fildes@lancaster.ac.uk

The demand and pricing of a portfolio of broadband services

TERJE AMBJØRNSEN, KJETIL ANDERSSON AND BJØRN HANSEN

Firms typically offer more than one price-quality version of a product. Broadband providers, for example, offer a number of download access speeds, such as 704 kbit/s, 1024 kbit/s and 2048 kbit/s. This is known as "versioning", reflecting that the firm offers different versions of a product. In the present paper we discuss, within a theoretical framework, how consumers react to price changes and the rationale for a firm to involve in "versioning". Furthermore, we review a number of empirical broadband-demand studies and discuss the relationship to the theoretical predictions.

Terje Ambjørnsen is Researcher at Telenor R&D

Kjetil Andersson is Researcher at Telenor R&D

Bjørn Hansen is Researcher at Telenor R&D

1 Introduction

Firms typically offer several varieties of a product, in the economics literature often called versioning.[1] A broadband offering from a network access provider for instance may consist of a number of download access speeds such as 704 kbit/s, 1024 kbit/s and 2048 kbit/s. The firm's rationale for versioning is to increase profits. A requirement for versioning to be profitable is that the consumers are heterogeneous, i.e. that consumers differ with respect to their preferences and thereby their willingness to pay for the different varieties. If consumers are identical there will exist a single variety that is optimal for all customers, and all will have the same willingness to pay for this variety.

Versioning is complex. The provider must conjecture the marginal cost of different varieties and then choose the optimal number, qualities and prices of the varieties in a setting where demand is highly interrelated: The consumer will compare the price and performance before choosing one variety before the other, and if she changes her mind with respect to the most preferred variety she will unsubscribe from the existing service and subscribe to a new. Thus, when changing the price or quality of one variety, demand for one or more of the other varieties will also typically change.

In this paper we will provide an overview of some results from both the theoretical and empirical literature that can give guidance with respect to pricing and forecasting of the demand for a product portfolio consisting of close substitutes. We will focus on broadband services, but the results will also have relevance for other services from the telecommunication industry like portfolios of mobile subscription plans and content packages.

The paper is organised as follows: In the next section we give a brief overview of horizontal and vertical differentiation before we, in section 3, present a simple analytical model of the demand structure for a portfolio of vertically differentiated varieties. In section 4 we discuss some theoretical and experimental results on the optimal number and quality of varieties. In section 5 we review the empirical literature on the demand for broadband with a particular emphasis on price effects and cross-price effects between versions. In section 6 we offer some concluding remarks.

2 Product and price differentiation

The literature distinguishes between horizontal and vertical differentiation. A set of vertically differentiated goods is defined as goods being differentiated with respect to one quality parameter and where all consumers agree that more is better with respect to this quality parameter.[2] This is opposed to horizontally differentiated goods where consumers disagree with respect to the most preferred variety or product design. That is, if a set of purely horizontally differentiated goods have identical price, then all varieties will be sold in positive quantities.

Horizontal differentiation is present when consumers differ in preferences with respect to product attributes. These attributes can be directly related to the technical characteristics (like the mix of characteristics of a car, e.g. space in the back seat vs. space in the car boot), but they may also be related to complementary goods, i.e. one may prefer a particular brand of car if the local auto repair shop has a good reputation. Horizontal differentiation may also be linked to brand image etc.: Some prefer Mercedes, others BMWs for car varieties where price and technical characteristics are comparable.

1) *See Shapiro and Varian (1998) and Varian (2000).*

2) *See Eaton and Lipsey (1989), p. 752*

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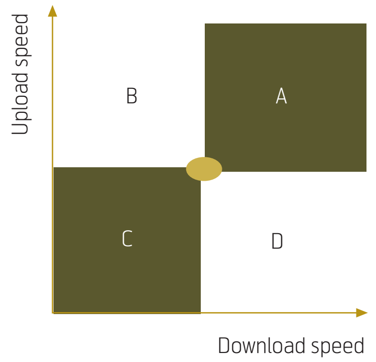

Figure 1 Horizontal and vertical differentiation

Broadband access is a candidate to be characterised as a vertically differentiated good. It is reasonable to expect all consumers to prefer more bandwidth to less. It is however a complicating factor that suppliers offer download and upload speed in different proportions. This introduces an element of horizontal differentiation that is illustrated in Figure 1.

In the illustration we have indicated a broadband offering with a particular up-load and download speed by the solid dot. Compared to this service, any service belonging to region A and C are vertically differentiated products, whereas services belonging to region B and D may be horizontally differentiated if the customers disagree with respect to the value of upload speed and download speed. If we look at product characteristics of asymmetric broadband offerings in the Norwegian market we find the distribution as shown in Figure 2 (source: www.telepriser.no 15.09.2004).

As we can see there is a strong, but not perfect correlation between download and upload speed. The correlation coefficient is 0.73. In the following we focus on the vertical differences between broadband offerings.

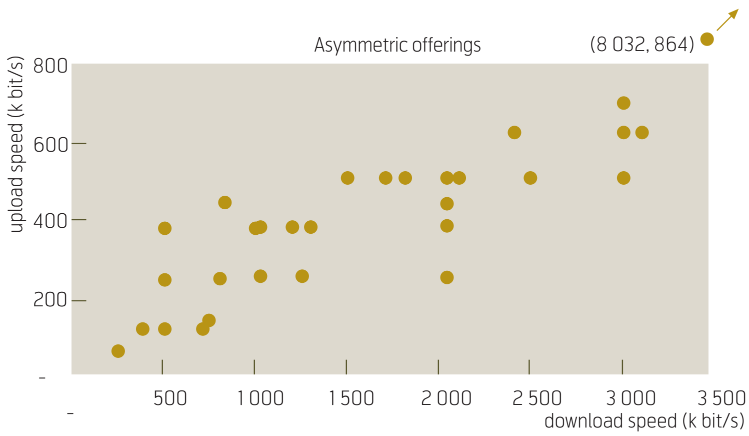

Figure 2 Broadband offerings in the Norwegian market

As pointed out in the introduction, the rationale for introducing product differentiation is to increase profits by providing different product varieties for different consumer segments. The provider seeks to take advantage of differences in willingness to pay such that the high-willingness-to-pay segment pays much and the low-willingness-to-pay segment pays what they can afford. In order to do so the provider needs a mechanism to implement price discrimination to assure that the high-willingness-to-pay segment indeed buys the relatively high priced variety.

The tradition is to distinguish between three forms of price discrimination. This classification is due to Pigou (1920) and is described in for example Varian (1989) and Tirole (1988):

First-degree price discrimination, or perfect price discrimination is present if the provider is able to have one price for each consumer type and price such that the entire willingness to pay is extracted from all types. This type of discrimination is rarely observed, firstly since it is hard to reveal the true willingness to pay for each potential customer, and secondly because the provider must be able to prevent resale.

Second-degree price discrimination, or discrimination by self-selection, is present if the provider offers a menu of price differentiated product varieties and lets consumers select their most preferred variety. The two most frequently observed ways of implementing such price discrimination is price-quantity discrimination and price-quality discrimination (versioning). Under price-quantity discrimination consumers are typically offered a menu of two-part tariffs. This is well known for instance in mobile telecommunications where subscribers choose from a menu of price plans (subscription fees and minute price combinations). Consumers themselves select the price plan giving them the highest utility. Price-quality discrimination is present when a product is offered in more than one variety and where the differentiation in price is greater than the underlying differences in production costs.[3)] This type of discrimination is the primary focus of the present article.

Third-degree price discrimination is present when the provider can observe a signal correlated with consumers' willingness to pay and price discriminate based on this signal. A typical example is student discounts. In order to implement such discrimination the provider has to prevent resale (arbitrage). For some goods it is straightforward to prevent resale, one example is travels where student IDs can be checked before letting people with discounted tickets inside the train. Broadband access is a candidate for such discrimination. Since it is a subscription, one can

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make the renewal of the subscription contingent upon e.g. student status. A broadband connection is however typically shared among the residents in a household, and then we may get a kind of resale where the student is the one officially having a subscription but where other residents in the house pay the bill.[4)]

It follows from the discussion of the various types of discrimination that the possibilities for resale is crucial with respect to differentiation possibilities. Broadband access is typically, but not always flat rate priced, i.e. there is a fixed monthly subscription fee and no variable element in the pricing. Under this pricing regime customers may have strong incentives to share broadband access. There are two gains from such access sharing. Firstly, the pricing of broadband is typically less than proportional to bit access speed, i.e. one 1 Mbit/s link is cheaper than two 500 kbit/s links. Secondly, households sharing the same broadband access will experience an "aggregation" gain. They will rarely make use of the access line at exactly the same time, thus they will on average experience an access speed exceeding half the (shared) access capacity. Experience so far indicates that customers rarely engage in such access sharing. This may be due to coordination costs or contractual factors.[5)] Technical change may change this with the introduction of cheap off-the-shelf WLAN equipment. If it turns out that access sharing becomes widespread it will restrict the possibilities for price discrimination and the operators will have to rethink their pricing regimes.

The focus in the current paper is on second-degree price discrimination. There is a brilliant quotation from the French economist Jules Dupuit (1849) highlighting important aspects of such practices:[6)]

> *"[I]t is not because of the few thousand francs which would have to be spent to put a roof over the third-class carriage or to upholster the third-class seats that some company or other has open carriages with wooden benches ... What the company is trying to do is prevent the passengers who can pay the second-class fare from travelling third class; it hits the poor, not because it wants to hurt them, but to frighten the rich ... And it is again for the same reason that the companies, having proved almost cruel to the third-class passengers and mean to the second-class ones, become lavish in dealing with first-class customers. Having refused the poor what is necessary, they give the rich what is superfluous."*

This example indicates how product quality can be used as a tool for sorting customers into segments and then charging differentiated prices – second-degree price discrimination. A provider of broadband access will seek to employ similar pricing tactics.

3 A simple demand model of vertical differentiation

Assume there is a total of J different varieties of a product offered in the market – say the total number of different ADSL download speeds in the market place.[7)] Let these varieties be ordered after increasing quality such that the variety with the lowest quality is number 1, the variety with the second lowest quality is number 2 and the highest quality variety is J. Let the quality of variety number j be s_j, such that $s_1 \leq s_2 \leq s_2 \ldots \leq s_J$.

Consider a consumer of type θ buying one unit of quality s_j at price p_j. Her utility is:

$$U = \theta s_j - p_j \qquad (1)$$

The type parameter θ is drawn from some distribution and measures the willingness to pay for quality. The distribution can be described by a density function defined over an interval $[\underline{\theta}, \bar{\theta}]$ depicting the fraction of all consumers with a taste parameter within a given interval as illustrated in Figure 3.

The area under the entire density function equals one, (i.e. all consumers) and the shaded area illustrates the fraction of consumers with a taste parameter in the interval θ_1, θ_2. We will in the following normalise the total number of consumers in the market to unity. Thus the area under the density function equals the number of consumers. Define the cumulative density function:

$$F(\theta) = \int_{\underline{\theta}}^{\theta} f(x)dx \qquad (2)$$

3) *A definition due to G. Stigler is referred by Varian (1989)* "price discrimination is present when goods are sold at prices that are in different ratios to marginal cost". *See Clerides (2003) for a discussion on the definition of price discrimination.*

4) *In Norway NextGenTel offer student discounted broadband access whereas Telenor does not.*

5) *The standard subscriber contract is typically restricting customers from resale. It is harder to prevent the sharing of an access, e.g. by a group of households in an apartment building.*

6) *The quotation of Dupuits is given in Varian (1989).*

7) *The modelling in this section is inspired by Mussa Rosen (1978) and Tirole (1988).*

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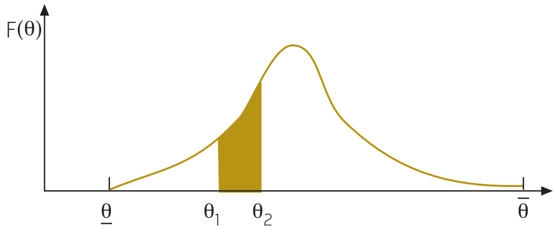

Figure 3 The distribution of consumers

Thus $F(\theta_2) - F(\theta_1)$ equals the number of consumers in the shaded area in Figure 3.

For the analysis in this section of the paper we will not have to place restrictive conditions on the shape of the density function, it is however not uncommon, in order to simplify, to assume a uniform distribution.

Consider demand for variety J with quality s_J. The consumers, if any, buying this product will be the consumers with the highest willingness to pay since this is the product of the highest quality.[8)] Then there exists a consumer being indifferent as to buying the variety of the highest quality or the variety of the second highest quality. Let θ_{J-1} denote the taste parameter of the consumer being indifferent to these two varieties. It is defined by:

$$\theta_{J-1}s_J - p_J =$$
$$\theta_{J-1}s_{J-1} - p_{j-1} \Leftrightarrow \theta_{J-1} = \frac{p_J - p_{J-1}}{s_J - s_{J-1}} \quad (3)$$

All consumers with taste parameter exceeding θ_{J-1} will strictly prefer variety J. The number of consumers in this category is illustrated in Figure 4.

The number of consumers buying variety J is accordingly:

$$y_J = \int_{\theta_{J-1}}^{\bar{\theta}} f(x)dx = 1 - F(\theta_{J-1})$$
$$y_J = 1 - F\left(\frac{p_J - p_{J-1}}{s_J - s_{J-1}}\right) \quad (4)$$

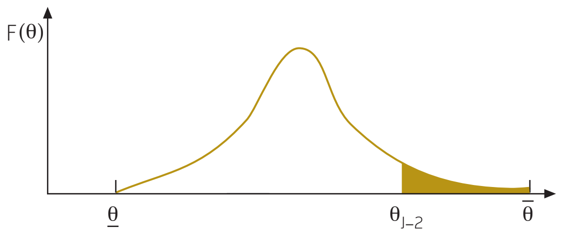

Figure 4 Consumers preferring variety J

Consider now demand for the second highest quality s_{J-1}. Consumers with the highest taste parameters are already allocated to s_J and we have readily calculated the taste parameter of the consumer being indifferent to s_J or s_{J-1}. By calculating the taste parameter of the consumer being indifferent to the second and third highest taste parameter, θ_{J-2} ,we can infer the number of consumers buying s_{J-1}. The taste parameter of the indifferent consumer is given by:

$$\theta_{J-2}s_{J-1} - p_{J-1} =$$
$$\theta_{J-2}s_{J-2} - p_{J-2} \Leftrightarrow \theta_{J-2} = \frac{p_{J-1} - p_{J-2}}{s_{J-1} - s_{J-2}}$$

The number of consumers buying variety $J - 1$ is accordingly:

$$y_{J-1} = F\left(\frac{p_J - p_{J-1}}{s_J - s_{J-1}}\right) - F\left(\frac{p_{J-1} - p_{J-2}}{s_{J-1} - s_{J-2}}\right)$$

By following this procedure we can calculate demand for any variety:

$$y_j = F\left(\frac{p_{j+1} - p_j}{s_{j+1} - s_j}\right) - F\left(\frac{p_j - p_{j-1}}{s_j - s_{j-1}}\right) \quad (5)$$

Consider finally demand for the variety of the lowest quality. The consumer, if any, being indifferent as to buying a product of quality s_1 or not buying at all, is given by:

$$\theta_0 s_1 - p_1 = 0 \Leftrightarrow \theta_0 = \frac{p_1}{s_1}$$

Demand for the product of quality s_1 is accordingly:

$$y_1 = F\left(\frac{p_2 - p_1}{s_2 - s_1}\right) - F\left(\frac{p_1}{s_1}\right)$$

Based on the assumed utility function we have derived the following demand system for variety 1, 2, … J:

$$y_1 = F\left(\frac{p_2 - p_1}{s_2 - s_1}\right) - F\left(\frac{p_1}{s_1}\right)$$
$$y_j = F\left(\frac{p_{j+1} - p_j}{s_{j+1} - s_j}\right) - F\left(\frac{p_j - p_{j-1}}{s_j - s_{j-1}}\right) \quad (6)$$
$$y_J = 1 - F\left(\frac{p_J - p_{J-1}}{s_J - s_{J-1}}\right)$$

Two results follow directly from this demand system:

1 Demand for a given variety is only affected by
  - Its own price and quality
  - The price and quality of the two neighbouring varieties

2 Total penetration rate, $Y = \Sigma y_i$, is only affected by the price and the quality of the variety with the lowest quality.

8) *This statement is true given some restrictions on the price structure. These restrictions will always be fulfilled under monopoly and they will also typically be fulfilled in a (imperfectly) competitive equilibrium.*

Thus by doing this exercise we have managed to establish two results that provide some guidance to the task of pricing a portfolio of services.

From result 1 we have that if one price is changed, it will affect demand for the variety itself and the two closest substitutes. Thus if an ADSL provider that is offering the varieties 512 kbit/s, 704 kbit/s, 1024 kbit/s and 2048 kbit/s changes the price of 704 kbit/s it will not lead to increased penetration, it will however increase demand for 704 and reduce demand for 512 and 1024. Demand for 2048 is unaffected. From result 2 we see that if one wants to increase penetration one has to focus on the low quality end of the market.

4 On the optimal quality and number of varieties

Price-quality discrimination, or versioning is a widely used pricing tactic.[9)] Although a firm may select from a number of varieties, it typically does not maximize the number of versions. There are a number of reasons why a firm should not offer too many versions of a product.

Firstly, it is costly. For example, when offering one additional version of a product, fixed costs, such as monitoring, developing, marketing and administration costs may accrue. Secondly, too many varieties may confuse consumers and decrease their willingness to pay. These two factors, in combination with the fact that the positive contribution to variable profit from adding one additional variety to the product line decreases with the number of varieties, implies that it is not optimal to maximize the size of the product line.

In addition, a firm is typically able to manipulate the quality of these varieties. For example, a car producer does not only decide on the number of car models, but also the quality level of each model. The quality of each model depends on factors such as the quality of the material used, the amount of horsepower, whether the car has a CD-player, and so on.[10)] A broadband provider can vary the access speeds and bundle different complementary services to the subscription.

To illustrate our points above, consider a profit maximizing broadband monopolist. As a simplification, suppose there are only two types of consumers, *H*(igh) and *L*(ow). As before, the utility of type *H* and *L*, when consuming a good of quality s, is $\theta_H s$ and $\theta_L s$, respectively. High-type consumers care a lot about quality, while low-type consumers are less sensitive to quality. That is, $0 < \theta_L < \theta_H$. The total number of consumers is normalized to 1. The fraction of type *L* is $n \in (0,1)$, and the fraction of type *H* is $1 - n$. Each consumer has either zero or unit demand for the product.

There exists a continuum of qualities that may be produced. Unit production costs are increasing and convex in quality. A unit production cost function satisfying these assumptions is $c(s) = 0.5\ s^2$. Furthermore, for each additional variety that is added to the product line, *K* dollars in fixed costs accrue.

Let (p_H, s_H) and (p_L, s_L) be a menu of contracts, where p_H, s_H, p_L and s_L is the price and quality designed for type *H* and *L*, respectively. The firm is free to set price and quality, but there are two types of constraints that reduce the firm's freedom of action. Firstly, it must be individually rational for the two types to participate. There are therefore two participation constraints:

$\theta_H s_H \geq p_H$ (participation constraint type *H*);
$\theta_L s_L \geq p_L$ (participation constraint type *L*).

Secondly, in order to make type *H* consumers prefer the type-*H* contract and type-*L* consumers the type-*L* contract (self-selection), the contracts must be incentive compatible. There are therefore two incentive-compatibility constraints:

$\theta_H s_H - p_H \geq \theta_H s_L - p_L$
(incentive compatibility type *H*);
$\theta_L s_L - p_L \geq \theta_L s_H - p_H$
(incentive compatibility type *L*).

Welfare

Before we analyze the monopolist's maximization problem, it is interesting to start with the welfare optimum (*W*), as a reference point. It is straightforward to show that welfare is maximized when each of the two types consume a quality where their marginal willingness to pay for quality, θ_H and θ_L, equals marginal cost of quality, $c'(s) = s$. This implies that a consumer of type *H* consumes a product of quality $s_H^W = \theta_H$, while a consumer of type *L* consumes a lower quality, $s_L^W = \theta_L$. A price schedule where type *H* and *L* are charged prices that reflect production costs, that is $p_H^W = 0.5\ \theta_H^2$ and $p_L^W = 0.5\ \theta_L^2$, respectively, induce consumers to self-select in a welfare maximizing way. Whether a welfare maximizing firm will

9) *See for example Phlips (1983), Varian (1989) and Ambjørnsen (2002a) for guides to the literature.*

10) *See Kwoka (1992) for an analysis of the automobile industry.*

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offer zero, one or two qualities depends on the level of K, fixed costs.

The monopoly case

In contrast to the objective of a welfare maximizing benevolent planner, a broadband monopolist puts only weight to its own well-being, that is profits. The monopolist can choose between three marketing strategies:

- Cut-off strategy
- Pooling strategy
- Price-quality discrimination strategy

Cut-off strategy (cut)

In this case, the monopolist offers only one quality version that is sold to type-H consumers. Their consumer surplus is extracted completely; $p_H^{cut} = \theta_H s$. Type-L consumers are not served. In this case profit is given by $\Pi^{cut} = (1 - n)(\theta_H s - 0.5s^2) - K$, where $1 - n$ reflects the fraction of type-H consumers, $\theta_H s$ the price, $0.5s^2$ unit production costs, and K fixed costs. Profit is maximized when $\partial\Pi^{cut} / \partial s = (1 - n)(\theta_H - s) = 0$, that is when $s_H^{cut} = \theta_H$. Profit in the cut-off case is then given by $\Pi^{cut} = 0.5(1 - n)\theta_H^2 - K$.

Pooling strategy (pool)

In this case, the firm offers the same quality version to both types. Profit in this case is maximized when the participation constraint of type L binds; $p^{pool} = \theta_L s$. Profit is then given by $\Pi^{pool} = (\theta_L s - 0.5s^2) - K$. Profit is maximized when $\partial\Pi^{pool} / \partial s = \theta_L - s = 0$. $s^{pool} = \theta_L$ constitutes an interior solution to the problem. The pooling case differs from the cut-off case in the sense that the price is lower but the number of consumers is higher. Note that $s^{pool} < s^{cut}$. Total profit is given by $\Pi^{pool} = 0.5\theta_L^2 - K$.

Price-quality discrimination strategy (pd)

The idea in this case is to offer two quality versions: a high-quality version to type H and a low-quality version to type L. Let $(s_H; p_H)$ be the contract designed for type H and $(s_L; p_L)$ the contract of type L. The firm maximizes profit, $\Pi^{pd} = (1 - n)[p_H - c(s_H)] + n[p_L - c(s_L)] - 2K$ but is constrained by the participation and incentive constraints of both types. Note that in this case fixed costs are equal to $2K$, reflecting that the firm offers two variants rather than one. It is straightforward to show that in equilibrium the participation constraint of type L and the incentive constraint of type H bind: $p_L^{pd} = \theta_L s_L$ and $\theta_H s_H - p_H^{pd} = \theta_H s_L - p_L^{pd}$. The profit function may now be written as $\Pi^{pd} = (1 - n)(\theta_L s_L + \theta_H(s_H - s_L) - 0.5s_H^2) + n(\theta_L s_L - 0.5s_L^2) - 2K$.

Profit is maximized when $\partial\Pi^{pd} / \partial s_H = 0$ and $\partial\Pi^{pd} / \partial s_L = 0$. $s_H^{pd} = \theta_H$ and $s_L^{pd} = (1/n)(\theta_L - (1 - n)\theta_H)$ are interior solutions to the problem. By substituting these values into the profit function, we may calculate the maximized profit.

Before we start comparing the three different strategies it may be interesting to highlight three results:

- In the *cut-off case* there is a welfare loss, since type-L consumers are left without service. Type-H consumers receive their optimal quality level.

- In the *pooling case*, there is a welfare loss since type-H consumers consume a quality that is too low. Type-L consumers are served optimally.

- There is "no distortion at the top" in the *price-quality discrimination case*, reflecting the fact that type-H consumers consume their optimal quality level. There is, however, "distortion at the bottom" since type-L consumers consume a product quality that is too low. The latter result reflects that the firm has an incentive to charge a high price from type-H consumer. To prevent high types from preferring the low-quality product, the firm makes this alternative less attractive by distorting the quality. The higher the fraction of type H consumer (the higher $1 - n$ is) and the more intensive their taste for quality is (the higher θ_H is) the more distorted the low-quality product will be.

These findings are based on an assumption that unit production costs are increasing and convex in quality. This is not always a reasonable assumption. In the software industry, for example, the best model is typically produced first. Producing an inferior unit is typically not cheaper since it is a stripped version of the top model. This type of quality manipulation is known as "damaging" or product crimping since damaging the state-of-the-art technology produces inferior variants.[11)] In this case it is more reasonable to assume that costs are independent of quality up to an upper bound. An example of damaging in the broadband access industry may be volume constraints on flat-rate offers. This requires that the marginal costs of traffic is zero, otherwise it may be an example of cost based pricing.

If unit production costs are independent of quality, and not increasing and convex in quality, it turns out that price discrimination is never a profitable strategy in our model. The reason for this is the way preferences are modelled. However, with more general utility functions price discrimination may reappear as a profitable strategy, even if costs are independent of quality.[12)] If unit production costs are independent of quality, the firm brings the state-of-the-art technology to the market in the cut-off, but also in the pooling case. The pooling case and the welfare maximum coincide, while the cut-off strategy will continue to give a welfare loss since type-L consumers are left without service. The "no distortion at the top" and "distortion at the bottom" results continue to hold, in the price-quality discrimination case.

We are now ready to compare profits in three alternatives. It is straightforward to see that the optimal strategy is dependent on the level of θ_H, θ_L, K, n. To simplify the discussion, and without too much loss of generality, let $n = 0.5$ and $\theta_L = 1$.

Price discrimination is profitable if $\max\{\Pi^{cut}, \Pi^{pool}\} < \Pi^{pd}$, that is if $\max\{0.25\theta_H, 0.5\} - K < 0.5\theta_H^2 - \theta_H + 1 - 2K$. If this inequality does not hold, offering a single variant is profitable. A single-quality strategy will typically be profitable when it is sufficiently costly to add variants to the quality-line (K is high). If the difference between type-L and type-H consumers is minor (that is, if $1 < \theta_H \leq 2$), then the firm offers a low-quality product for the mass market. If type-H consumers are sufficiently valuable to the firm (that is, if $2 < \theta_H$), then it is optimal to serve only the part of the market with a high willingness to pay.

So far we have argued that a) offering a quality line may be a profitable way to sort consumers, and b) it may not be profitable to maximize the number of varieties. How many versions a firm should bring to the market depends on a number of parameters, including the number and heterogeneity of consumer classes, and costs. However, there are some arguments based on experiments that suggest a firm should offer three rather than two varieties.

Simonson and Tversky (1992) describe an experiment in which two groups were asked to choose a microwave oven. Group 1 had the choice between Emerson and Panasonic I. In this group 43 % preferred the Panasonic I and 57 % preferred the Emerson, see Table 1.

Group 2 was offered the same microwave ovens, at the same prices as group 1, but in addition they were also offered the high-end Panasonic II. By offering the high-end Panasonic II, Panasonic increased its market share from 43 % to 73 % percent. 13 % preferred the high-end microwave oven, Panasonic II. More surprisingly, Panasonic I increased its market share from 43 % to 60 %. As noted by Nagle and Holden (1995).[13]

Microwave oven model	Choice (%) Group 1 (n = 60)	Choice (%) Group 2 (n = 60)
Panasonic II (1.1 cubic feet; regular price \$199.99; sale 10 % off	–	13
Panasonic I (0.8 cubic feet; regular price \$179.99; sale 35 % off)	43	60
Emerson (0.5 cubic feet; regular price \$109.99; sale 35 % off)	57	27

Table 1 Extremeness aversion. Source: Simonson and Tversky (1992) (reproduced in Nagle and Holden (1995))

> *"Adding a premium product to the product line may not necessarily result in overwhelming sales of the premium product itself. It does, however, enhance buyers' perceptions of lower-priced products in the product line and influence low-end buyers to trade up to higher-priced models."*

This result is also known as "aversion against extremeness". Interestingly, the finding by Simonson and Tversky contradicts our theoretical result in section 3, since the demand for the low-end product (Emerson) changed although the price and the quality of the nearest substitute, the medium quality microwave oven (Panasonic I) remained unchanged. Thus, if it is not clear how many versions a firm should offer the discovery by Simonson and Tversky suggest that three, rather than two versions should be included in the product line.

5 Empirical results

The empirical literature on broadband demand is still in its infancy and more explorative than targeted towards testing fine-grained hypothesis of demand in a setting with several vertically differentiated versions offered in the market. The reason is probably related to a scarcity of high-quality data, partly because broadband Internet access for the residential market has not been commercially available for more than a couple of years, and partly because the annual and quarterly reports of the industry players do not contain details of the number and usage pattern of subscribers on different subscription plans.

Monopoly and horizontal competition

Before we turn to results on vertical differentiation in the next subsection we briefly review some main

11) *See Deneckere and Mcafee (1996) for additional examples of damaging.*

12) *See Salant (1989) and Ambjørnsen (2002b) for discussions.*

13) *See also Shapiro and Varian (1998), and Nagle and Holden (1995) for a discussion.*

 ISSN 0085-7130

empirical results. Table 2 displays empirical estimates of the price elasticities of the demand for various kinds of Internet access in different kinds of competitive settings.

The two first lines display results for the demand for dial-up (Duffy-Deno (2001) and Rappoport, Kridel, Taylor and Alleman (2003)). The estimates of these own-price elasticities may be interpreted as some kind of market elasticity or aggregate elasticity. That is, what would be the percentage increase in the number of dial-up access demanded if the average price fell by 1%. We see that the demand for dial-up is quite inelastic.

Line 3 displays results for the demand for cable modem when a one step down substitute, dial-up is present (Kridel, Rappoport and Taylor 2002). The cross-price elasticity is small but highly significant indicating that dial-up is a substitute to cable (but see the discussion in the next section). The demand for cable modem is much more price elastic than the demand for dial-up, and the own price elasticity increases with price. As for the two previous studies, the results must be interpreted as an aggregate elasticity: Ceteris paribus, the price-elasticity for a particular brand offered in an area served by more than one provider is likely to be larger since in this case the customers churn between the providers.

The two last lines display results for a case of horizontal competition: ADSL vs cable modem. The size of the cross-price elasticities indicates, as expected, that the two products are close substitutes. The own-price elasticities are above 1 in magnitude, but still not very high. In comparison with the cable modem results we would have expected the own price elasticities to be higher in a setting with horizontal competition.

Vertically differentiated versions

Broadband vs dial-up

From the perspective of the customer, dial-up and broadband may be seen as two vertically differentiated versions of Internet access. Dial-up is the low quality version since many of the applications supported by a broadband connection are not available with a dial-up connection; important examples include video and audio programming. In addition, common applications like web surfing and email are supported at higher speed (i.e. higher quality) with a broadband connection.

A prediction from the simple theoretical model in section 3 is that such products will be substitutes. Few will question that broadband is a substitute to dial-up: If the price of broadband becomes low enough, a significant number of dial-up customers will substitute the dial-up Internet connection with a broadband connection. There is, however, some controversy as to the substitutability the other way round; that is: Will a price decrease of dial-up cause a significant amount of actual and potential broadband customer to switch to a broadband connection? As discussed in detail in Hausman, Sidak and Singer (2001b) with respect to the AT&T-MediaOne merger, the distinction is crucial when it comes to defining the relevant antitrust market: Even if broadband is a substitute to dial-up, broadband is a separate market from narrowband if dial-up is not a substitute to cable.

Year of study	Demand for	Price	Substitute	Elasticity	Cross elasticity
1998[1)]	Additional telephone line	$20.18	None	-0.59	
2000[2)]	Dial-up	$20.38	None	-0.37	
1999[3)]	Cable modem	$29.95	Dial-up ($22)	-1.08	(0.15)
		$35.95		-1.29	
		$49.95		-1.79	
2000[4)]	Cable modem	$41.80	ADSL ($43.08)	-1.18	0.42
	ADSL	$43.08	Cable ($41.80)	-1.22	0.59

Table 2 Selected price elasticities

1) *Duffy-Deno. 2001. Logit estimates.*
2) *Rappoport, Kridel, Taylor and Alleman. 2003. Logit estimates. Sample where broadband was not available.*
3) *Kridel, Rappoport and Taylor. 2002. Logit estimates. Own price elasticities calculated at three different prices. The cross-price elasticity is calculated at the mean dial-up price.*
4) *Crandall, Sidak and Singer. 2002. Nested, conditional logit estimates. Sample where cable, ADSL and dial-up were available.*

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Hausman, Sidak and Singer (2001a) set forth to test whether the price of dial-up Internet access affects the price of cable modem Internet access (broadband). If dial-up is indeed a substitute to broadband, we would expect that the pricing of cable access in one area would be constrained by the price level of dial-up access in the same area. The authors use price data from 59 cable suppliers in 41 states collected in August 1999 and run a regression of this cable price on the dial-up price in the same area. They find that the coefficient of dial-up is close to zero and never close to being significant. The result is robust to different specifications regarding amortization of installation fees and inclusion of different control variables. Accordingly they conclude that broadband is a separate relevant market from narrowband for antitrust purposes.

Interestingly, Kridel, Rappoport and Taylor (2002) utilize survey data from roughly the same period, i.e. the 4th quarter of 1999 and finds that dial-up is a substitute to cable, see Table 2. They use survey data from the Taylor-Nelson-Sofres (TNS) Telecoms ReQuest survey of households, which, among other things contains information on expenditures on access to and use of the Internet. The dependent variable is a dummy variable indicating whether the household has a cable modem or not. A standard logit model is then used to model the probability that the household possesses a cable modem as a function of cable modem price, dial-up price and a set of socio-demographic variables. The sample includes only respondents in areas where cable modems were available; hence the household faces the choice of no Internet connection, dial-up or cable modem. The study finds a negative coefficient of cable modem price (significant at the 10 % level) and a positive coefficient of dial-up price (significant at the 1 % level).

Apparently this contradicts the results of Hausman et al. However, the findings of Kridel, Rappoport and Taylor may reflect their definition of dial-up price: *"The second price variable is a price for regular dial-up Internet access, inclusion of which allows for the estimation of a substitution cross-price elasticity. This price variable was constructed in the same way as the price of cable-modem access, that is from self reported Internet expenditures."* (page 18, Kridel, Rappoport and Taylor 2002). The paper is not explicit on exactly how these expenditures are used to construct the dial-up price. However, if there is a positive correlation between expenditures and the dial-up price and there is a usage component (or perceived usage component) in this price, the substitution interpretation of the dial-up coefficient may be flawed since in this case a high dial-up "price" will reflect a heavy usage.[14] Hence the positive coefficient may simply reflect the fact that the heavy users are most eager to switch to a flat rate cable modem Internet access.

A later study by Rapport et al. (Rappoport, Kridel, Taylor and Alleman 2003) confirms the Hausman, Sidak and Singer result. They match survey data collected in the first quarter of 2000 containing information on type of Internet connection, dial-up, cable modem or ADSL with price data in the household area. They run separate regressions for different areas including areas where only dial-up and cable modem are available and only dial-up and ADSL are available. For these areas, they find that broadband (cable or ADSL), as expected, is a significant substitute to dial-up. The effect of dial-up price on broadband demand is however insignificant and small (the cross-price elasticity is calculated to 0.001 for cable and 0.04 for ADSL). All in all, our reading of the literature on the market boundaries between broadband and dial-up, makes us conclude that dial-up is hardly a substitute to broadband.

Broadband vs broadcast

The majority of broadband offerings in the Norwegian market have down-link bandwidth from about 250 kb/s to slightly above 3 Mb/s, see the overview presented in section 2. The next generation of digital subscriber lines[15] and fibre connections will offer bandwidth in excess of 10 Mb/s. This increase in bandwidth will facilitate a new set of applications including traditional broadcasting and various interactive TV-services. Similar to the dial-up/broadband controversy discussed above this development will raise the question as to the market boundaries between today's broadband offerings and a vertically superior "very high speed broadband offering" facilitating a new set of services.

Andersson, Fjell og Foros (2004) utilize survey data from Norway collected in 2001 to investigate the potential demand for two different versions of broadband access: "Basic broadband" and "Premium broadband". Basic broadband comprises today's high speed Internet connections, while Premium broadband comprises a future product including high-speed Internet access, traditional broadcasting and a set of

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[14] *The authors are aware of a potential problem with the prices. In the conclusion they warn that the results "must be viewed as highly provisional and preliminary" and call for better price data in future research.*

[15] *ADSL2+ and VDSL.*

iTV services, like choice of camera angle when watching a sports event and so on. In the study, the product characteristics of basic broadband and premium broadband were presented to the respondents. They were then asked to state their purchase intentions at various price combinations of the two broadband versions. The authors found that demand for basic broadband was highly dependent on the price of premium broadband confirming that premium broadband is a substitute to basic broadband (cross-price elasticity of 1.13). The price of basic broadband did not however affect the demand for premium broadband suggesting that a possible "broadcast oriented" broadband offering is a separate market from today's broadband Internet offerings.

Versioning experiments

The sections above surveyed the literature on the market boundaries between i) dial-up, ii) basic broadband, and iii) broadcast-oriented premium broadband. These offerings may be seen as three vertically differentiated access versions. Contrary to the predictions from the theoretical model presented in section 3, the substitutability seems to be asymmetric: In a pairwise comparison the upper version is a substitute to the lower version, but the lower version is not a substitute to the upper version. There are several possible explanations to this, see e.g. Blattberg (1995). One is that the preferences change once the customer has tried the high-end version. Few change from Mercedes to Lada if the price of the latter falls.

Bandwidth	p128	p96	p64	p32	p16
128	-2.00				
96	1.70	-3.10	0.43		
64		1.80	-2.90		
32			1.00	-1.40	
16				1.20	-1.30

Table 3 Price elasticities from the Index experiment

Source: Varian 2002. Only significant cross-price elasticities are displayed

Bandwidth	p2048	p1024	p704	p384
2048	-9.97	1.54		
1024	1.06	-3.72	1.45	
704			-1.58	
384				-0.26

Table 4 Price elasticities from the Hb@ experiment

Source: Andersson and Myrvold 2002. Only significant cross-price elasticities are displayed

The above comparisons are pair-wise between quite different versions – the upper version facilitates a whole set of new applications. To our knowledge there are no public studies that estimate broadband demand functions on real industry data in a setting where more than two versions exist although this seems to be the common situation in the markets.

There are two experimental studies, however: Varian (2002), and Andersson and Myrvold (2002). Varian analyses data obtained from one of the INDEX experiments conducted at Berkley in 1998–1999. About 70 individuals were given the opportunity to choose between five narrowband connections: 16, 32, 64, 96 and 128 kb/s. 8 kb/s was always offered for free. Bandwidth could be changed at all times. Each week the (minute) price was changed and the number of minutes used was measured. Table 3 presents the results, i.e. the price elasticities from a simple log-log regression of minute use on prices. Andersson and Myrvold analyse data obtained from a Norwegian experiment, the HB@ experiment conducted in Stavanger, Norway in the last quarter of 2001. 680 households were given the opportunity to choose between four broadband Internet access connections: 384, 704, 1024 and 2048 kb/s. Every two weeks the (flat race) price changed and the household were allowed to change bandwidth. The price elasticities calculated from separate logit regressions are displayed in Table 4.

We see that both experiments display positive cross-price elasticities from some one-step up and some one-step down alternatives. Hence, these results confirm the predictions from the theoretical model given in section 3: Only the closest substitute matters. It may also be noted that the own price elasticities from some of the middle alternatives are quite large. This is probably due to the existence of very close substitutes in the above experiments.

6 Conclusions

In this paper we have provided an overview of some results from both the theoretical and empirical literature that can give guidance with respect to pricing and forecasting of the demand for a product portfolio consisting of close substitutes. The focus has been on broadband services, but the results are also of relevance for other services from the telecommunication industry like portfolios of mobile subscription plans and content packages.

ISSN 0085-7130

We have demonstrated that theory provides some structure to the problem of pricing of broadband portfolios. In particular we have shown that in a setting of pure vertical differentiation, the only cross-price effects one needs take into consideration is towards the two neighbouring qualities. Reviewed empirical results lend support from this result (an exception is the extremeness aversion result reviewed in section 4). Furthermore we have demonstrated that the market penetration rate is determined by the price and quality of the variety of lowest quality.

There is no clear-cut answer to the question of optimal number of varieties. Several factors affect the result, in particular the cost of providing different varieties, the distribution of consumer willingness-to-pay and the degree of consumer heterogeneity. In cases where consumers have extremeness aversion experimental evidence does indicate that three may be better than two.

We have reviewed a number of empirical studies of broadband demand. Recent studies indicate that the market elasticity is in the range –1.1 to –1.8. Thus one can expect penetration to increase by 1.1 % to 1.8 % when the overall price level falls by one percent. Furthermore, if we group Internet access into three broad categories, low quality medium quality and very high quality (e.g. dial-up, ADSL and VDSL respectively) empirical results indicate that higher qualities is a substitute for lower qualities, but not vice versa. Thus, if the price of low quality (dial-up) decreases, no (or very few) consumers will switch from medium to low quality. Similar results are obtained for very high quality compared to medium quality. So in a similar way as above, reducing the price of medium quality will not result in consumers switching from very high to medium quality.

Finally it can be worth noting that the theoretical understanding of how markets evolve under (imperfect) competition when firms engage in price-quantity discrimination is limited. Choices with respect to the number and characteristics of varieties are evidently affected by the strategy chosen by competitors. There are few robust results characterising equilibria under such circumstances. The results will typically depend upon the types of competitive advantages (“home territory”, cost advantage, better design etc.) of the firms involved and thus the form of market power the involved players possess. Thus, one will have to study characteristics of the market under consideration carefully before making recommendations with respect to pricing and segmentation strategy. Under such circumstances market players may even have to rely on a trial and error approach. Nevertheless, the empirical results obtained in competitive markets reviewed above indicate that our theoretical results predict reasonably well both substitutability and the structure with respect to both pricing and the degree of quality discrimination in the market place.

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Terje Ambjørnsen is a researcher at Telenor R&D. He graduated from the University of Oslo as CandOecon in 1996 and DrPolit (PhD) in 2002. In his PhD thesis he focused on the economics of price-quality discrimination. Before joining Telenor R&D in 2004, he held a position as senior advisor in the Competition Department in the Ministry of Labour and Government Administration. Ambjørnsen has also working experience from the National Competition Authority and the Ministry of Finance.

email: terje.ambjornsen@telenor.com

Kjetil Andersson is Research Scientist at Telenor R&D. He holds a Bachelor of Commerce (1990) from the Norwegian School of Economics and Business Administration (NHH), and a Master Degree in Economics from the University of Oslo (1992). Before joining Telenor R&D he was Research Associate at the Department of Economics, the Norwegian University of Science and Technology (NTNU). His main current research interests are business strategy, applied econometrics and telecommunication market analysis.

email: kjetil.andersson@telenor.com

Bjørn Hansen is Research Manager, Business Models and Strategy at Telenor R&D. He is Cand.Oecon. from the University of Oslo (1992). Before joining Telenor he was Research Associate at the Foundation for Research in Economics and Business Administration at the University of Oslo. Current research interests are regulatory issues and business strategy in the ICT sector.

email: bjorn.hansen@telenor.com

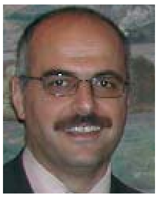
Towards the next generation broadband network platform

LEIF AARTHUN IMS, ANJALI BHATNAGAR, ERIK ØSTLYNGEN, KUROSH BOZORGEBRAHIMI AND ANDRÉ BERSVENDSEN

Leif Aarthun Ims is Director of Network Strategy in Telenor Nordic Fixed

Anjali Bhatnagar is Senior Strategic Advisor in Network Strategy in Telenor Nordic Fixed

Erik Østlyngen is Senior Strategy Advisor in Network Strategy in Telenor Nordic Fixed



Kurosh Bozorge-brahimi is Senior Strategic Advisor in Telenor Nordic Fixed

André Bersvendsen is Senior Strategic Advisor in Telenor Nordic Fixed

The article addresses an incumbent network service provider's view on major trends and development in networking technology observed within the telecommunications industry. This significant change and development in networking technologies is expected to impact telecommunications forecasting through enabling of a range of new market opportunities on new technology platforms. The key technology areas addressed include core- and distribution technologies such as IP/MPLS, and access technologies such as DSL, fibre and wireless (WiFi and WiMAX). The necessary network requirements are identified, and in view of these requirements the future direction for the development of Telenor's fixed broadband network will be outlined.

1 Introduction

The telecommunications industry has been going through significant changes over the past ten years, mainly due to the introduction of the Internet and the mobile networks in the last half of the nineties. The number of broadband accesses grew by over 80 % world-wide last year, bringing the total up to 125 million broadband lines by mid-2004. Broadband access via DSL on telephony lines and cable modems in cable-TV-networks dominates. Currently the increasingly large volume of broadband connections worldwide combined with IP technology is enabling further development and changes in the industry.

Over the next ten years the telecommunications infrastructure is likely to change from being a telephony-based infrastructure to becoming a pure broadband network infrastructure. This significant change and development in networking technologies is expected to impact telecommunications forecasting – the topic of this issue of *Telektronikk* – in several ways. This is mainly due to the fact that the new technology platforms will enable a range of new market opportunities, such as:

- Network delivery of services previously delivered by other, conventional means;
- Delivery of completely new services;
- Further development of existing telecommunications services;
- New cost structures, pricing and business models;
- New usage patterns.

Incumbent operators like Telenor typically have old, complex and legacy infrastructure including support systems, which are more suited for traditional telecom services than new data services. Currently this directly impacts the incumbent's market abilities as they face challenges related to:

1 *The highly competitive broadband market*, experiencing competition both on low, fixed price and higher and more symmetrical access rates. In Norway more than 100 broadband competitors are established – often representing a new trend in the competition by operating from higher levels in the value chains. The power utility companies are building alternative infrastructure in many municipalities. Some of the competitors are bundling their services and products and reselling the concept to others.

2 *The voice market experiencing substitution from new products*. The revenue generating telephony traffic has decreased because of Internet traffic migrating to broadband, migration to telephony competitors, mobile and VoIP traffic.

3 *The leased lines market* where there is a leakage of leased lines revenues to the packet-based communication channels.

In developing their infrastructure to meet these challenges, the telecommunications operators are seeking benefits from the new network such as:

- Potential for future revenues, including a better and simpler production platform for new products and services;
- Potential for investment avoidance and cost savings through simplification of network infrastructure;
- Scalability and flexibility of network in order to handle the expected growth in the data traffic and also provide basis for new revenue generating services;

 ISSN 0085-7130

- Potential for simplification of operation and maintenance, rollout and delivery processes including IT-systems.

In this article we will address an incumbent network service provider's view on major trends and technology development in key networking technology areas observed within the telecommunications industry. In view of these drivers, the future direction for the development of Telenor's fixed broadband network will be outlined.

2 Basic definitions and reference model

The network layer is defined as the highest common protocol entity in the communication between the end systems, transparent to the underlying transmission technologies in access, distribution and core. Networks (and network protocols) are means of transportation for service layer, where IP represents the network even if ATM, SDH or other technologies are used to realize the infrastructure segments.

Services are usage value consumed by the end-user while *Platforms* (network- or service-) are infrastructure put in place to create a set of products (or solutions).

This article refers to a hierarchic model with three levels which are used to divide the network into core, aggregation/distribution and access; seen from top to bottom in Figure 1.

Globally it has been observed that several operators and vendors have chosen to deploy a hierarchic network model with three levels, taking into account geographical aspects and not necessarily functionality and capacity only. In general a core network has a limited geographic spreading in addition to high capacity being available in this part of the network. The access network is much more spread geographically and covers larger areas. The available capacity on access lines is modest with respect to availability in aggregation/distribution and core parts of the network. The distribution network secures the seamless connection of the access and core. This is effectively done by the use of high bandwidth. The geographical spread for distribution part is larger than for core and it is usually desired to make use of the cheaper technological solutions in this part of the network.

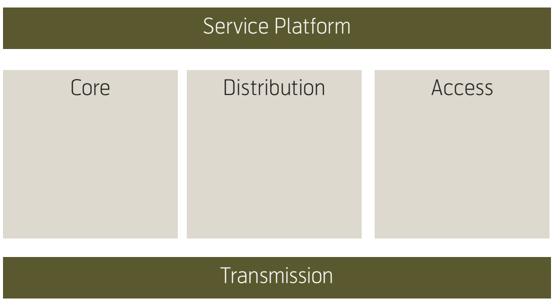


Figure 1 A network model

There is a differentiation of functionality available in different parts of the network. It is quite possible to deploy hierarchic principles for design within each of the three groups to consider one or more of the following features: capacity, functionality and geographic spread. In the core and aggregation an underlying infrastructure is needed which optimizes the use of fibre and takes care of the transmission on long distances. This infrastructure is based on WDM and also includes the legacy SDH technologies. It should be kept in mind however that transmission layer only treats pure bit transmission and there are no advanced functionalities or intelligence available in this layer. This means that a link between two network components in core and distribution is not necessarily dark fibre and can be realized with the help of CWDM/DWDM and SDH equipment. The WDM and SDH infrastructure takes care of the transmission between network components within the core and distribution networks. The infrastructure for transmission can also consist of hierarchic structure; with national, regional and local network.

3 Drivers, long term trends and corresponding network requirements

Here the objective is to establish a target network vision and describe drivers and long term direction of evolution of networking. Each major trend is described in the following nine sub-chapters.

3.1 Towards the next generation global IP network

The development towards an all-IP environment where most applications use IP for connectivity is the observed self-amplifying trend. Cost efficiency will be gained through common standards for protocols and interfaces.

New applications and services demand more capabilities from networks and will force the development towards the next generation of the global Internet. This development will first become visible within the operator's networks (autonomous system, AS) where multimedia services are introduced locally in addition to the traditional Internet connectivity. The next step is when these operators interconnect with interacting control plane for network and services across auton-

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Figure 2 The interacting development of consumer electronics, broadband and wireless technologies

omous systems, and thereby open for secure and guaranteed service provisioning across the global Internet built up by several interconnected operators.

3.2 Integration of real-time communication

Enhanced user experience is the most important driver for service integration. Convergence and standardization on one network for all communication will implicate sufficient support for real-time communication like voice and video. IP, Ethernet, MPLS, multicast and Quality of Service are representing some of the elements used to support these services. Functionality needs to be implemented across autonomous systems and peering partners to gain the possibility to separate the service layer and network layer and thereby extend the service coverage via third party networks.

Voice service will be developed towards application based IP services transported by any IP capable network and regardless of access technology as long as the capabilities support the service demands. There will no longer be dedicated fixed and mobile telephony networks. Television broadcast will develop towards high definition On-Demand and real-time TV services aimed at large flat-panels and home-cinema projectors and surround sound environment.

The interacting development within the consumer electronics industry, broadband and wireless technologies is likely to result in changes in the way the broadband communications infrastructure is used. A selection of products available in the stores in 2004 is shown in Figure 2.

3.3 Security, identity and address space

Terminal identity, user and host identities, and network addresses will be separate entities. Confidentiality and integrity will be initiated from the application layer for each end user separately and established end-to-end. Public/private key technology is the main building block for confidentiality and integrity. The identity management will be related to terminal login and support Single-Sign-On (SSO) for all or groups of services. The need for MPLS based VPNs where private IP addresses are used will in the long term be eliminated by the larger address space provided by IPv6. IPv6 will be used for host, terminal and network address space. Migration to IPv6 will eliminate the need for Network address translation (NAT) from the networks. DHCP and IPv6 auto-configuration will be used for local address provisioning to hosts and terminals. IPv6 transition will be implemented flexible when and where needed.

3.4 Willingness to pay is derived from services

In a developed broadband market end-users will have several services available, and the residential (private end-user related) traffic will be dominating. End-

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users are willing to pay for these new services if the services satisfy their demands, and at the same time reduce the willingness to pay for access and transport. In fact this development is not a threat. It can actually bring higher ARPU and revenues for both service and network operator in a model where the network operator charges service providers for transport of services, and differentiate price based on volume, session type, used network features, etc. This stimulates the network operator to increase coverage to establish a larger marketplace for service provider's business and gain higher revenues for both parties.

3.5 Wireless access to movable objects

User mobility drives wireless accesses to movable objects. Fixed wireless accesses will most places continue to deliver less performance than existing copper for equal investments. Fixed and wireless networks will complement each other and use common core and distribution networks. Wireless accesses will, even for voice purposes, develop towards generic IP accesses. Different wireless technologies (like GSM, GPRS, Edge, UMTS, WiFi, WiMAX) will complement each other and exist in parallel for a substantial time. Local short reach wireless accesses will be implemented at the edge of the fixed network to substitute fixed wiring. Mobile IP or further similar development in session mobility technologies will be implemented to support application continuity and handover between different wireless accesses and networks. User and terminal mobility will be supported.

3.6 IP in access domain

The need for Quality of Service, multicast and other functionality will induce development of network components like wireless base stations, DSLAMs and fibre nodes to contain advanced IP router functionality. Time-multiplexed bit stream traffic will be replaced by statistical-multiplexed packet based traffic in IP/MPLS network and attached access networks. Infrastructures for terrestrial, cable and satellite TV and radio will exist as separate, alternate low cost access for a substantial time. Transition from ATM switch based DSLAMs towards IP-capable router-based DSLAMs will occur after a period of Ethernet swith based DSLAMs.

3.7 Transport simplification

Standardizing on IP/MPLS removes the need for fail over mechanisms in transmission infrastructure and therefore do not depend on SDH infrastructure. Rerouting will be managed from the IP/MPLS-layer. Intermediate independent optical solutions will in the long term be integrated with the IP network in the GMPLS/ASON model. The target network will simplify protocol hierarchy and network management. Capacity products will be packet based. Dedicated capacity to support other network operators will in addition be delivered through optical channels and SDH for some time before the SDH infrastructure is terminated.

3.8 Threats in an open network

The need for connectivity and communication will be large enough to justify the cost associated with handling threats that hosts and systems are exposed to on an open network such as the Internet. Interconnection with an open network requires robust client and network components. Network design and security cannot rely solely on firewalls. Business critical applications that are acting in an open environment between partners and towards customers need adequate mechanisms in network, operating system and application against several forms of attacks and threats against integrity and availability to authorize users.

3.9 The terminal domain

Terminals will be the user interface for a wide selection of services and service providers, manifest the services and perform as the interface for payment of services. The stationary Personal Computer has been the flexible workstation for software, but will be supplemented and after a while superceded by specialized devices in a converged network like TV, radio, telephones, HiFi systems, cameras, portable computers, tablet PCs, PDAs and set-top boxes. A similar development may be foreseen in the personal network area with terminals like mobile phones, personal storage, mp3-players and digital still and video cameras. To maximize the usage value in such a convergent environment there will be imlemented interaction points between terminal and network functionality. Reliability and simple user interface will be prime demands. Wireless networked home equipment will be standardized equipment offered at a low price.

3.10 An open service platform

An open service platform is required to support rapid service creation, operational efficiency, automatic service provisioning and enhanced end-user experience. Simplified user application interfaces and self-service will be required. Enhanced end-user experience is created from IS-generated functionality in the service area. More intelligent systems will be developed to realize cost effective and complex network operation. The information in technical and administrative IS systems will be accessible from user systems. Services will be built on top of the network layer with open interfaces to standard network mechanisms like class of service and multicast. IS technology in the service platform will become a dominating part of the value-creating system.

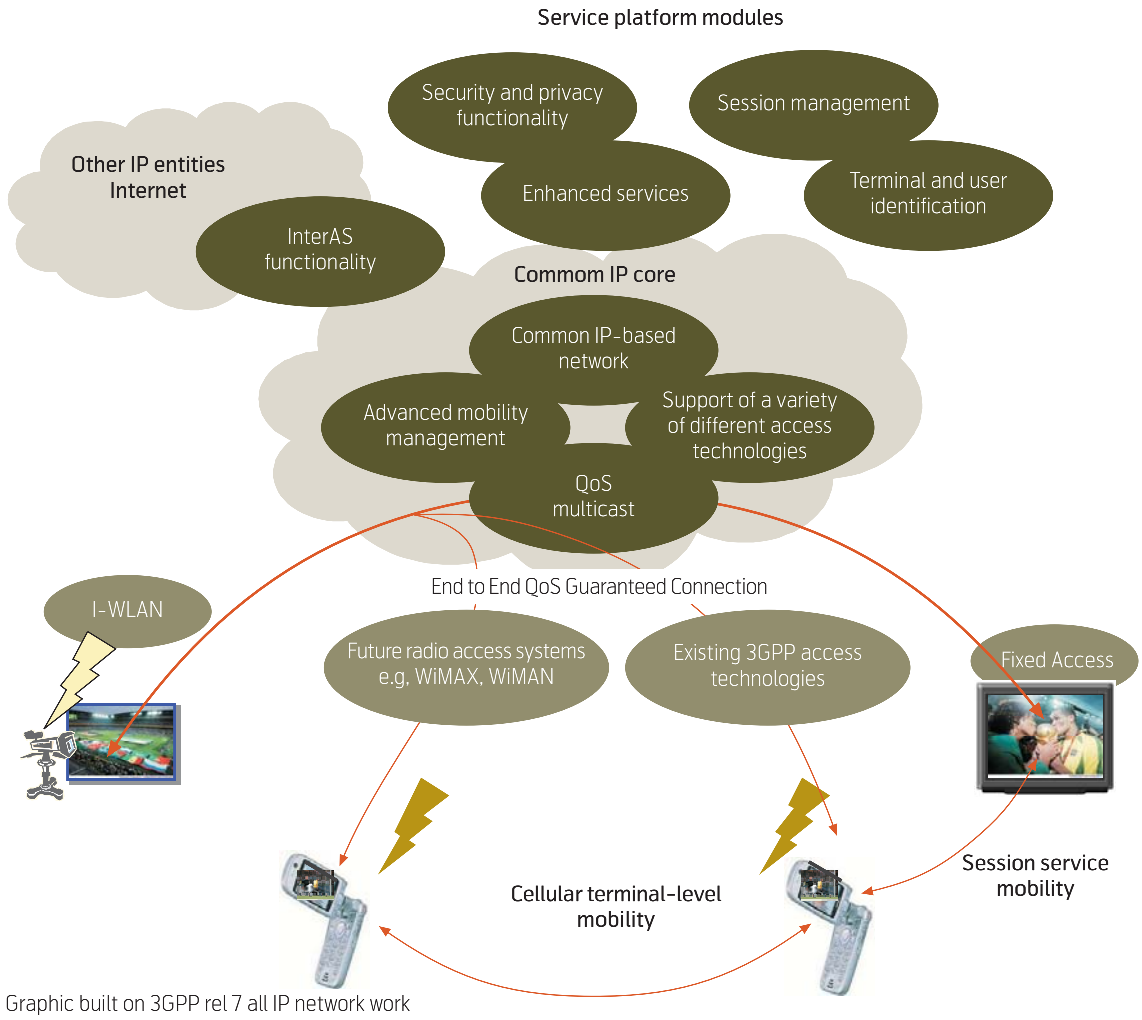

Figure 3 The target network vision indicating long term direction of evolution of networking (the illustration is built on the 3GPP release 7 work on All IP Network

3.11 Summarizing statements on drivers and networking trends

Each one of the nine areas addressed in the previous sub-chapters 3.1 – 3.10 may be summarized in a corresponding statement on the future evolution, resulting in the following list of statements on drivers, long-term trends and network requirements:

1 The target network is part of the next generation global IP network.

2 The target network will support real-time services using MPLS, multicast and Quality of Service.

3 The target network is an open IPv6 network where protection measures and identity are initiated from the application (or operating system) layer.

4 Development of willingness to pay in the residential market will be directly derived from services.

5 Public wireless broadband accesses will complement private wireless connections to fixed network using network handover technology.

6 IP components will extend toward the network edge.

7 IP will be transported directly over simple high-capacity mechanisms.

8 Critical traffic and applications will be protected by robust and intelligent mechanisms.

9 Interaction points between terminal and network functionality will be implemented.

10 Differentiation will be through services, simplicity and adding to end-user experience.

Figure 3 gives a graphical interpretation of the key building blocks in the target network vision described in this chapter.

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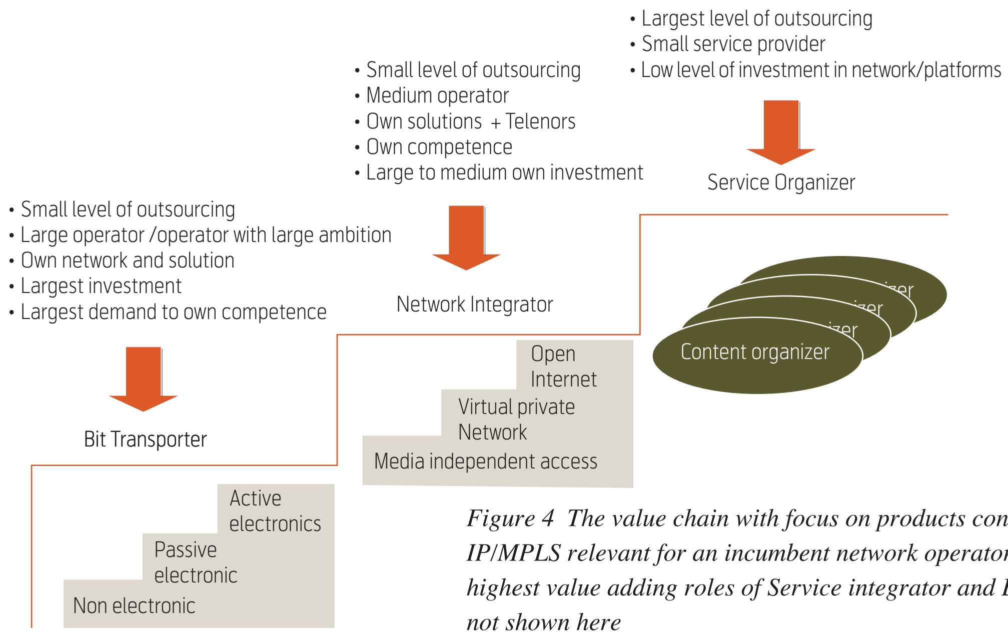

Figure 4 The value chain with focus on products connected to IP/MPLS relevant for an incumbent network operator. The two highest value adding roles of Service integrator and Broker are not shown here

4 New products, roles and corresponding network requirements

The market and technology development will challenge the fixed network operators and their top line revenues. Most likely the operators will consider offering more value added services to the customers as a prerequisite in order to maintain revenue levels and profitability. The operator may choose to take on new roles providing more value added products and services, primarily to channel traffic into their own network, to secure and possibly increase existing revenue in the network, and secondly in order to secure revenues on the actual new service(s)/role(s).

The value chain in the telecommunications industry consists of the following roles with value adding in increasing order; Bit transporter, Network integrator, Service organizer, Service integrator and Broker. However, from an incumbent network operator's perspective, it is the three lowest roles which are most relevant and important for their business. Therefore, in the present article we will just concentrate on these roles.

Figure 4 shows an expanded value chain as seen by an incumbent telco, with focus on an IP/MPLS-based broadband network. The new roles as well as existing and new products are shown in the different steps in the value chain. Operators, service providers and re-sellers trade at different levels in the value chain. The market players can be characterized in different ways. Large players who have an ambition to compete with the fixed network operation of Telenor at an infrastructure/net integrator level trade on the lowest step in the value chain. These players have the highest level of investment and are very competent. Small players like re-sellers and service providers have a different type of business model and are active on a higher level in the value chain. They aim at a higher level of outsourcing and their main focus is on the end-user market.

The three main roles for the operator are considered to be the roles of *Bit transporter*, *Network integrator* and *Service organizer*. As a Bit transporter the operator will cultivate the role as a supplier of "bit transport" to the traders at the next level, like internal or external service providers. The Bit transporter will have to support the next role level in an optimal way. The Network Integrator role will be based on a huge installed network infrastructure base to be able to utilize the possibilities inherent in seamless integration of various types of networks. Taking on the role as *Service Organizer* will require that the operator has a good understanding of the needs that service developers and service- and content providers have for cost effective development and profitable products.

In Figure 4 the main steps are divided into smaller steps. The products represent different degrees of value added, and products with the lowest value added are positioned at the bottom. This is seen from a technological view. Every step has a general description indicating the type of value added to the products at the actual step. Acting as Network integrator will imply that the operator provides seamless communication between networks, both wireless and fixed, as well as between its own networks and between its own networks and other IP/MPLS operators' networks. The latter is a particularly strategic question. As a Network integrator the operator must base its operation on open and standardised products to secure robust and cost effective solutions.

As Service organizer the operator will organize network and service platforms for service providers (third party) over all types of accesses. As Service organizer the operator provides key components and vital information, such as network independent adaptation of services to different terminals and networks, security-, authentication- and payment solutions. By acting as Service organizer the operator will have a better opportunity to channel traffic in its own networks. In the longer term it may also provide greater opportunities for new revenue flows by charging for the provided functionality.

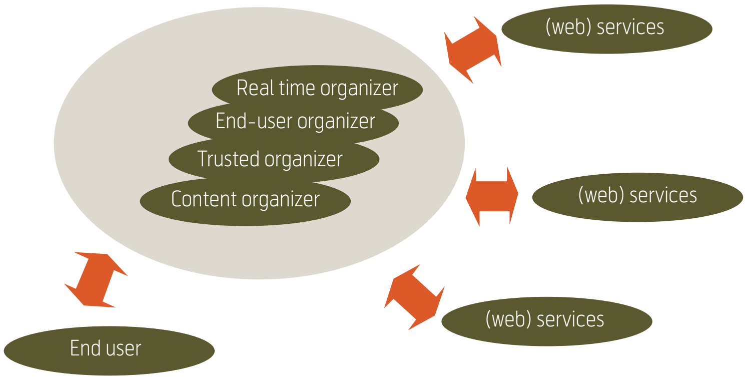

Figure 5 Examples of functionality provided by the Service organizer

The distinction between Bit transporter and Network integrator is defined as the border between L1/L2 in the OSI model infrastructure in a point-to-point view with a specific encapsulation depending on the media type, and a Layer2/Layer3 network service with common encapsulation regardless of underlying media type.

The access technologies have to support the IP/MPLS network in the Network integrator role. New capacity products for transport and access have to be simple and transparent in a way as to support the operator as Network organizer. The operator will enable this by offering media independent access products based on parameters related to capacity, delay and SLA.

As broadband and mobile Internet becomes widely distributed there will be niches for both small and large value adding service providers. Many players in the software business as well as in telecom are actively pushing the development of web services. The target group for products provided by Service organizers consists of small and medium sized service developers as well as service- and content providers. The Service organizer will organize network and service platforms for service providers (third party) over any type of access based on the Network integrator providing seamless connectivity over relevant types of access (DSL, GPRS, WLAN etc.).

Figure 5 shows some examples of the types of functionality provided by the Service organizer. Functionality may be seen as different modules or tools that can be combined and built on each other. It is assumed that the interfaces they are provided over are based on the prevailing standards and developments at the time of being offered to the market.

The following key features may be provided by the network operator:

- *"Known/Recognizable" address identity*. In the residential market, the demand for a "Known/Recognizable address identity" is increasing. One easy solution is Dynamic Domain Name Server.

- *QoS – Quality of Service*. Two main approaches to QoS in IP networks are defined: DiffServ and IntServ. Marking, shaping and policing are the three cornerstones of DiffServ. DiffServ should be deployed differently in normal and in fault state of the network and should be implemented in an end-to-end perspective. Several mechanisms exist for implementing DiffServ and they may solve the task in different ways. IntServ is session oriented and allocates resources to specific sessions or connections.

- *Seamless Communication*. Seamless communication is a term used on several areas today. IP gives a seamless communication over Layer 1/Layer 2 infrastructure. In a more mobile sense of the word two fundamental challenges arise; tracking of identity and session handover. IPv6 gives address space for tracking of identity and Mobile IP solves the session handover. Solutions handling intercommunication between IPv4 and IPv6 are also a part of seamless communicating.

- *Authentication*. Authentication is used on many levels and forms in broadband services. In this setting it is thought of as the ability to exchange and forward information about end-users' identity and authentication request to the entity that accepts or denies the end-users' authentication request. This is important in a role for Network integrators that operate between end-user and Service providers.

- *Traffic Statistics*. The foundation for SLA monitoring, accounting, scaling and planning etc. is

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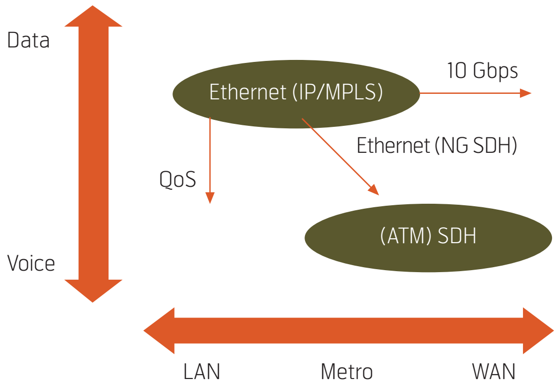

Figure 6 The technology shift from ATM and SDH towards Ethernet and IP/MPLS

based on traffic statistic. It is important to ensure that the network elements have the functionality to gather statistics for a particular level and enable it to be used by IT systems in a cost efficient way.

- *CNM – Customer Network Management*. The threshold for customers to outsource their network needs to the operator can be lowered using CNM. CNM is a product category that gives customers a network view and ability to do some network management themselves.

5 Development in core and distribution network technologies

The following sections present an overview of major issues in technology development which are relevant for the distribution and core parts of the network.

5.1 Technology shift from SDH and ATM to Ethernet and IP/MPLS

The demand for Ethernet as the standard service interface is continuously increasing. Ethernet as the transport technology for packet-based networks is also within the trends. This technology adopts functionality that in most cases makes it the preferred interface by end-customers who need virtual leased lines and connections to IP VPNs. Global trends show a distinct migration among telecom end-customers from the legacy SDH- and ATM-based network services to IP- and Ethernet-based network services. There are two main drivers behind the implementation of Ethernet services. The first one is customers' demand for Ethernet services, expecting these to have a lower price than traditional services. Some customers want Ethernet services to be used as an underlay network for their own IP network.

The second driver is lower production cost than for traditional alternatives such as ATM and SDH, both for network owner and for customer. Specifically, the current ATM-based DSLAM aggregation networks will no longer be a cost efficient platform when IP multicast, application aware QoS and higher bandwidth are introduced. The overall traffic increment will be divided between Ethernet, IP VPN and Internet services.

An IP/MPLS core and distribution network makes a cost efficient handling of traffic growth possible. Ethernet services give additional services to the IP/MPLS network that together with IP VPN will move traffic and customers away from legacy services based on ATM and SDH. An optimised IP/MPLS-network provides the possibility to introduce higher level services such as VoIP, VoD, TV-Broadcast, and to fetch and keep customers that are migrating from the legacy telecom services such as Frame-Relay and SDH-based leased line etc. This will also give the possibility to start the termination of legacy platforms such as ATM and later SDH and then even the legacy telephony platform ISDN/PSTN.

However, different paths are taken towards the IP/MPLS technology, as depicted in Figure 7. Traditional vendors develop ATM and SDH equipment in the directions of IP/MPLS nodes. IP centric vendors

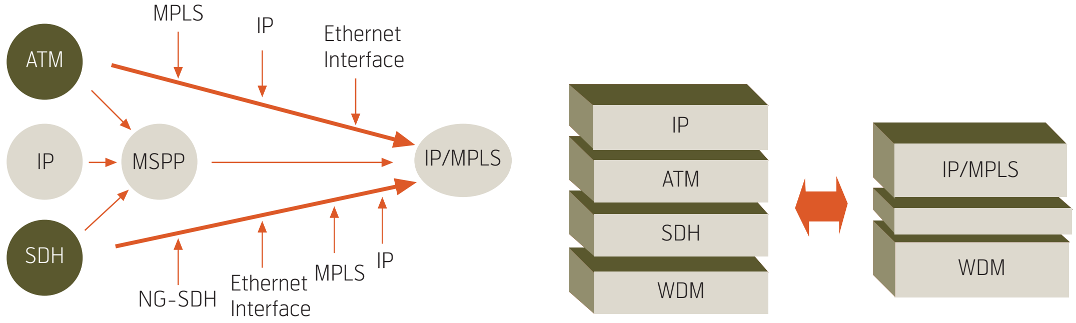

Figure 7 There is a drive in the industry towards IP/MPLS and Ethernet over WDM

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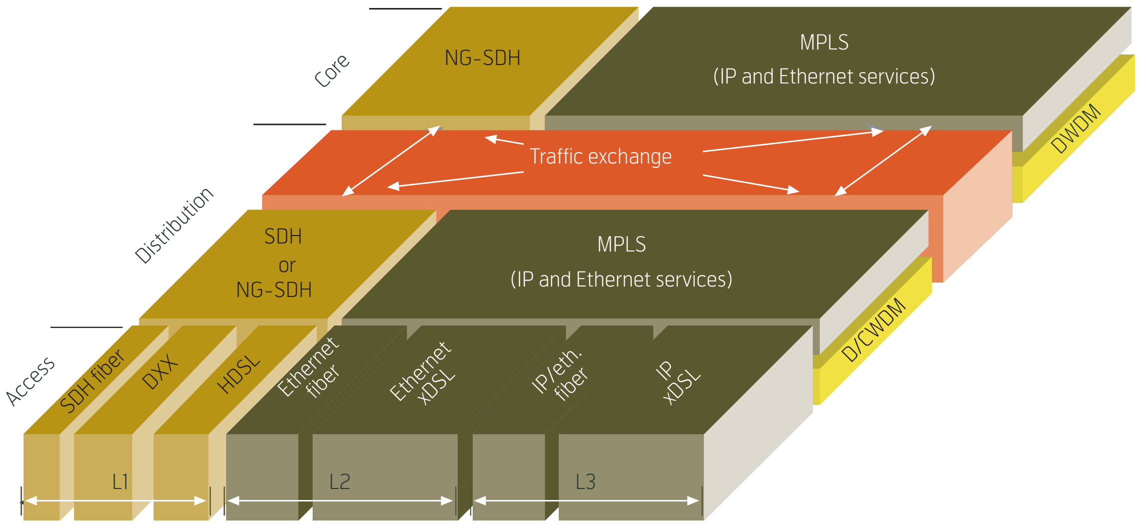

Figure 8 The use of IP/MPLS and NG-SDH to reach high coverage for Ethernet services

include more functionality directly into the MPLS core solutions. Others are merging technologies in the same platform with MSPP (Multi Service Production Platform). MPLS is basically mature, but it is also a technology that is under constant development. It may therefore be necessary to bear in mind that some services can already be provided with the current version and implementation of MPLS, while other services may have to wait until further development has taken place.

Ethernet services should be produced in an IP/MPLS-network to be able to achieve a common network infrastructure for different services. This technology has been adopting functionality that in most cases makes it the preferred solution when consolidating transport networks.

Alternatively, Ethernet services may be produced as an overlay in the SDH or NG-SDH infrastructure. SDH is originally designed to carry circuit switched voice traffic, while NG-SDH (Next Generation SDH) is designed to carry Ethernet as well as legacy traffic. This gives the possibility to use NG-SDH for transport of Ethernet in the migration towards an IP/MPLS network with an adequate geographical coverage. However, this is not likely to be a cost effective production method compared to IP/MPLS. Development of new features on SDH platform does not seem to be able to compete with the development and possibilities that IP/MPLS-based platforms provide. Ethernet services on SDH will in the near future be obsolete compared to newer and more flexible services that can be provided and developed within the IP/MPLS solution. Ethernet services produced in an SDH or NG-SDH infrastructure must however be considered as an alternative to IP/MPLS to gain the possibility to reach out to geographical areas that in a migration phase are not yet covered by an IP/MPLS network. The SDH or NG-SDH must also be considered as an alternative in those cases where the primary traffic is and will be TDM-based for several more years, as illustrated in Figure 8.

When considering SDH or NG-SDH as an alternative to IP/MPLS in these cases it is important to bear in mind that the overall evolution prefers packet-based traffic, and that the SDH or NG-SDH infrastructure may be obsolete or unsuited to carry the traffic volume of the future long before the IP/MPLS infrastructure. Most likely the MPLS infrastructure will be able to produce Layer 1 services and TDM services in the near future. This must then be considered as an alternative to traditional SDH based infrastructures. Especially in cases where TDM is considered to be a minor part of the total traffic volume.

5.2 Introduction of optical cross connects in core networks

The highest level of switching in current networks is typically handled by SDH cross connects on VC-4 level. This means that all signals need to be broken down to this level before the switching process itself. On the other hand, it is expected that traffic growth due to explosive implementation of DSL services and higher demand for capacity connectivity will push the need towards wavelength switching.

The demand for implementation of optical cross connects (OXC) will come, but the challenge is to foresee the correct timing for this introduction. There are two main drivers that determine the implementation of OXC. The first one is the amount of traffic carried by the core network and the second one is the degree

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of dynamics needed in the network. It is assumed that one would have capacity needs at the level of several wavelengths in the core network in the target network period. By dynamic optical networks we mean that there exists a need for rerouting on wavelength level. The degree of rerouting per year is related to the degree of dynamics in the network. When introducing large volumes of point-to-point optical circuits to customers and service providers, OXC will most likely be the preferred platform.

Commercial optical cross connects have existed for some years. There are two main kinds of wavelength switching equipment available on the market: the O-E-O (Optical-Electrical-Optical) and all-optical switches. We expect further long-term innovation and development in the optical area. In the same context the technical development within the GMPLS integration between OXC and IP/MPLS networks has to be monitored.

The introduction of OXC makes it possible to implement GMPLS and UNI in the optical domain. The technological consequences on other network elements will be less investment due to bypassing of traffic and automated switching. Implementation of optical cross connect will reduce the need for manual patching and save both time and patching cost. It will also reduce the need for extra investment in network elements such as MPLS nodes, since some of the traffic will be bypassed by optical cross connects. Implementation of optical cross connects will give a better overall monitoring and configuration possibility and therefore simplify OAM process. This will however implicate that Operation would need to upgrade competencies in optical network technologies.

5.3 Introduction of GMPLS and UNI interface in the network

GMPLS has been a buzzword for some time in the telecommunications industry. Certain benefits have been identified with the deployment of GMPLS; on top of IP and MPLS, GMPLS brings intelligence to the optical network. For example, it allows for automatic network topology discovery and route circuits (whether SDH, ATM, Ethernet framed, wavelengths, bundle of wavelengths, etc.) based on constraints specified by the operator. As GMPLS spans all layers and distributes the intelligence, it unifies all layers in an overlay or peer model with a standard based, universal control plane. This allows for interoperability and definition of a global protection and restoration strategy with various link protection capabilities being advertised throughout the network using GMPLS extensions to routing protocols. GMPLS will also allow for optical VPNs and a range of new services that require more dynamics in the network such as bandwidth on-demand and time-of-day request management. However, the development of GMPLS on standardisation front and consequently with vendors has been slow in the past five years.

One benefit obtained with GMPLS is to use GMPLS as a control plane to dynamically integrate several networking layers, from IP to switch ports. There are at least two ways of integrating different networking layers using GMPLS as a control plane:

- One GMPLS process for each level and a UNI between them (“overlay model”);
- A common GMPLS process for several or all layers (“peer model”).

In a network that has not been GMPLS enabled, optical management has to be done via a separate network management tool. Nevertheless, even an integrated GMPLS network will need a support system. Below are examples of what GMPLS cannot deliver:

- Resource planning and reservation in advance;
- Keeping record of events in the network;
- Coordinating technical and business related information;
- Systems for error handling, delivery and network extension are by definition separate, including their processes and support systems.

However, the dominant idea in GMPLS, a common control plane, supports integration of these systems.

With a UNI interface and signaling over this interface, a GMPLS enabled transport network will offer on-demand connections. The UNI signaling only solves the technical side of interfacing, much additional functionality is needed and we are unsure if there will be a demand for UNI services. As mentioned before, GMPLS may be implemented without a UNI interface.

There are a number of examples of how an IP network would use a dynamic infrastructure. Some possibilities are error protection and traffic engineering, to use capacity better both internally and externally. To achieve this it is required that the IP control plane has enough intelligence and is closely integrated with the multi-layer routing. Which way to go is still an open question and is partly deployment and partly technology dependent.

There are ongoing activities in standardisation organizations like IETF and OIF. However, some vendors have proprietary solutions which are already field-tested by some European operators like Deutsche Telecom.

In summary, the technological consequences or benefits of inroducing GMPLS-UNI for a network operator are as follows:

1 The introduction of GMPLS-UNI makes it technically possible to introduce "on-demand" high bandwidth services.

2 The GMPLS protocol suite works with different switching granularities and layers and makes it possible to achieve interoperability between different network layers.

3 An IP-based control plane for different switching layers and granularities simplifies and automates management of network resources.

6 Development in access network technologies

The future development in access network technologies is closely related to the issues of increasing the geographical coverage of broadband communications and increasing the access capacity available for the end user. With the access network being the part of the network associated with the highest part of the overall network investment and operational costs, the need for cost-effective solutions remain a major access technology driver.

6.1 Development in access capacity requirements

Over the past years there has been a significant development in the availability of access capacity. Figure 9 shows the evolution of the access bandwidth available to at least 10 % of the European population at around 50 Euro/month [ECOC2004, Mo3.11]. The figure shows that bandwidth between 10 and 100 Mbit/s by some sources are expected to become generally available by 2010.

The use of broadband connections is expected to change, leading to an increase in access capacity demand. Currently residential broadband accesses are mainly used for high-speed Internet and telephony. The requirements for higher access capacities are primarily driven by the increase in the simultaneous use of several broadband user terminals in the home and introduction of live TV streaming. New usage patterns will increase capacity demand, but technology development will reduce it. Thus, the evolution of capacity demand will depend on usage, competition, technology development and cost, as illustrated in Figure 10.

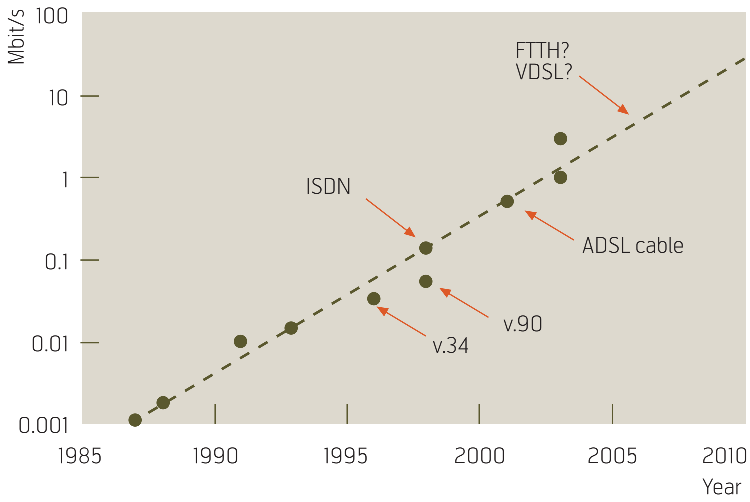

Figure 9 Evolution of commercially available access bandwidth for residential users [ECOC2004, Mo3.11]

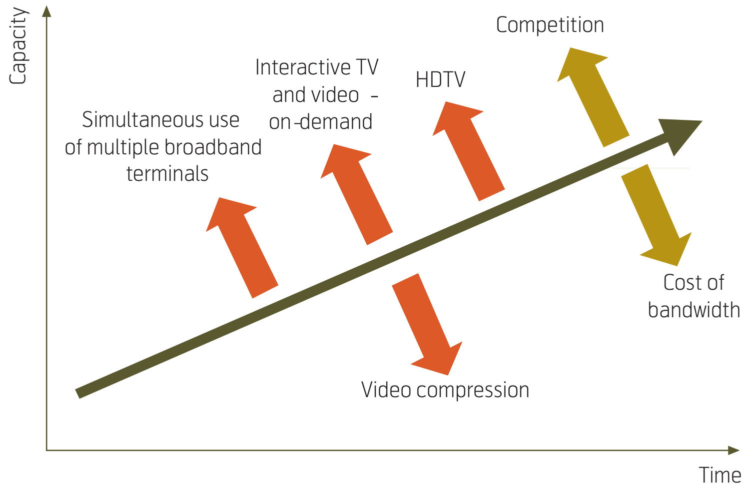

Figure 10 The evolution of capacity demand

A product portfolio covering video, data and voice or equivalent types of services and combinations of these, has to be supported by a large number of specific requirements. For example, considering TV distribution and provisioning of video-on-demand services for the residential market, the need for capacity per channel is 5 – 6 Mbit/s. This is based on current standards of coding technology and service provider requirements to secure quality to the content. New coding technologies will reduce the capacity requirements during the next five years, at the same time as the expanding use of larger TV screens and a potential introduction of High Definition TV (HDTV) will result in increased capacity requirements. In addition, applications like online gaming and file sharing may result in a need for increase in upstream access capacity in the residential market from the current

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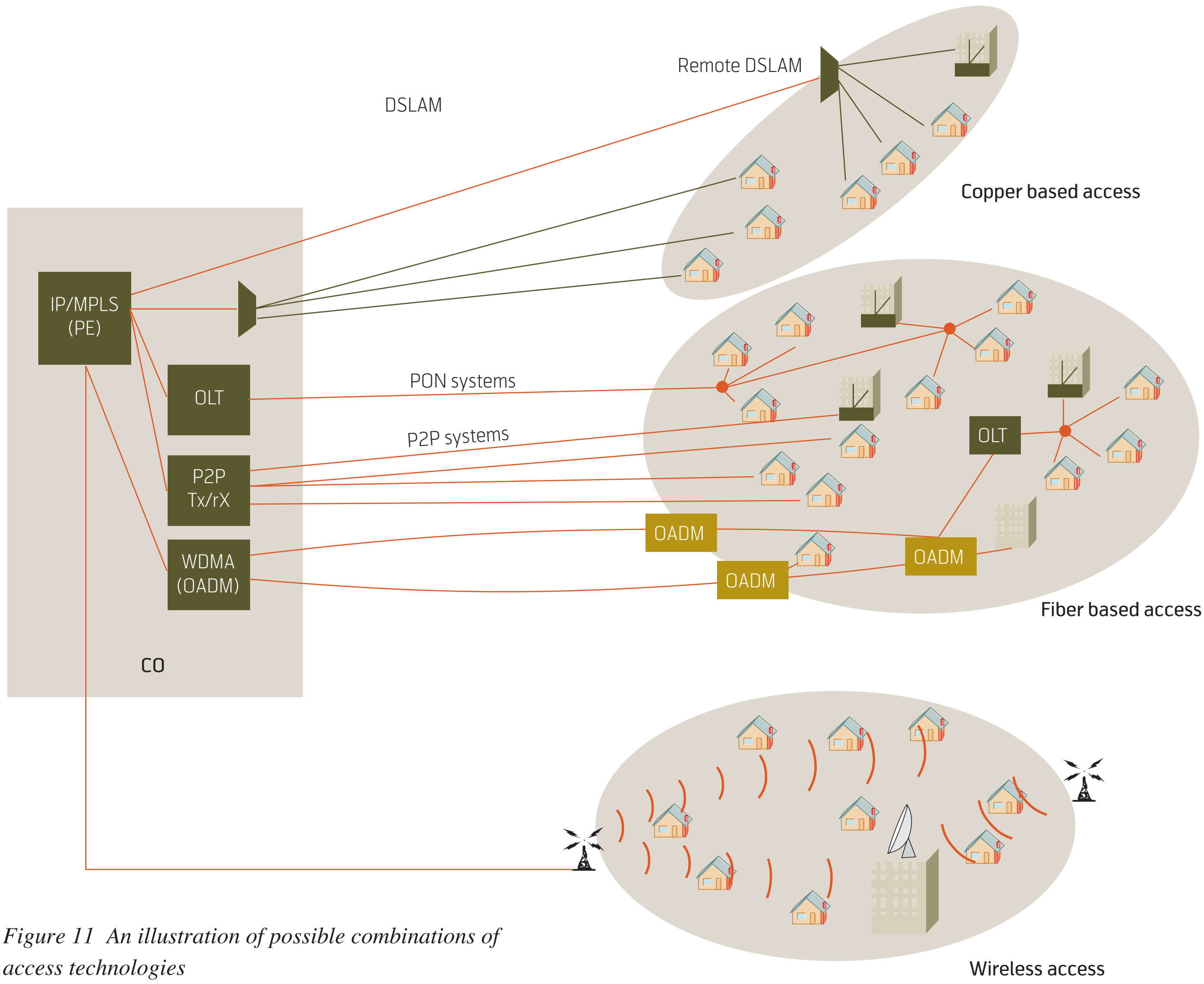

Figure 11 An illustration of possible combinations of access technologies

128 kbit/s to possibly as high as 3-5 Mbit/s during the period.

6.2 Access technologies

Access technologies should be deployed with a view to future bandwidth and functionality demands in the residential and business markets. In general access technologies can be classified by the physical medium in three major groups, namely copper-based, fibre-based and wireless systems. Figure 11 illustrates possible combinations of these technologies. Ethernet connectivity will most likely be the common key element in all access technologies. The customer interface should be Fast Ethernet (FE) or Gigabit Ethernet (GbE).

6.3 Development in high capacity DSL technology

Over the next years we expect a development towards DSL-multiservice access platforms covering services like video, data and voice with a combined access line capacity typically in the range 10–30 Mbit/s, and possibly even higher. There are different DSL technologies which are able to provide future services demanding higher access capacities than can be offered with the current ADSL and SHDSL technologies.

The technologies for symmetric capacities are VDSL or bonded SHDSL systems. VDSL and ADSL2plus are both future-proof DSL technologies capable of providing asymmetric access capacities enabling a combined offering of services like video, data and voice, also called triple-play. The closest competitive technology to VDSL is ADSL2plus. But VDSL will fully cover ADSL2plus features and in addition provide much higher capacity at lower distances (up to 1.5 km). In the standardization process it is the intention to merge further development of ADSL2plus and VDSL (ADSL2plus+ and VDSL2+) to a common standard. This area of technology is progressing continuously. It is important to work close to standards as standards focus on compatibility between generations of technology.

With increasing access capacity on DSL, the reach is reduced, and the number of lines that will be within

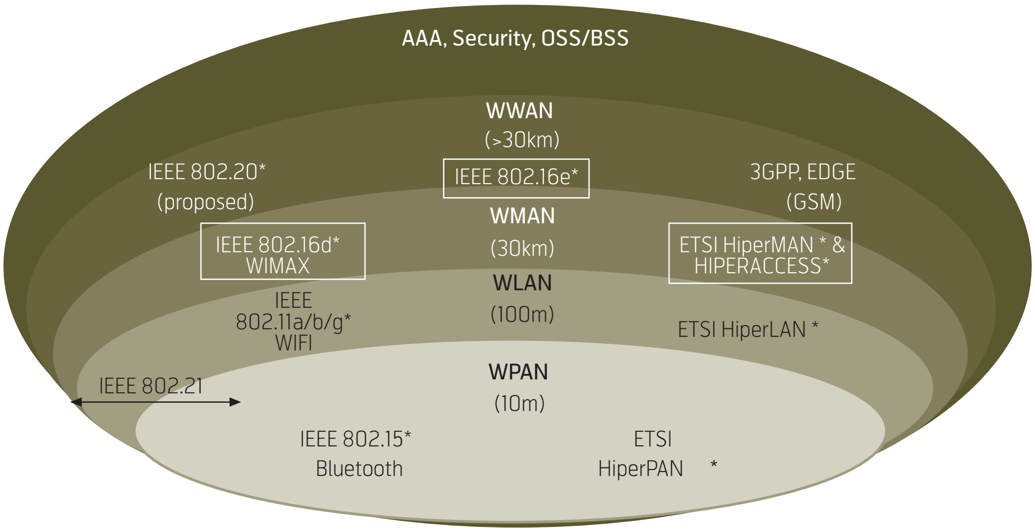

Figure 12 The family of wireless technologies

reach from the Main Distribution Frame (MDF) for higher access capacities will be smaller than the current number of access lines within reach of the 704 kbit/s high-speed Internet access product offered on ADSL and the current symmetric access products offered on SHDSL. Thus, the copper line length of those lines beyond reach of high capacity access must be reduced. This will imply replacing parts of the copper close to the local exchange with fibre-optic cable and establishing fibre nodes beyond the MDF, closer to the end-user (as described in section 6.5).

Restructuring the access network implies regulatory consequences with respect to other operators. These consequences should be addressed and investigated. Assuming deployment of new DSL technologies in the initial phase directly from the existing MDFs, the required new access network investments on a line-by-line basis will be similar to current DSL line card and modem investments of ADSL and SHDSL. However, increasing the coverage beyond the current coverage from existing MDFs will result in a significant investment need in access network restructuring. This is addressed in a separate chapter on fibre nodes.

Dynamic spectrum management (DSM) has the potential of a further increase in utilisation of the existing twisted pair copper access network beyond what is considered possible with the current DSL systems. DSM represents a wide range of maintenance management functions that may be deployed to obtain a more efficient use of spectral resources in the copper access network. The optimised spectral loading of each individual cable pair may be implemented in the connected transmission system, for instance, by dynamically selecting the actual modulation frequencies to be used and the depth of modulation to be applied for the specific modulation frequencies. This is particularly the case for transmission systems based on discrete multitones (DMT) – like ADSL and VDSL.

An intelligent DSM system should exchange primitives with the particular DSL transceiver to modulate and load the terminated cable pair with the exact amount of signal components needed to maintain an error-free transmission. This results in less crosstalk signals disturbing the other cable pairs. With less impairment the neighbouring pairs may now be extended in length or may carry excessive transmission capacity. Though the principle is quite simple, the implementation and strategy of an intelligent dynamic spectrum management system may demand exhausting signal processing and correlation among all the present DSL systems.

An intelligent dynamic spectral management system within an environment of compatible DSL systems, have great potential to significantly improve the transmission capacity and the quality of service in the copper access network. However, the potential of dynamic spectral management may suffer substantially in the cases where the demand for local loop unbundling reaches a significant volume. Technically it should be possible for equipment belonging to different operators to inter-work with one (or two) DSM centre(s), but this is not likely to be the case; at least for the cases where old and incompatible DSL systems are already in place. This is particular the case where regulations of local loop unbundling are kept at a primitive level with almost no aspects of (dynamic) spectral management implemented.

6.4 Development in wireless technologies (WiFi and WiMAX)

Wireless technologies have recently reached a maturity that makes them suited for general access to the Internet. There is a wide range of technologies available. IEEE, ETSI and others define those technologies, as depicted in Figure 12.

Following the IEEE terminology, the 802.11 standard suite (often referred to as Wi-FI) includes short-range solutions in the 2.4 GHz unlicensed band (802.11b and 802.11g) and 5 GHz band (802.11a). These systems typically have a service range of 50 metres from the antenna. The recent development of the WiMAX-technology (IEEE 802.16aRevD) enables a further extension of the use of wireless access. While 802.16RevD will allow connectivity to fixed users, 802.16e (late 2005) will allow for mobile use. There are many proposals for application of WiFi and WiMAX systems. They include, but are not limited to, remote broadband access, access to 'white islands' within urban areas, broadband access within buildings and in public spaces, backhaul for WiFi base stations, flexible VPNs, mesh networks, etc. WiFi IP zones are considered a forerunner of the broadband wireless access (BWA) technology and are being built at strategic sites.

WiMAX and similar future fixed wireless technologies will enable nomadic and movable services, which probably will motivate operators to deploy fixed wireless access not only in rural areas but also in urban and suburban areas in order to be able to generate value added services to already existing broadband users.

6.5 Optical access

The future access capacity demand will most likely force deployment of fibre-optic cables as close to the end-users as possible. The ultimate form of access is to have direct fibre-optic cable access to each end-user. Fibre-optics will provide high-speed architectures and network performance that should be capable of handling customers' increasing data traffic requirements for many years to come. However, an extensive introduction of fibre-optics in the access network will depend on incentives amongst the network operators in order to make commitments to the significant levels of investment required.

Optical fibre access can be deployed on both Passive Optical Network (PON) and active point-to-point optical networks. There are several kinds of solutions in each of these two categories, and the choice of desired solutions will depend on economics and technological factors.

In addition to deploying fibre to end-users, the optical solutions can play a major role in feeding DSLAMs and base stations for cellular networks, and in the future even be able to run DSL and RF on the fibre itself. This will save space primarily in remote stations and make a centralized central office based distribution possible and therefore reduce the operational expense.

Optical wireless can also be named as another solution that should be considered in areas with high fibre deployment costs.

7 Migration towards IPv6

The current IP address space IPv4 will in the long term be unable to satisfy the potentially huge increase in number of users and/or the geographical need of the Internet expansion. Because of today's extensive use of Network Address Translation, NAT, IPv4 is definitely not able to satisfy the address space requirements of the emerging applications such as Internet enabled personal devices (PDAs, home area networks, Internet connected transportation, integrated telephony services and distributed gaming, among others). IPv6 quadruples the length of network address from 32 bits in IPv4 to 128 bits in IPv6, which hopefully provides more than enough globally unique IP addresses for every network device on the planet.

The use of globally unique IPv6 addresses simplifies the mechanisms used for reachability and end-to-end security for network devices. This functionality is crucial to the applications and services driving the demand for addresses.

The lifetime of IPv4 has been extended using techniques such as address reuse with translation and temporary allocations. Although these techniques appear to increase the address space and satisfy the traditional client/server setup, they fail to meet the requirements for direct addressable addresses of the new applications.

We in the Western hemisphere are in the early stages of IPv6 deployment with fewer IPv6 applications than IPv4 on the market. However this situation may change drastically in the future triggered by services implemented in the huge eastern markets. The successful market adoption of IPv6 technology depends on an easy connectivity with the existing infrastructure without significant disruption of services.

Although the success of IPv6 will ultimately depend on the innovative applications that run over IPv6, a

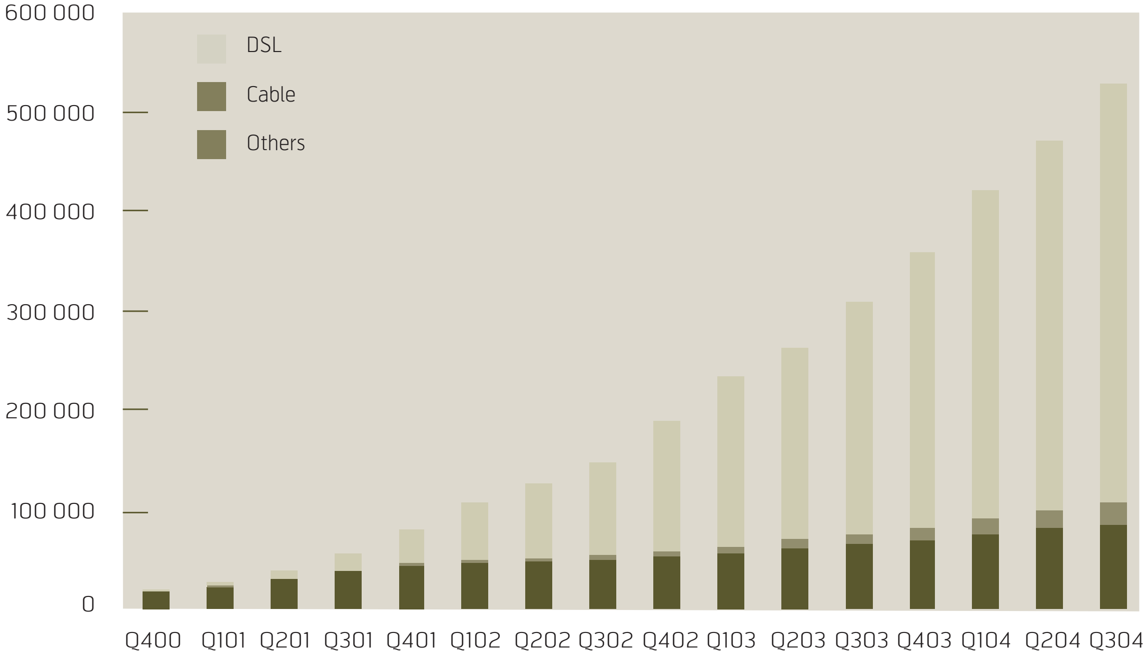

Figure 13 The number of residential broadband accesses in Norway passed 500,000 in the third quarter of 2004

key part of the IPv6 design is its ability to integrate and coexist with current IP networks. We expect that IPv4 and IPv6 hosts would need to coexist for a substantial period of time during the steady migration from IPv4 to IPv6. Selection of a deployment strategy will depend on the current network environment and factors such as forecast amount of IPv6 traffic and the availability of IPv6 applications on end-systems and the stage in deployment.

In an IP/MPLS-based core network, IPv6 can easily be transported since MPLS is transparent to IP versions. Therefor focusing on the primary goal, i.e. to enable IPv6 applications to communicate, the deployment of IPv6 will most likely occur at the edge first, where the applications and hosts reside, and then move towards the network core to reduce the cost, operational instability and impact of integration. Also the migration of IPv6 into the edge or user site is relatively easy, as major operating systems (Microsoft, Linux) are already IPv6 capable.

The main strategies used in deploying IPv6 at the edge of a network involve carrying IPv6 traffic over an IPv4 network infrastructure, allowing isolated IPv6 domains to communicate with each other prior to a full transition to a native IPv6 backbone. In a full upgrade, it is possible to run both IPv4 and IPv6 throughout the network from edge through the core. Additionally a mechanism may be required to translate between IPv4 only and IPv6 only devices to allow hosts supporting only one protocol to communicate transparently with hosts running the other. All techniques allow networks to be upgraded and IPv6 deployed incrementally with little or no disruption of IPv4 services.

8 Telenor's targeted future network platform

8.1 The broadband status in Norway

In the last two years the growth in Norway has mainly been in DSL accesses with 704 kbit/s access capacity. The number of residential broadband accesses in Norway passed 450,000 in the first half of 2004, as shown in Figure 13. Some estimates indicate a doubling of the number of broadband accesses by the end of 2007.

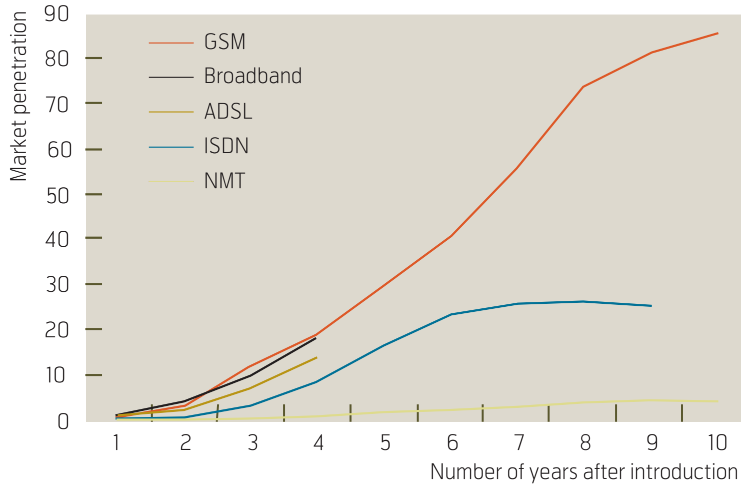

Figure 14 The initial broadband growth in Norway has been stronger than the growth in ISDN

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The initial growth in the number of broadband subscriptions in Norway has been stronger than what was seen for ISDN and GSM, as depicted in Figure 14.

Worth noting is that NMT and GSM were introduced in 1981 and 1993 respectively. The mobile penetrations are measured as the sum of business and residential subscriptions as a percentage of the total number of persons in Norway. ISDN and ADSL were introduced in the residential market in 1995 and 2000 respectively. The fixed network subscription penetrations are measured as the number of residential subscriptions as a percentage of the total number of households in Norway. GSM experienced a 18.6 % penetration four years after introduction, whilst the broadband penetration four years after introduction was 17.5%. In comparison, ISDN experienced an 8.4 % penetration four years after introduction.

8.2 The target network characteristics

In view of the recent service and market developments and the technology trends described in the previous chapters, Telenor's long-term ambition is a development towards a target network with the following characteristics:

- New revenues and products are implemented and available on the new IP/MPLS network, and these are platform independent and transmission media-transparent products.
- The user equipment has Ethernet interface or Ethernet wireless as standard.
- The access network is transmission media transparent and with different capacity based on DSL, fibre and wireless technologies and supports a corresponding IP/MPLS-based distribution and core network.
- A new and consolidated high capacity distribution and core network is based on IP/MPLS and WDM systems.
- The communication interface between network functions and internal and external service platforms uses open, easy to use and well defined industry standards that support terminal and user mobility.

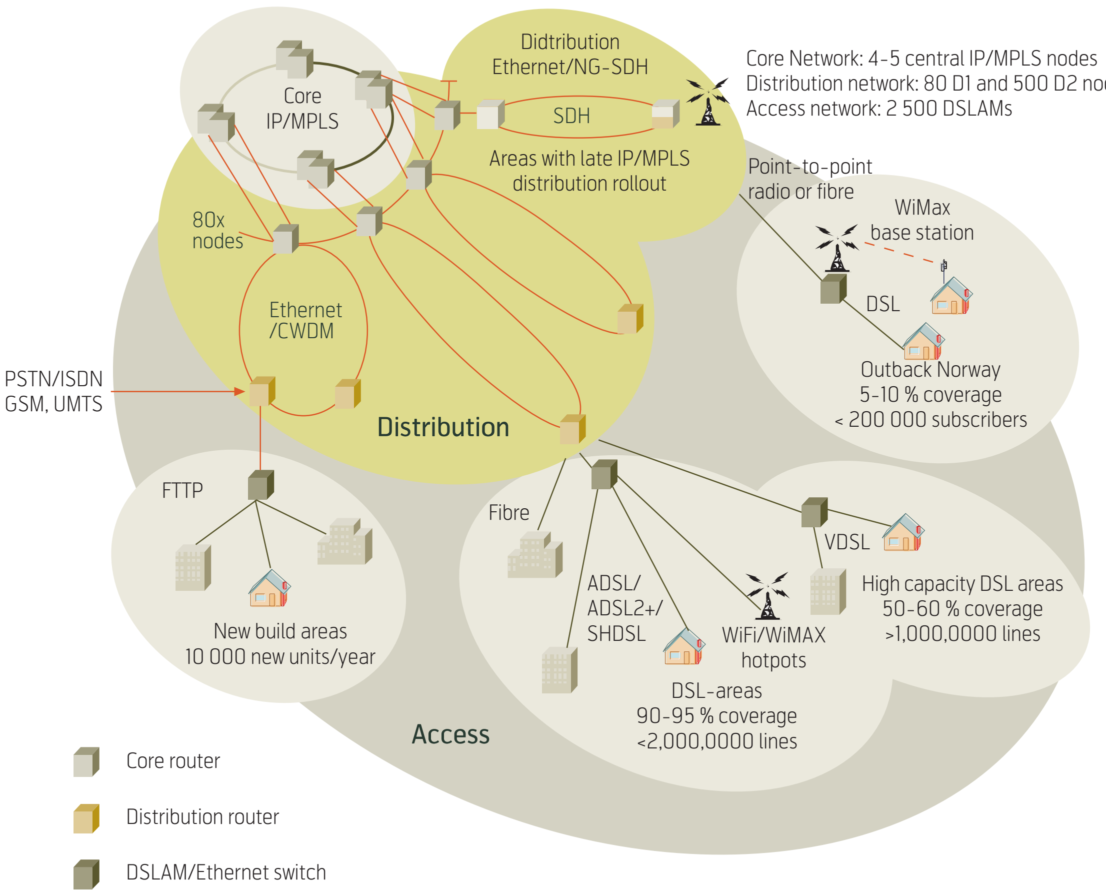

Figure 15 A future-proof network infrastructure, considered by Telenor to be the 2010 target network architecture for the Norwegian fixed network

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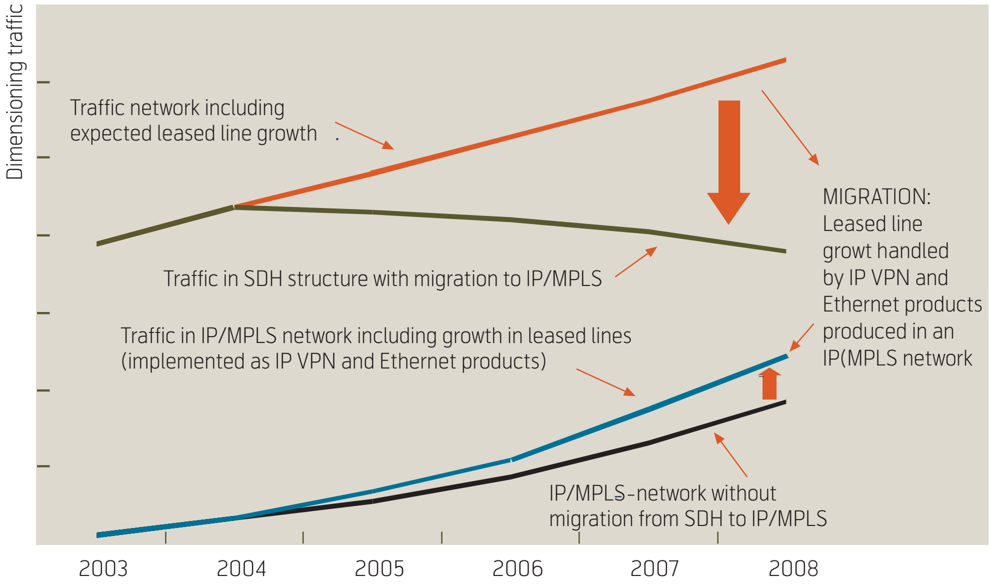

Figure 16 The red curve shows expected SDH-traffic without migration to IP/MPLS-based products, the brown SDH-traffic with migration, the black IP/MPLS, traffic without migration and the blue IP/MPLS traffic with migration of SDH traffic on IP/MPLS

- A full functional open IP-based service platform makes the differentiation of products and integration with customer systems possible at the higher layer. The service platform also includes service agents in customer equipment.

- Network IT and management systems including customer network management systems are simplified and consolidated

8.3 The IP/MPLS-based network infrastructure

Figure 15 illustrates Telenor's future network.

The target network vision pictures an IP/MPLS network in distribution and core. This network is used as the underlying production network for all services. There will be a need for support for real-time video communication and multicast through the whole net-

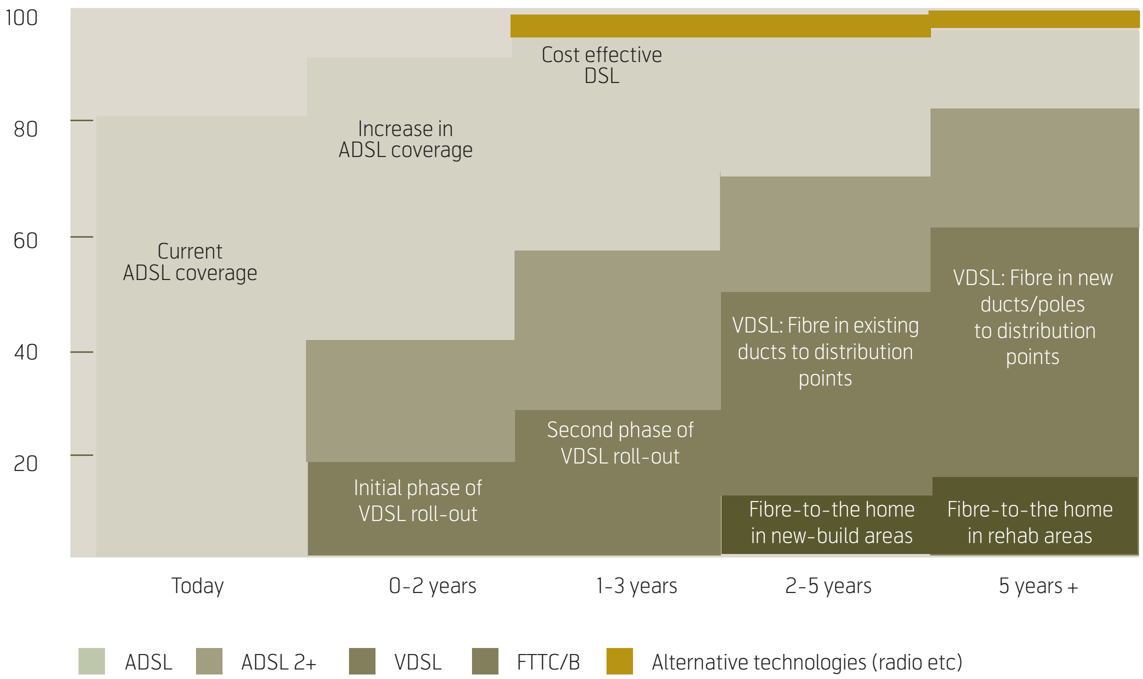

Figure 17 The expected introduction of new access technologies in Telenor's network in Norway, enabling both growth in coverage and increased capacity

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work. To meet the future capacity demands the target network vision is a stand-alone network on top of a transport network based on optical channels. A key issue will be to handle the expected growth in data traffic cost effectively. This is illustrated in Figure 15, which illustrates the effect of growth in SDH traffic without migration to IP/MPLS-based products, and the effect of growth with migration to IP-MPLS.

8.4 Access network development

The future access network will be built on a common platform with DSL as the dominating broadband technology in terms of volume. Fibre nodes will be installed to increase coverage of high-speed DSL solutions to a larger part of the population in established residential areas. Fibre to business solutions will be deployed in established and new building areas. Ethernet will be the dominating technology for connecting the access network to the distribution network, either carried on fibre, copper or radio-based transport solutions. Ethernet metro is often the used term for such aggregation networks.

Better business possibilities could be available through provisioning to a larger segment of the broadband residential market, including remote areas. A key question is therefore related to the technical solutions to deploy to achieve a coverage for broadband Internet access as close to 100 % as possible with reasonable profitability. The basic assumption in Telenor is related to the choice of DSL technologies to provide such a coverage. However, between 5 and 10 % of Norway's households cannot easily be reached due to technical limitations or the high cost of using DSL technologies. Hence, wireless broadband solutions such as WiMAX may come into use as complementary technologies. The range of these systems may typically be 30 km (line-of-sight) and 5 km (non-line-of-sight in urban areas).

Figure 17 shows the expected introduction of new access technologies, enabling both growth in coverage and increased capacity.

9 Acknowledgments

The present article is a result of the Telenor project Telenor Nordic Fixed Target Network 2005–2010, which has been carried out during 2004 with close cooperation between and participants from Telenor AB and Telenor Networks. The authors are grateful for all contributions from project participants, both in terms of written material and oral discussions.

Leif Aarthun Ims is Director of Network Strategy at Telenor Networks, responsible for the long-term development of Telenor's fixed network in the Nordic region. Prior to that he held positions as Vice President at Telenor's CTO office, responsible for the company's activities on video on DSL, project manager for the company's initiative on next generation broadband access networks, and research manager with Telenor R&D. He has also been involved in several RACE, ACTS and EURESCOM projects. He was editor of the book "Broadband Access Networks" (Chapman&Hall, 1998). Leif has published more than 90 papers in international journals and conferences. He has been Guest Editor of two issues of Telektronikk*: Broadband Access Networks in 1999 and Interactive Opportunities of Broadband Communications in 2002.*

email: leif-aarthun.ims@telenor.com

Anjali Bhatnagar is Senior Strategic Advisor in Network Strategy in Telenor Networks. She has been with Telenor Networks since 2002 where her main responsibility has been the long-term development of Telenor's fixed network, including project management of the project Telenor Fixed Target Network 2005–2010. Anjali holds a PhD from the Department of Physics at the University of Oslo from 1998. From 1998 to 2002 she worked at Telenor R&D where she was project manager for the EURESCOM (http://www.eurescom.de) project P1116, focusing on GMPLS issues in a combined IP over optical transport network. In addition to this project Anjali has participated in and has had responsibility for several activities in other EURESCOM projects like P709, P918, P917 etc. Her areas of expertise are project management IP-based signalling and routing protocols in core networks, WDM-based transport networks, PON-based optical access networks, GMPLS and analysis of self-similar behviour of data traffic. Anjali has published more than 30 papers in reputed international journals and conferences, among them Physical Review B and Physica C. She has also been author of several international and Telenor internal reports.

email: anjali.bhatnagar@telenor.com

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Erik Østlyngen (53) is Senior Strategy Advisor in Network Strategy at Telenor Networks. He has a broad experience from data communication products, production and technology within Telenor from 25 years of service. He was manager of development for Next Generation Services from 1998 to 2003, focusing on IPVPN, IP wholesale services, IP content distribution, IP real-time services and network convergence towards IP. He has also been involved in workflow process optimization and IS development.

email: erik.ostlyngen@telenor.com

Kurosh Bozorgebrahimi has been working with the Telenor 'Transport Network' and 'Innovation Group' since 1996. He has participated in and managed various research and development projects within xDSL, Ethernet/NG-SDH and optical networking for Telenor Networks. In 2003 he joined the 'Network Strategy Group', where he is currently participating in defining Telenor's fixed network strategy. His main fields of interest are access and optical networks. Kurosh received his Masters degree in Physical Electronics (Optical Communication) from the Norwegian University of Science and Technology in 1995.

email: kurosh.bozorgebrahimi@telenor.com

André Bersvendsen (30) is Senior Strategy Advisor in Network Strategy at Telenor Networks. He has been with Telenor Networks since 2001 where his main responsibilities have been long-term development of Telenor's fixed networks, including project management. Focus is development of strategies for IP/MPLS network, and migration towards Next Generation Network including platform for service production. He has a broad experience from various network implementations, technologies, development and deployment of network infrastructures, and has achieved certification via Cisco Systems CCIE certification program. He has also been responsible for the technical infrastructure used in Telenor's VDSL pilot.

email: andre.bersvendsen@telenor.com

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Dynamic Spectrum Management
– A methodology for providing significantly higher broadband capacity to the users

JOHN M. CIOFFI[1)] AND MEHDI MOHSENI

John M. Cioffi is a Professor at Stanford University, California, USA

Mehdi Mohseni is a PhD student at Stanford University, California, USA

Dynamic Spectrum Management (DSM) methods are overviewed and analyzed in terms of benefit to DSL performance, rates, ranges and operational costs. Two DSM steps are recommended for near-term and longer-term improvements in DSL: (1) transmit power-minimization at fixed good quality of service by all or many DSLs in service, and (2) cooperative physical-layer signal vectoring at line-terminal access multiplexers. These steps are show to make 100 Mb/s symmetric DSL services practically viable everywhere DSL subscribers demand service.

1 Introduction

The successful installation of a largely fiber-based network over the past two decades has encouraged higher access network speeds, a trend expected to continue. While high capacity can be delivered to individual customers over leased fiber facilities, lower cost access alternatives have become increasingly interesting. In particular, the world-wide success of the digital subscriber line (DSL) service, which can deliver increasingly high speeds on the existing copper twisted pair at a fraction of the cost of leased facilities, intensifies interest to best use this copper.

Cable television facilities have been upgraded to include a portion of fiber, enlarging the bandwidth to each customer and to provide two-way digital communication allowing fast internet and digital voice services to be provided on that facility, thus creating competition for incumbent telephone-company service providers. Thus, telephone companies have then studied the business case to enlarge the fiber network closer to, but not all the way to the customer with connections to the households that utilise the already existing copper lines. During the last years there has been an interesting evolution of the DSL technology that provides higher and higher capacity. The increase in capacity depends on a set of factors like length of the copper line, diameter on the twisted pairs, degree of symmetrical and asymmetrical traffic, the coding, etc. To be able to make good broadband demand forecasts, it is of crucial importance to understand the technological evolution.

This paper gives perspectives of the new Dynamic Spectrum Management (DSM) methods, which have the potential to increase the data rate capacity for broadband significantly compared with the DSL methods used today. Dynamic Spectrum Management (DSM) automates the provisioning, maintenance, and operations of DSL. Figure 1 decomposes a typical service provider's DSL costs into equipment and operations. The fraction of cost attributed to operations is already more than half for most service providers (and as high as 70 – 80 % in countries with higher labor costs) and increasing relative to equipment costs.

Customer service (truck rolls) visits contribute most of the "operations" cost. Higher DSL service rates at any given range (loop length) increase the probability of a customer service visit and consequently increase operations costs. The exact DSL data rate and range and consequent cost depend on the service provider, local practices and demand, and the cost of labor. Some service providers with longer loops already incur very large operational costs while others with largely urban populations and short loops (and perhaps lower local labor costs) have not yet experienced operations costs as high, but will eventually.

This overview of DSM suggests and details two steps in DSL evolution that allow significant operational-cost decrease each while progressively increasing the data rates at those lower operational costs: The first step is most simply and colloquially described as "stop hogging". This step introduces a politeness in DSL transmission spectra that allows each user to get excellent quality of service without overwhelming (via crosstalk) other DSL signals in the same trans-

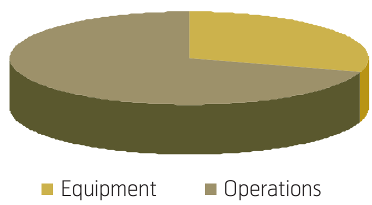

Figure 1 DSL cost decomposition

1) *J. Cioffi is also with ASSIA Inc and SBC and many of the results in this paper merit credit to ASSIA and SBC.*

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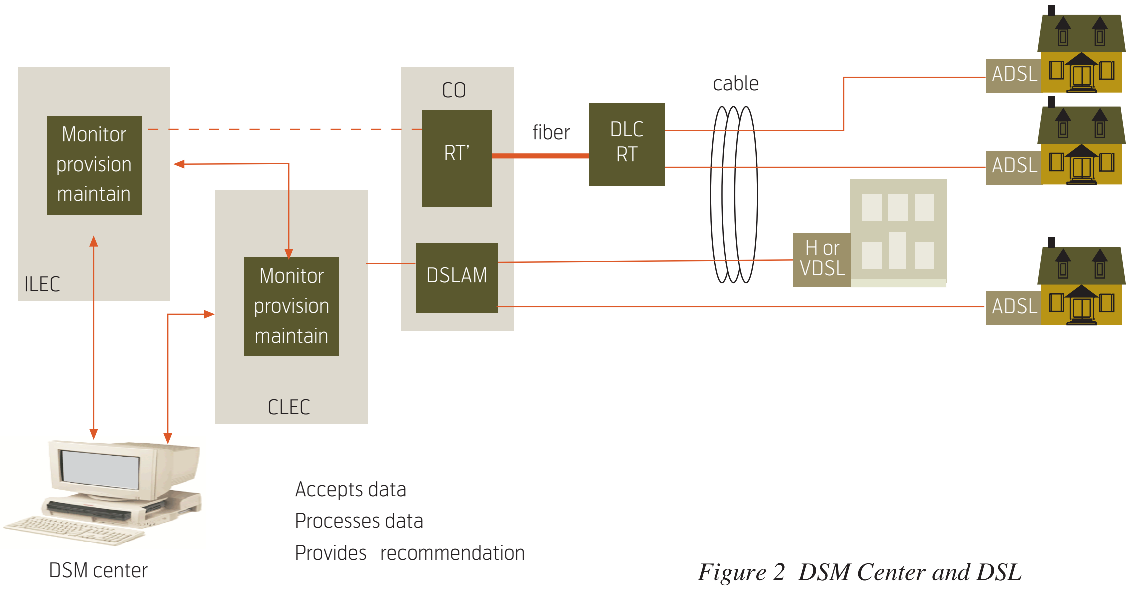

Figure 2 DSM Center and DSL

mission binder. This step is more formally described as "adaptive spectrum" control. Section 2 describes the adaptive spectrum concept and provides some DSM example improvements from DSL customers in service – this first step can be implemented largely on existing DSL service platforms with increasingly automated (software) use of information and controls available in those platforms. The second step is more long-term and involves conscious signal alignment of different transmissions through vectored DSLAMS that attach to many or all of a line terminal's distribution lines. Section 3 projects the further improvements of this second future 3rd-Generation-DSLAM DSM step. DSM is presently a standards project in the T1E1.4 American group and the current draft is at [1], while a complete list of many contributions to that DSM effort is in [2]. Other overview references occur in [3] – [5].

2 Adaptive spectra and the DSM center

Figure 2 illustrates the generic DSM Center that accepts and processes data before providing recommendations to a service provider's maintenance and provisioning tools. The types of data that can be forwarded to the DSM Center include line margins, transmit power levels used, bits/tone tables, insertion-loss per tone, noise per tone, actual power-spectral-density levels/tone, errored seconds, and known loop conditions like bridged taps, loop lengths, and binder taper-code/service-area (allowing the knowledge of other lines in the same binder).

The types of recommendations that are returned after processing can be the data rates (and associated reliabilities of achievement), allowed maximum margins, forward-error-correction choices, and power-spectral densities. Such recommendations can change daily or even more often, especially as DSL speeds increase and approach levels where a service-visit without DSM would be too likely.

2.1 The ADSL RT and DSM

Figure 2 also illustrates a classic problem for the growing DSL service provider, mixture of an existing DSL service and a new DSL service from a fiber-fed terminal in the same binder. Movement of the existing subscriber to the fiber terminal may not occur immediately (or ever) and increases operational costs. The fiber fed lines are usually short. Practice today (despite standards indications to the contrary) is for the fiber line to play at full power (say 20 dBm in ADSL) and the long line to play at reduced power (say 12 dBm) because of ill-conceived spectrum masks in current static spectrum management standards. Actually, the short line creates a very large crosstalk into the long line, reducing the rate of or disrupting the existing long-line customer. The short line meanwhile plays with 100 -100,000 times the power it needs to achieve a high data rate with no errors.

The situation in Figure 2 can be described by the rate region shown for two users in Figure 3. The rate

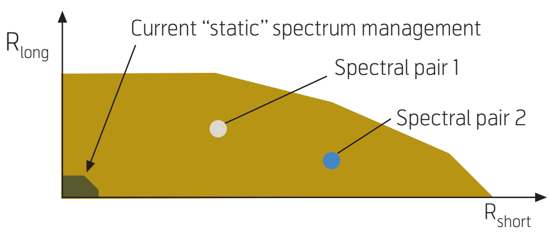

Figure 3 2-user rate region

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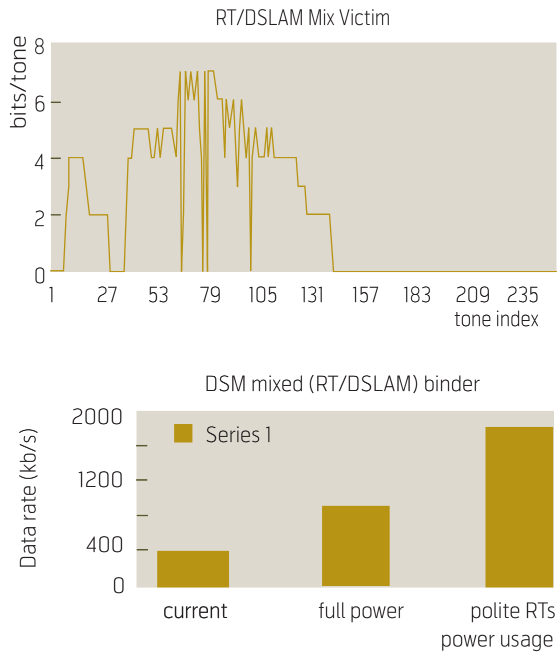

Figure 4 Victim ADSL bit distribution and rates

region in Figure 3 illustrates that different combinations of data rates are possible but each such combination requires a different pair of spectra. Static spectrum management's use of worst-case spectra causes a much smaller region to be achievable. The rate region is particularly appropriate for the situation of ADSL remote-terminal/central-office mixture.

Figure 4 illustrates at its top the bit distribution of a customer in service on a 13.6 kft loop in the USA and various rates below. Several newer RT ADSL circuits are crosstalking in the same binder and cause the rapid bits/tone drop in spectrum use for this medium-length line, rendering a service data rate of only 384 kb/s. This line is also using only 14 dBm of transmit power (instead of the full 20 dBm) because of a concern that such transmit power would cause an excess power spectral density of more than –40 dBm/Hz (an optional limit suggested in some current static spectrum management [6]). This limit is intended to protect HDSL circuits from down-to-up ADSL NEXT. The spectrum in Figure 4 also suggests that HDSLs are present in the binder (because it slopes up in downstream spectrum instead of immediately rising in the 140–250 kHz range). However, the HDSLs in this binder are all operating with highly excessive margins, so an increase of ADSL spectra could be possible (high HDSL margins are common – cursory calculations can show the likelihood of long-length HDSL in the same binder as a very long ADSL, where both are at margin limits, occurs in about one binder out of 100,000 or more – the cost of repairing such a rare event might well be less than the service revenue lost by lowering the rates of millions of ADSL customers). Thus, simply increasing the ADSL power to the allowed maximum of 20.5 dBm increases the data rate to 904 kb/s. Alternatively, if all the RT lines in this binder operate with minimum power for 16 dB of margin at 1.536 Mb/s (and even at rates as high as 3–6 Mb/s), the 13.6 kft loop sees much less crosstalk and actually operates itself in excess of 1.536 Mb/s (the same speed as before the RT is installed and still with 14 dBm of transmit power). Thus DSM provides two solutions for this line, either one of which would lead to very large data rate increase. Similar rate increases have been independently noted in [5], [7] and [8].

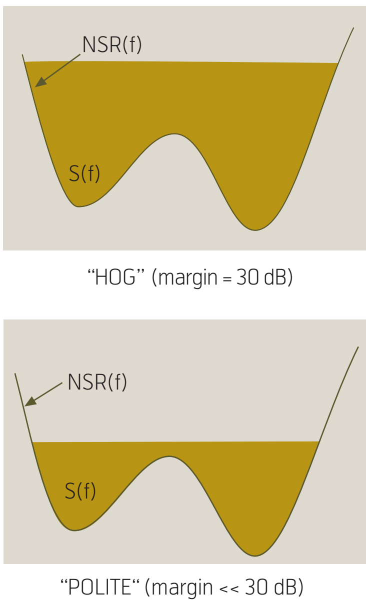

Figure 5 Illustration of water-filling for both hog and polite DSL modems

2.2 Iterative water-filling

The analysis of the situation shown in Figures 2 – 4 is often called "iterative water-filling". Water-filling is a term (see [6]) used to describe the calculation of the best spectrum for a transmission line, in particular a DSL loop. The water-filling procedure is illustrated in Figure 5 for both a "hogging" modem that uses too much power and a polite modem. In both cases transmitted power is viewed as "water" poured from above into the noise-to-signal-ratio frequency curve *NSF(f)*. The dark region is the best power spectral density that can be used on this line viewed by itself without knowledge of other lines. The impolite or "hog" modem continues to pour energy in until the source is exhausted, while the polite modem only uses enough energy to ensure no errors (or high quality of service).

Water-filling is typically approximated within various practical constraints by the DMT DSL modems that are used in most DSL services (see [9] for a discus-

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sion of how simple PSD constraints can be used with water-filling to implement "optimum spectrum management."). Polite water-filling modems transmit at no greater than some service-provider-specified maximum rate (usually the maximum rate the customer was offered or purchased). At this rate, good DSL modems then minimize the power they need to achieve this rate with some maximum margin, typically called MAXSNRM in DSL standards. In particular, polite-water-filling spectrum use also avoids or reduces noise/crosstalk in bands where crosstalk is damaging, more important yet than simple power reduction. When this is implemented correctly, "hogging" DSL lines that use too much power are eliminated, greatly reducing crosstalk. The DSM center recommends data rates and the MAXSNRM to the various DSL lines of the service provider. There is no coordination of the modems other than the usual service provider's specification of maximum data rates and maximum margin to be attempted by any given customer. The results can be simulated in a computer simulation by simply running the water-filling procedure for each line successively with all other spectra (and thus consequent crosstalk) viewed as noise. Repeatedly iterating this process imitates the actual binder action, allowing the "iterative water-filling" to project the performance of the system. Note this simulation is very different from the incorrect static-spectrum-management assumption that each line uses a fixed spectrum – the results are also often very different. (The assumption is incorrect because ADSL modems do not have fixed spectra.)

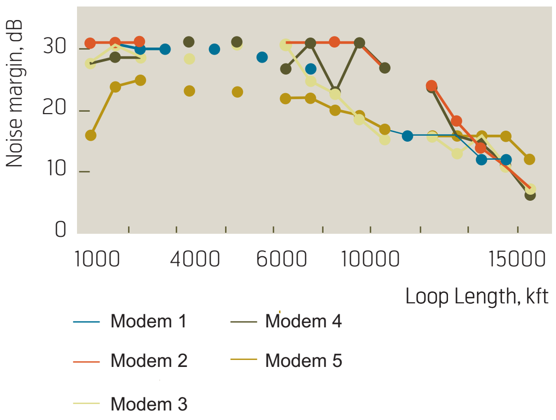

Figure 6 Margins for 1.536 Mb/s DSL

An unfortunate note:
Figure 6 illustrates the measured and reported margins for several different manufacturers' modems (the names have been removed and simply referred to as "modem1," "modem2," etc.). All the manufacturers here exceeded an already high 16 dB MAXSNRM required by the service provider by a significant amount to as much as 13,000 ft (at 1.536 Mb/s). The excessive margins are an artefact of early ADSL standards limiting the amount of power back-off that can be imposed by a receiving modem running water filling to 14.5 dB, which is clearly not enough in Figure 6. This high-margin problem can be repaired by DSLAM software releases that allow the DSM Center to specify the initial transmit spectrum/power level as a function of line history (so a line with 20 dB more margin than the maximum required would be trained on its next initialization at a power level 20 dB lower for example).

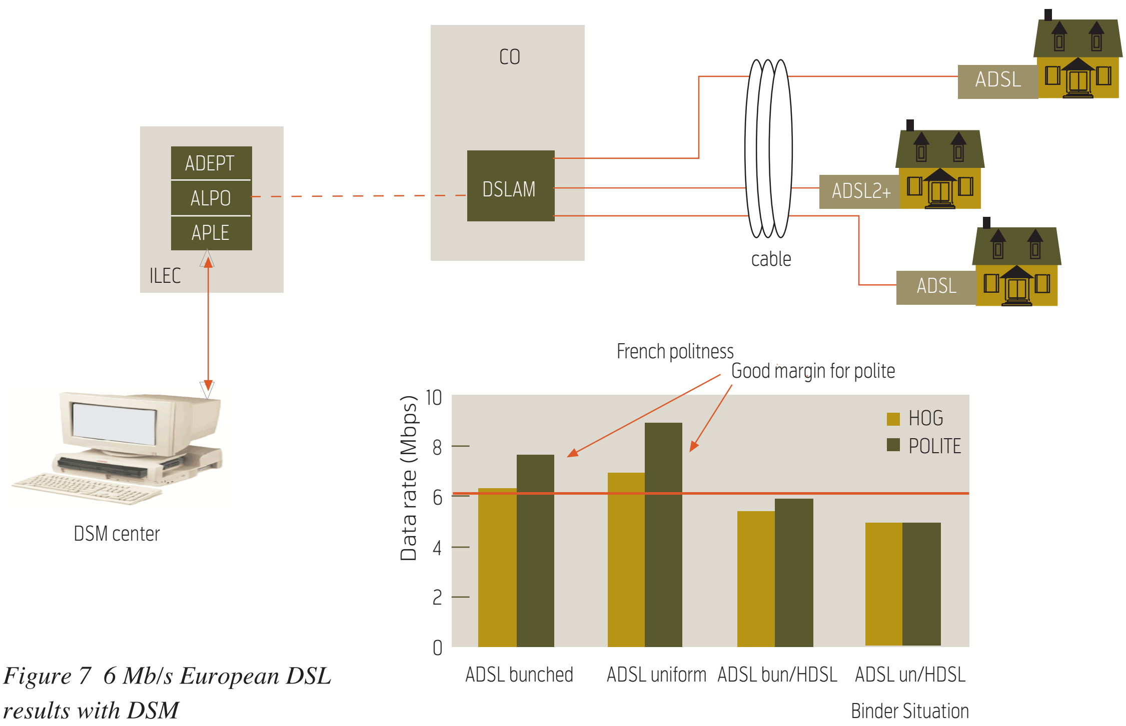

Figure 7 6 Mb/s European DSL results with DSM

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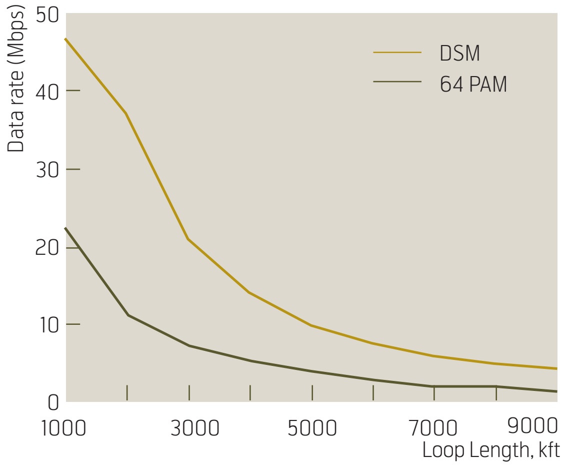

Figure 8 Symmetric rate limits of DSM without band preference

2.3 DSM for higher asymmetric speeds without RT mixture

Many service providers may not have RTs or mixtures of fiber-fed and central office loops in the same binder. Nonetheless, the simple "iterative water-filling" DSM procedure of Section 2.2 still leads to large improvements, especially at higher data rates because shorter lines do not excessively transmit power. Thus, the dominant impairment at higher speeds, crosstalk, is reduced substantially from "shorter lines." An example appears in Figure 7.

In this DSM simulation, a service provider desired 6 Mb/s at 3 km for video expansion of their DSL services. Static spectrum management with assumptions of fixed spectra and "hogging" DSL modems leads to the results on the left (ochre) in each pair of columns where 6 Mb/s is not achievable or just barely achievable. However, with simple limiting of MAXSNRM to 6 dB and aversion of HDSL in the same binder, the DSM results (on the right [brown] in each pair of columns) show plenty of extra data rate (or extra safety for ensuring the rate). The result is true whether the lines are "bunched" (all in the last 2.5 to 3 km) or "uniform" (uniformly distributed between 0 and 3 km). In particular, with HDSL in other binders and polite operation, the DSM situation shows 8 – 9 Mb/s, leaving some room for non-ideal effects. Operation without politeness clearly will not be possible.

2.4 Ultimate limits of balanced adaptive spectra

Figure 8 illustrates the ultimate limits of non-vectored uncoordinated transmission systems using iterative water-filling. In this figure, no spectral limits are placed on any DSL system downstream or upstream and each adapts for best symmetric transmission rate. All lines are the same length, which represents a worst-case situation (mixtures of shorter lines and longer lines allows the shorter lines to use less power, use higher frequencies, and thereby yet less crosstalk into the longest lines). The entire binder of 25 lines was active and 1 % worst-case crosstalk coupling between all pairs of lines was used.

Also shown in Figure 8 is a best-case fixed-spectra (PAM or "SHDSL-like") symmetric data rate. The range is doubled for both 10 Mb/s symmetric service and 5 Mb/s symmetric service by iterative water-filling (two bonded 5 Mb/s make one 10 Mb/s symmetric service). It can also be shown that this symmetric performance with iterative water-filling will not significantly reduce the data rate of any existing ADSL service if instead some of the lines in the binder were asymmetric instead of symmetric. However, the fixed spectra SHDSL-like choice essentially annihilates ADSL performance if in the same binder.

2.5 Band preference

Band preference in water-filling can essentially achieve optimum (largest) rate regions (such as in [8], [9]). In band preference, the DSM Center is presumed to know all the crosstalking paths and line lengths (while in Subsections 2.1–2.4, just worst-case assumptions were made and no line knew the length of any other and adapted only locally). This central knowledge is called "Level Two" coordination in the DSM standard [1]. In this case a coordinated allocation of energy can be determined by jointly optimizing all spectra used at the DSM Center. Such best spectra can be imposed by setting PSDMASK parameters (for instance see ADSL2 standards G.992.3 [10] or G.992.5 [11] – so-called "spectrum toolbox" or tssi parameters) for each line on a basis of the DSM Center predictions of binder performance. Such "band preference" can force a short line to use higher frequencies even though lower frequencies would have been better in iterative water-filling with no spectral masks imposed. Figure 9 illustrates an upstream VDSL rate region increase from the use of band preference for two lines of lengths 600 meters and 900 meters in upstream VDSL for "998-Plan" [13] iterative water-filling with noise A ([13]) and for water-filling using band preference with PSDMASK levels of –72 dBm/Hz below 5 MHz and –55 dBm/Hz above 5 MHz on the 600 meter line, and –50 dBm/Hz on the 900 meter line. The data rate on the shorter line is dramatically improved with band preference.

To the extent that Noise A is based on static ADSL models, Figure 9 represents worst-case performance because the ADSLs then are not modelled correctly (they water-fill also, so model "A" noise in standards is grossly incorrect, but used anyway here). Note that 6 Mb/s on the 900 m loop upstream can be achieved while nearly 20 Mb/s upstream occurs on the 600 m loop. These rates are considerably higher than what would be achieved if fixed spectra were used on the VDSL lines and more than double what is achievable with fixed spectra today.

Figure 10 illustrates that band preference provides most of its gain when mutually crosstalking loops have very different lengths. As the lengths approach the same, no band preference is necessary and all iterative water-filling loops can use the same PSD mask levels. A single 900 m or longer loop was held at 10 Mb/s (80 % of its maximum rate when no other loop is present) while a single other loop was varied in length between 600 m and 900 m. The vertical axis plots the fraction of the maximum short-loop rate that is achieved with and without band preference.

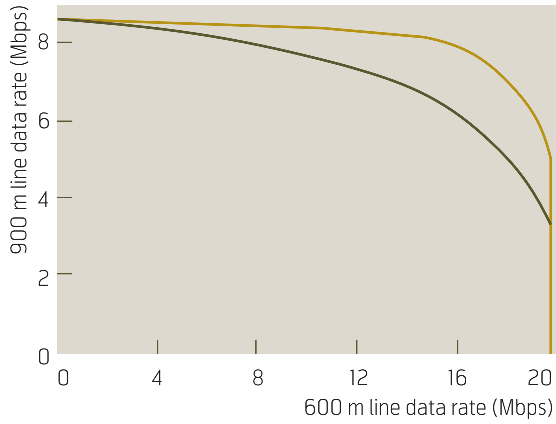

Figure 9 Upstream VDSL rate region for band preference (upper curve has band preference, lower has not) – four VDSL lines at 600 m and four VDSL lines at 900 m

2.6 Intermittent and impulse noise

Impulse noise is by its very nature not well characterized in DSL. A better term would be "intermittent noise" because customer premises (and sometimes other locations) noise can last much longer than 1 ms and can be repetitive and frequency selective. When it occurs in many cases, even interleaved operation of a DSL modem is insufficient to prevent severe erroneous seconds. Not all lines are "chronic" as such and have this problem. In fact, only a small percentage may be so adversely affected – but those lines can dominate operations costs through truck rolls to rewire the customer's premises. Increase of transmit power is of very little benefit for this type of noise. Proprietary "impulse-skewed-loading" assumes some consistency to noises that just may not often be valid.

The practical solution is forward error correction with sufficiently high percentage of parity to eliminate the errors on a line. Interleaving will not help remove the effect of an intermittent noise that is continuing to occur several times within an interleave depth. One might define a chronic line as

> **Chronic line**: *A line for which even interleaved forward-error correction is not sufficient to produce very low or zero errors.*

In ADSL and VDSL, Reed-Solomon (RS) codes are used and are characterized by N bytes in a codeword, of which P are parity bytes, and the remaining $K = N - P$ carry all other information. In an RS code, $t = P$ bytes in error can be corrected if erasures are used, which is common with DSL systems and intermittent noise. If no erasures are used, then $t = P / 2$ erroneous bytes can be corrected.

> **Correct-Chronic-Line Simple Rule**: *If the fraction of erroneous seconds (or time intervals) is denoted f_{errors}, then the selection of $t / N > f_{errors}$ will correct the errors and the line will no longer be chronic.*

The above rule essentially presumes any interleaving uniformly distributes errors, so is somewhat of a best case, but could be applied in an ADSL system. Usually $P = 16$ is the maximum value in DSL, so the fraction t / N is increased by decreasing N. The codeword length N is supposed to be programmable in ADSL standards, but it is not a parameter included in present management interfaces to the telco. It should be. Only the telco can make reliable assessment of the correct N value by evaluation of error performance and customer-service need. Decrease of N reduces the data rate on the line. However, chronic lines have poor or no data rate because of all the bit errors, so reduction in data rate using a lower N value that increases the effective throughput is an improvement.

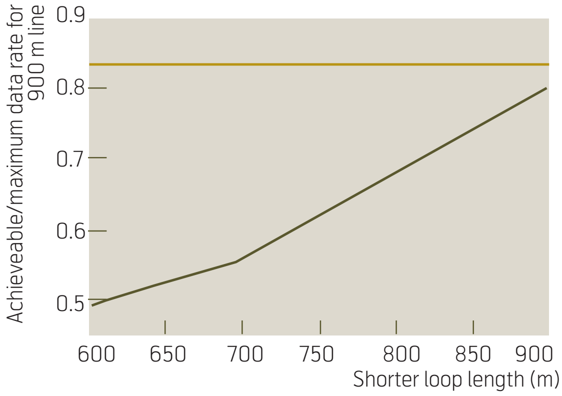

Figure 10 Band preference (upper curve) versus no preference when the shorter loop length is varied

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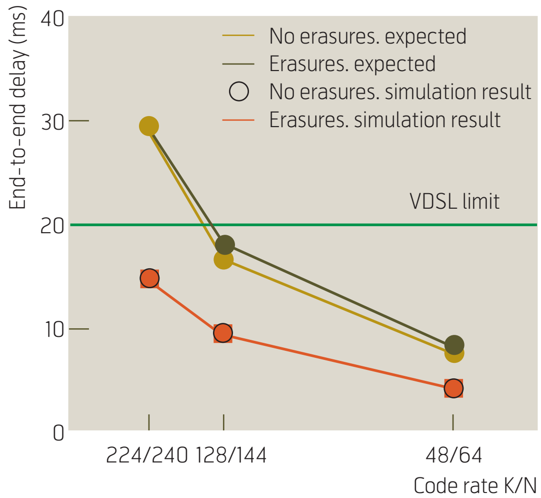

Figure 11 Delay versus code parameters ($K = N - P$) for FT "impulses"

ADSL1 [12] and VDSL1 [13] standards allow N to be set by the ATU-C. Thus, motivated DSLAM (or RT) manufacturers who want their customers to have better ability to correct intermittent noise will add the ability to change the default DSLAM N value on chronic lines (note the default N is often very good for lines without impulse problems or lines for which the current interleaving is sufficient to eliminate impulse errors, but not for chronic lines).

ADSL2 [10], [11] standards instead allow the ATU-R to select the N parameter according to two supplied parameters: Impulse "length" (INP) and maximum interleaving delay (DELAYMAX). The impulse length in ms is computed by (INP/4) ms. The DELAYMAX is given in ms and must be at least 4 ms. Unfortunately, current versions of the standards (which need an FEC amendment) only allow an impulse "length" of up to 2 DMT symbols (or 500 microseconds). A loading-algorithm engineer could use the following formulas to convert the supplied maximum delay and now renamed "impulse strength indication INP" into the usual FEC parameters (where $t = P$, the number of parity bytes chosen by the receiver if erasures are used, and $t = P / 2$ if no erasures are used and rate includes information and synch/control bits)

$$D' = depth\ in\ bytes = \frac{(INP/4) \times \left(\frac{rate\ in\ kbps}{8}\right)}{t} \quad (1)$$

$$N = \frac{(DELAYMAX) \times \left(\frac{rate\ in\ kbps}{8}\right)}{(D' - 1)} + 1 \approx \frac{DELAYMAX}{burst\ length} \cdot t \quad (2)$$

where burst length (INP / 4) and DELAYMAX again are in ms. Then the remaining G.992.3/5 [10], [11] DMT/framing parameters (M, T, L, see [yy]) can be computed and S (number of symbols/codeword) inferred for all latency paths as well as the values of B (the rate) for each frame bearer and latency path. Also once N is known, then $D = ND'$, the interleave depth in codewords. For current largest value of $INP = 2$ and smallest value of $DELAYMAX = 4$, one finds that $N \geq 8 \cdot t$, which with strong error correction so $t = 16$ leads to a smallest blocklength of $N = 128$, much larger than would occur on chornic lines according to (2).

An unused bit in the NPAR(3) of G.994.1 [14] used to convey INP will now allow an increase in INP to 4, 8, and 16 in the addendum to the ITU ADSL2 and ADSL2+ standards about to be released in 2004. With such values at lower data rates, all practical values of N could be attained, thus allowing ADSL2 to have almost as good error protection on chronic lines as ADSL1 where the DSLAM controls instead directly the N value. While maintaining the specified (DELAYMAX/burstlength) ratio, the ATU-R in ADSL2 should not pick a small t parameter just to decrease N. Such a poor strategy would increase the depth but not assist the chronic line – the choices should be made to obey the chronic line rule, which forces a larger value of t. Even approximate adherence to the above mathematical rules should assist on chronic lines. Service providers with DSM capability may well train the modem several times, each time increasing the INP value in ADSL2 until zero (or decreasing the N value in ADSL1 while holding t or parity constant) until small numbers of code violations and/or errored seconds are observed over a time period determined by the service provider.

An example of the delay necessary to eliminate all impulses measured (about 33,000) in France Telecom's network appears in Figure 11. Even in this study, many of the most severe impulses (those persisting much longer than 1 ms in intermittent patterns) could not be recorded, but the trend in the graph to the right as P / N increases would also be such that eventually as long as a few bits make it through the channel, the line can function (albeit at a lower data rate). Figures 12(a) and 12(b) illustrate a severe chronic American customer in service (with complaints to provider).

This chronic customer sees about 34,000 code violations in a 15-minute interval, about 60 % of the bytes are in error. Thus, with erasures then a code with $N = 24$ and $P = 16$ would correct all errors. This line otherwise has a maximum attainable rate in excess of 5 Mb/s and would function at 1.5 Mb/s with such

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error correction with no customer complaint at this maximum rate for which the customer paid. Figure 13 illustrates the concept of the DSM Center in this case, monitoring perhaps over a significant period of time (could be days or weeks) for code violations and then training the customer at an appropriate level. If the customer later desired a 5 Mb/s service, then the telco would know before provisioning that service that customer-premises wiring needs replacement (or a splitter perhaps located at the entry point) to reduce or eliminate the problem. The service provider might so notify the customer and advise of a charge covering the 5 Mb/s-upgrade service visit.

Both the ADSL1 and ADSL2 methods can be executed with a MAXSNRM also implied as in Subsections 2.1–2.5. The power used for a lower *N* will be higher, but still the minimum necessary to guard against stationary and crosstalk noise.

3 Signal alignment and DSM vectoring

Figure 14 illustrates the concept of a vectored DSLAM. All lines emanating from an LT are coordinated so that transmitted downstream signals are aligned or co-generated. Similarly received upstream signals are synchronized and aligned also. Such systems can eliminate ALL upstream NEXT and FEXT theoretically (even if the NEXT comes from signals that are not coordinated). Such systems can also eliminate all downstream FEXT (but not NEXT). Upstream NEXT is cancelled on each tone by subtracting constructed crosstalk of other users.

FEXT is eliminated in both directions via triangularization of the matrix binder response, followed by a successive cancellation on each tone of the effects of previously decoded (or previously precoded downstream) signals on other users on that same tone. These

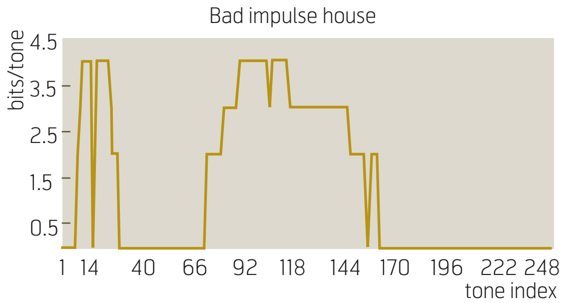

Figure 12(a) Bit distribution for American DSL customer with intermittent noise

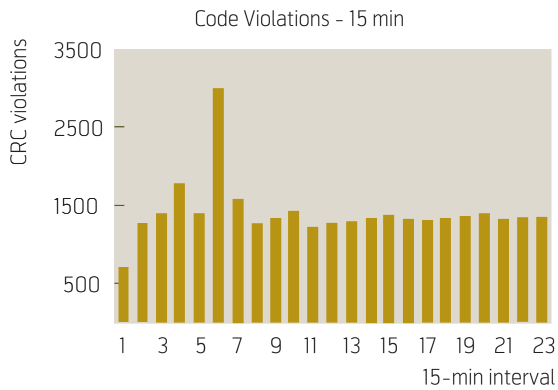

Figure 12(b) Code violations (with 24 ms interleave enabled) for same customer as in Figure 12(a)

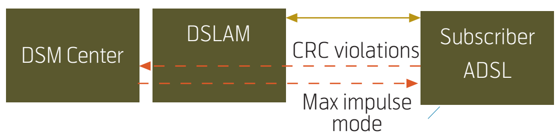

Figure 13 DSM Center with impulse/code adjustments

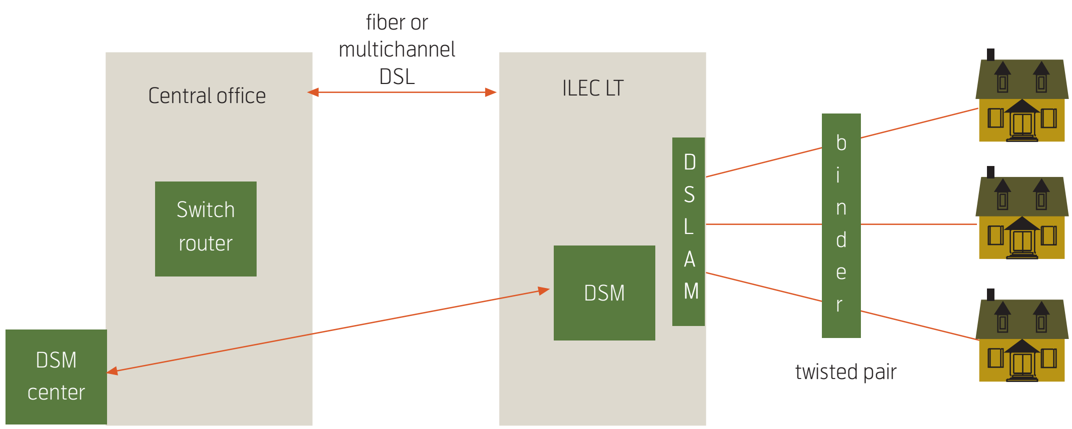

Figure 14 Basic signal alignment with vectored DSLAM

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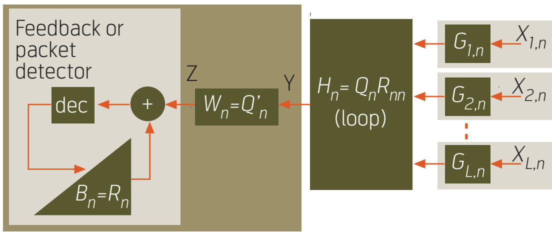

Figure 15 Upstream vectored-receiver coordination

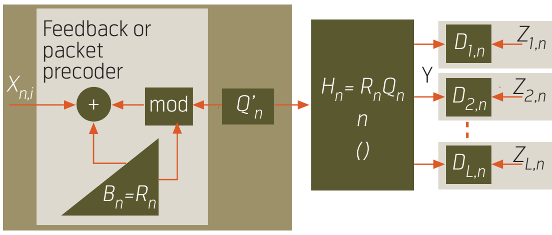

Figure 16 Downstream vectored-transmitter coordination

results are independent of the frequency band planning that is used. Allocating more downstream frequencies favors downstream rates, but does not change the elimination of crosstalk fundamentals of FEXT and NEXT upstream and only FEXT downstream.

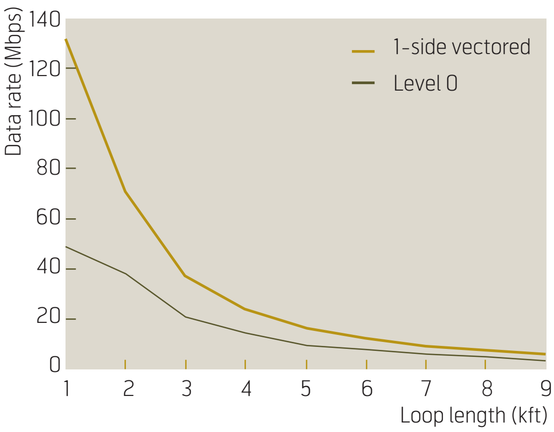

Figure 17(a) Signal Alignment, lengths to 9000 feet

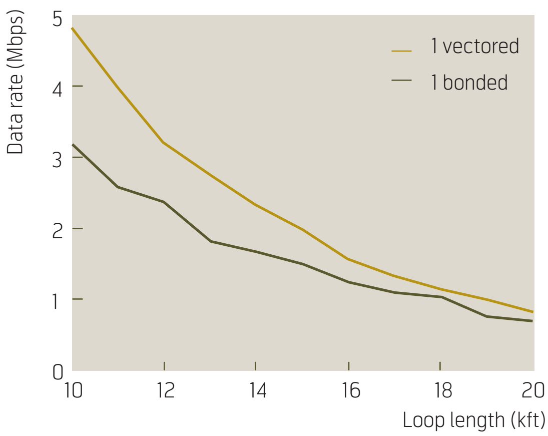

Figure 17(b) Signal Alignment, lengths 9–20 kft

3.1 Bonding versus vectoring

Bonding is a link-layer (TPS-PMS) multiplexing and de-multiplexing of data rates on several lines used to service a single DSL customer. Vectoring is the co-generation of physical-layer (PMD) transmitted signals, co-processing of physical-layer received signals, or both. Bonded lines may optionally also be vectored for the receivers on both sides (in which case NEXT and FEXT both can be eliminated if all the lines in a binder are coordinated and bonded, so there is then no crosstalk of any type upstream or downstream). More realistically, when only a few lines (say 2 or 4) are bonded, there is no advantage in terms of data rate per line with respect to just vectoring and no bonding. Bonding increases the speed of a service by using more lines. Vectoring instead increases the speed of a DSL service by better coordinated signal processing. Either can be used without the other or together.

3.2 Vectored signal processing structures for DSM

Figures 15 and 16 illustrate the basic processing structures for upstream and downstream (DMT-based) DSL systems with presumed digital duplexing on all lines [13] and all such lines using the same DMT symbol phase. For upstream, signals are co-received. Any locally generated downstream signals can be removed through crosstalk cancellation, which is essentially a multi-dimensional echo canceller, and is not shown. On each tone the remaining structure in Figure 15 first conditions the signal to a triangular interference structure through a matrix filter. One of the users will have no crosstalk whatsoever on each tone and is decoded first. Then that user's influence on the next user is constructed and removed from all subsequent user's decoding, one by one, in a successive process independently of each DMT tone. The matrix filter and triangular feed-back structure depend on knowledge of the exact binder crosstalk matrix and noise autocorrelation matrix. The matrix filter also rejects all NEXT from uncoordinated crosstalk signals.

Figure 16 illustrates the dual downstream (per tone) transmit structure that uses a matrix triangular precoder, followed by a matrix pre-filter to co-generate all signals.

3.3 Ultimate limits of signal alignment DSM

Figures 17(a) and 17(b) illustrate the increase in data rates over those of Subsection 2.4 and Figure 8 over iterative water-filling alone. Note that 100 Mb/s symmetric speeds (thus 200 Mb/s asymmetric) is possible at 1500' or 500 m while 10 Mb/s symmetric is possible to 7000' or 2 km. 100 Mb/s on two lines is about 900 m in range.

3.4 Finding MIMO (binder identification)

The identification of the crosstalk transfer functions between lines, both gain and phase, is necessary for vectored transmission. This is an extension of the insertion loss gain/phase presently reported by ADSL2 and ADSL2+ modems to inter-wire transfer functions. There are several sophisticated methods for identifying such crosstalk coupling, and only the simplest is described here for two cases: (1) synchronized start and (2) unsynchronized start.

Synchronized start:

Synchronization of the lines upon start-up means that they all train at the same time. This is feasible with bonded lines and in certain situations with no bonding also. Figure 18 illustrates the basic concept, which is that each line transmits independently (or a variant is all transmit at the same time, but with clearly distinct robust, i.e. "white" training sequences) at one time only during training a sequence that is used not only to determine insertion loss gain/phase on that line, but also to determine the FEXT transfer function from/to (upstream/downstream) all other lines in the binder. All XTU-R modems know the time slot of their line as well as all other lines through the single-sided coordination at the line terminal (or fiber-fed DSLAM). The learned transfer functions are combined into a matrix of transfer functions. QR factorization (see Figures 15 and 16, which is a factorization of the binder matrix transfer function at each tone into the product of an orthogonal matrix Q and a triangular matrix R) is then executed upon the resulting matrix to obtain the settings for the matrix filters and triangular processing of Figures 15 and 16. With digital duplexing on all lines to the same symbol clock, this process is independent for each tone of a DMT system. An overall bit/data assignment for all users (picking an acceptable point in the vectored rate region) can then be made. The learned downstream transfer functions must be reported back to the coordinated side via a reverse or secure channel (in much the same way that ADSL2 returns the insertion loss HLIN[n]).

For systems with overlapping spectra, the NEXT transfer functions can be simultaneously learned for downstream into upstream (and for upstream into downstream where desired) at the same time. Thus, only one transmitter is active at each time (or orthogonal to signals sent by all other transmitters).

Asynchronous training:

Asynchronous systems will be slaved to the same master symbol clock with digital duplexing on all lines in the same line terminal as with all vectoring systems. However, the individual customers may train at different times (representing time of energy excitation, offering of service, retraining for any reason, etc.). In this case upstream, a modem beginning its own training needs to energize at a low but detectable energy level. The upstream co-reception process will detect the new user and subtract all other users' signals (since they are in operation and detectable – a line for which signals are not detectable most of the time would retrain anyway, see synchronous training). In this case, the new row of the channel matrix would be determined (again independently for each tone) with the on-line transfer and all the FEXT coupling then known and used in subsequent calculation. For downstream asynchronous start, for full performance gain, all remotes have to be capable of either (1) determining downstream FEXT from a new subscriber themselves or (2) collecting packets of channel outputs periodically or on command that are returned to the central processor. This is called "Level 3" coordination in the DSM standard and preferred (so that client modems are otherwise not unduly pressed in terms of processing capability).

3.5 Phantom of the DSL

Figure 19 illustrates the basic concept of a phantom signal for two twisted pairs (the use of the term "phantom" is somewhat misguided as the signal is very real and exists – indeed the phantom is what creates what we normally call crosstalk, which exists). For quad situations, the phantom component can be high. Typically, the phantom is defined between

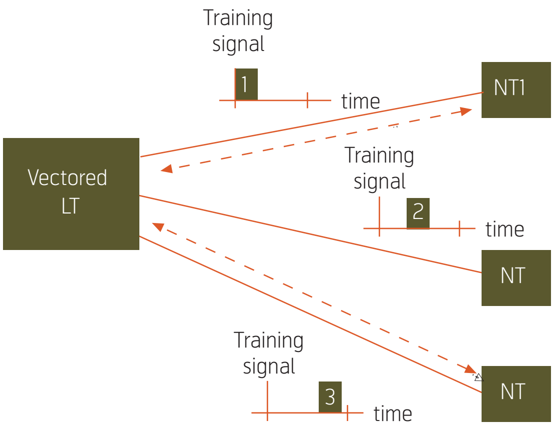

Figure 18 Synchronous training illustration

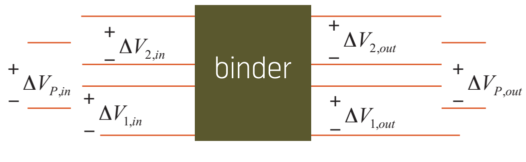

Figure 19 Illustration of phantoms (see [1])

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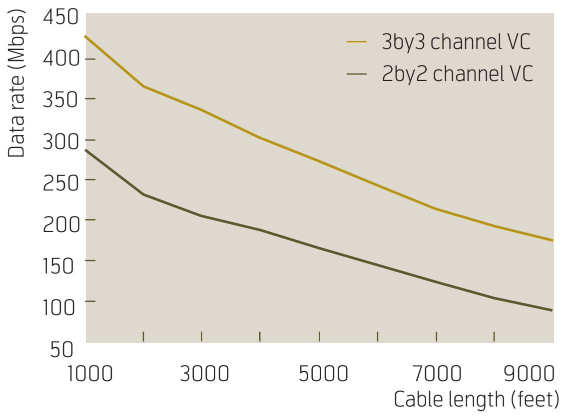

Figure 20 Illustration of quad capacity (2 loops or used with phantoms so 3 loops)

hypotentical "center tap voltages" of the two pairs, denoted ΔV_p in Figure 19. In reality, there are four conductors that create three closed loops, not two, if appropriately terminated and excited as a group. The third or extra loop can have very real and significant data-carrying capacity. It can thus be exploited in bonded and vectored schemes. The gain can be more than 50 % or less depending on loop geometries, imperfections, and coupling. Bonding lines with significant coupling may indeed be physically and practically difficult, except for the case of so-called "quads" where the four wires of a single quad twisted as an ensemble (so a twisted quad) may in many cases be maintained to a customer. The concept of a quad generalizes to any number of conductors but would then require yet further bonded and vectored use of multiple pairs. In reality, this is a random possibility for transmission that is very real (i.e. not a phantom) but would not be reliable unless pairs were selected carefully for customers. The data rates for vectored quads (based on French cable) are shown in Figure 20.

Such auto-selection and routing of pairs in a cable in a distribution frame and at customer premises may be possible in multiple-dwelling units or elsewhere and likely represents the last known physical capacity in the copper loop plant that can be exploited to squeeze the very last highest rates from copper. It would be highly adaptive and capacity would need to be assessed by a DSM center on a binder-to-binder basis for the various customers. Given the high costs of fiber in the very last segments of the network, this last frontier of bandwidth in phantoms may need to be someday exploited. Fortunately, DSM offers significant bandwidth increase of very large factor even without exploitation of this last opportunity.

3.6 Data-dependent DSM

The exploitation of silent intervals that abound in data transmission (and even in video when video is off) create a very interesting possibility for DSM that has not yet been exploited in a centrally coordinated manner. The use of vectoring allows several opportunities for such systems. Silent signals on other lines reduce crosstalk for the period of silence, meaning another victim line could increase its rate during that time frame. Futhermore, a vector transmitter could actually exploit crosstalk from other lines to reinforce a signal when its nominal signal is silent, allowing a statistical boost in data rate over the theoretical level of "no FEXT and no NEXT" so actually not only is noise low, but signal received is higher also. The shortest lines in a binder would benefit most when longer lines are silent and can temporarily boost the short-line's rate.

4 Conclusion

Dynamic Spectrum Management through automated intelligent control of basic DSL line parameters can significantly reduce operations costs for DSL service providers. Simultaneously, data rates can be substantially increased, readily to 100 Mb/s symmetric services on no more than two lines to 1 km range and beyond. The ultimate limits of DSM may require new chips and vectored equipment, but a great deal of improvement is possible with existing systems through the use of basic MIB parameters and procedures already inherent in existing DSL systems like ADSL.

DSL methods through the use of DSM can resurrect a viable broadband strategy with good operational cost and excellent service providers, enabling a real worldwide and sustainable broadband revolution. No other solution has such realistic promise. These higher speeds will establish a continuing improved business case for wider bandwidth telephone company networks via the higher speed lower-cost copper connection to the customer.

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John M. Cioffi – BSEE, 1978, Illinois; PhDEE, 1984, Stanford; Bell Laboratories, 1978–1984; IBM Research, 1984–1986; EE Prof., Stanford, 1986–present. Cioffi founded Amati Com. Corp in 1991 (purchased by TI in 1997) and was officer/director from 1991 to 1997. He is currently on the Board of Directors of Marvell, Teknovus, ASSIA (Chair), Teranetics, and ClariPhy. He is on the advisory board of Portview Ventures and Wavion. Cioffi's specific interests are in the area of high-performance digital transmission. Various Awards: Holder of Hitachi America Professorship in Electrical Engineering at Stanford (2002); Member, National Academy of Engineering (2001); IEEE Kobayashi Medal (2001); IEEE Millennium Medal (2000); IEEE Fellow (1996); IEE JJ Tomson Medal (2000); 1999 U. of Illinois Outstanding Alumnus, 1991 IEEE Comm. Mag. best paper; 1995 ANSI T1 Outstanding Achievement Award; NSF Presidential Investigator (1987–1992), ISSLS 2004 Outstanding Paper award. Cioffi has published over 250 papers and holds over 40 patents.

email: Cioffi@stanford.edu

Mehdi Mohseni received the BS degree in electrical engineering from Sharif University of Technology, Tehran, Iran, in 2001 and the MS degree in electrical engineering from Stanford University, California, in 2003. Since 2003 he is working towards a PhD degree at Stanford University. His research interests include multi-user information theory, wireless and broadband communications.

email: mmohseni@stanford.edu

 ISSN 0085-7130 © Telenor ASA 2004

Models for forecasting cost evolution of components and technologies

BORGAR T. OLSEN AND KJELL STORDAHL

Learning curves are used in the industry to predict reduction in production time or production cost as a function of produced volume. The causes of cost reductions are better control of the production process, new production methods, new technology, redesign of the product, standardization and automatisation.

Borgar T Olsen is Senior Researcher at Telenor R&D

Kjell Stordahl is Senior Advisor in Telenor Networks

Wright and Crawford first developed the learning curve model for aircraft production [1, 2, 3]. This model is a simple exponential function where the decrease of production time is a function of number of produced units.

This paper describes an extension of the learning curve model [4, 5, 6]. The motivation for this extension was the need to model the cost evolution of new telecommunication network elements in business case studies. To be able to use the cost prediction model in economic calculations, it is important to forecast the cost evolution as a function of time, not as a function of produced units. The model is a combination of the learning curve model and a diffusion model which models the life cycle of the component.

Within the European research programs, the projects RACE 2087/TITAN, AC 226/OPTIMUM, AC364/TERA and IST-2000-25172 TONIC have worked out a methodology and a tool for calculating the overall financial budget of any telecommunication service and network project. The tool handles the discount system costs, operations, maintenance costs, demand forecasts, tariffs etc. The output of the tool is the life cycle costs, expected net present value (NPV) and internal rate of return (IRR). An important part of the tool includes the extended learning curves and cost prediction of network components.

The tool has been used to evaluate the life cycle costs of the different *telecommunications network technologies* with different maturity, and the results are fed back into more general forecast models (based on existing infrastructure, competition level etc.) of the market share of the technologies. In that sense the elasticity of technology volumes and cost levels are derived. In addition the tool is used for telecommunications network profitability studies, risk analysis and business scenario evaluations within many telecommunication companies and in several international research projects [7–15].

1 Background

In the European program RACE, project 2087/TITAN identified the need for modeling cost of network components and infrastructure deployment as a function of time [4, 5, 6]. One of the project objectives was to develop a methodology and tool for doing strategic business case studies. In studying future strategic telecom projects new and older cost components with a different degree of maturity have to be considered. It was decided that every cost component should be characterized with its own cost evolution. To be able to do this with a large number of cost elements, a model was developed and implemented in the tool. The model combines the learning curve and the logistic function into a closed form with a set of parameters, which have a clear meaning. This model is called the extended learning curve model and includes parameters representing:

- Cost of the product in the reference year;
- Relative accumulated production volume sold at the reference year;
- Main part of the life cycle time to the product;
- Cost decrease when the production volume is doubled (Learning curve coefficient).

In addition a fifth parameter can be used, which describes the asymmetry of the diffusion growth of the product.

2 Wright and Crawford learning curve models

The Wright-Crawford model is a simple exponential function where the decrease of production time is a function of number of produced units. The initial value of the function is the production time of the first unit. The parameter in the model is the learning curve coefficient K, which denotes the reduction in production time when the production volume is doubled. By assuming that the cost of production is proportional to the production time, the learning curve model describes the cost decrease per produced unit

ISSN 0085-7130

as a function of production volume. In the literature the learning curve is also used for describing individual learning. In an industrial process such individual learning is not the primary cause for cost reduction but a combination of several factors such as:

- More effective labor force
- Better control of the production process
- More effective organization
- Introduction of new production methods
- New technology
- Redesign of the product
- Standardization
- Automatization

Many of these factors are dependent on each other and are therefore not easily separable. For example, the development of software to support production of a product can be composed of better control of the production process, introduction of new production method and standardization of the production process.

T.P. Wright first proposed the concept of learning curves in 1936 to describe the production time of aircraft [1]:

$$T_n = n^{-\alpha} \cdot T_0 \qquad (2.1)$$

where T_n is the average production time for n units, given by

$$T_n = \frac{t_1 + t_2 + \ldots + t_n}{n} \qquad (2.2)$$

where t_n is the time to complete the n^{th} unit, T_0 the time to complete the first unit and n is the number of completed units.

J.R. Crawford applied the same formula, but interpreted T_n as the completion time for the n^{th} unit [2]. Wright's law describes the cumulative effect of learning, while Crawford's formula only refers to scale effects. A disadvantage of Wright's law is the appearance of strong autocorrelation, affecting the statistical estimation of its parameters, a problem that always arises when trying to correlate accumulated values.

In the literature many extensions and modifications of the Wright-Crawford's law has been proposed [3] but for our purpose the simple expression is used as a basis for deriving cost as a function of time. In principle we interpret P_n as the cost of the n^{th} component sold in the market of a specified component with a given functionality (e.g. GSM mobile phones), or a component from a specified product generation or series.

Suppose that component cost (price) P_n is somehow proportional with production time T_n for the n^{th} component, then we have from (2.1):

$$P_n = n^{-\alpha} \cdot P_0 \qquad (2.3)$$

Where
- P_n is the cost of production of the n^{th} component;
- P_0 is the cost of production of the very first component;
- n is the total number of produced units (possibly in a production series);
- α is a parameter in the model.

If the production volume is doubled, then:

$$P_{2n} = (2n)^{-\alpha} \cdot P_0 \qquad (2.4)$$

The relation between P_n and P_{2n} is given by:

$$P_{2n} = K \cdot P_n \qquad (2.5)$$

K is the factor by which the price is reduced when the production volume is doubled. K is called the learning curve coefficient and is related to α by

$$K = (2)^{-\alpha} \qquad (2.6)$$

or

$$\alpha = -\log_2 \cdot K \qquad (2.7)$$

The learning curve coefficient is a number less than 1. It is usually expressed in percentage and typical values are between 70 % and 95 %. The value depends highly on which product group we are taking about, the lower the value the steeper the learning curve. In Figure 2.1 the learning curve with K set to 80 % or α set to 0.32 is shown.

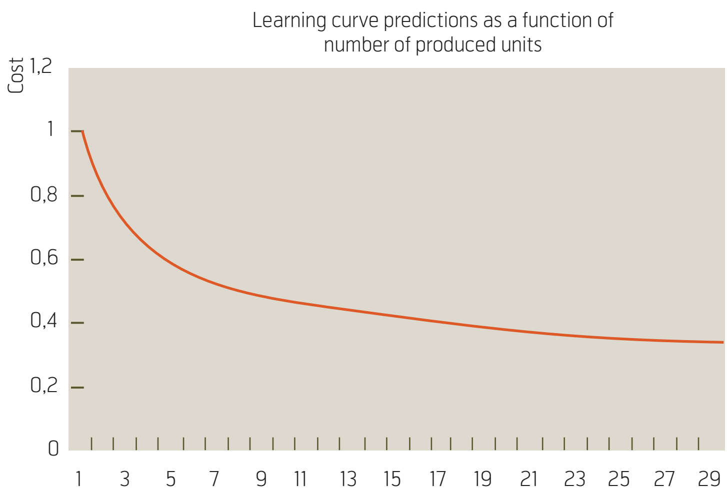

Figure 2.1 Wright-Crawford learning curve model

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3 The Logistic model and component cost as a function of time

We know that the production volume n and the production cost per unit P_n is a function of time. Thus the learning curve can be written as:

$$P(t) = n(t)^{-\alpha} \cdot P_0 \quad (3.1)$$

where $n(t)$ is the global volume (for the world production of a component) and P_0 is the cost of the very first component.

The description of the growth over time of the accumulated volume of a cost component can be modeled in many ways. In the situation where very little is known, because the component is new or not even introduced to the market, a standard demand Logistic curve with four parameters is chosen. This curve has the needed generality for most types of growth processes and has a sound theoretical basis. The Logistic model chosen is defined by:

$$n(t) = M[1 + e^{(c+d\cdot t)}]^{-\gamma} \quad (3.2)$$

where

- M is the total market potential
- c, d and γ are parameters
- t is time

The model predicts the yearly-accumulated production volume. If the production volume for several years is known, it is possible to estimate the parameters M, c, d and γ. An iterative estimation procedure where OLS (ordinary least squares regression) is one part of the method can be used for estimating the parameters [17].

However, in new network architectures there are a lot of rather new or completely new network components. Then there is no time series of the yearly production volume. In that case we need another procedure for estimating the parameters. Such a procedure is described in the next chapters.

4 Introduction of relative production volume and growth period as substitution for general parameters in the Logistic curve

Formulas 3.1 and 3.2 contain both the total market size M and the production cost of the first unit P_0. Both of those inputs are sometimes difficult to obtain.

Dividing the learning curve cost in eq. 3.1 by the value at the reference year, M and P_0 disappear and $P(0)$ means the cost in reference year 0. The subscript r indicates that we now have introduced normalized logistic functions (Annex 1) where *$n_r(0)$ is defined as the relative accumulated volumes sold at the reference year*.

$$\frac{P(t)}{P(0)} = \left[\frac{n_r(t)}{n_r(0)}\right]^{-\alpha} \quad (4.1)$$

This formula with the derived expression for α from (2.7) inserted can now be written:

$$P(t) = P(0) \cdot [n_r(0)^{-1} \cdot n_r(t)]^{\log_2 \cdot K} \quad (4.2)$$

Now we have the three parameters $P(0)$, $n_r(0)$ and K. The normalized logistic formula with γ set to 1 is now:

$$n_r(t) = \left[1 + e^{(c+d\cdot t)}\right]^{-1} \quad (4.3)$$

Instead of using the parameters c and d in the Logistic model only the *growth period* ΔT has to be introduced in addition to the *relative accumulated production volume* $n_r(0)$ sold at the reference year as already defined. It is easier to understand and also easier to have an opinion about the size of these parameters than the parameters c and d.

By setting the t equal to 0 in eq. 4.3 and rearranging the expression, c is expressed by $n_r(0)$.

$$c = \ln[n_r(0)^{-1} - 1] \quad (4.4)$$

The growth period, ΔT, is now defined as the time from the component reaches 10 % of the total production volume until it reaches 90 %. Then, the following expression for d can be derived:

$$n_r(t_1) = 0.1 \quad (4.5)$$

$$n_r(t_2) = 0.9 \quad (4.6)$$

By definition

$$\Delta T = t_2 - t_1 \quad (4.7)$$

which after some manipulation (Annex 2) gives:

$$\Delta T = \frac{-2 \cdot \ln 9}{d} \quad (4.8)$$

$$d = \frac{-2 \cdot \ln 9}{\Delta T} \quad (4.9)$$

Inserting c and d in the normalised diffusion curve we get the following formula:

$$n_r(t) = \left(1 + e^{\left\{\ln\left[n_r(0)^{-1} - 1\right] - \left[\frac{2\cdot \ln 9}{\Delta T}\right]\cdot t\right\}}\right)^{-1} \quad (4.10)$$

It is clear from Figure 4.1 that the meaning of ΔT and $n_r(0)$ are very intuitive and much easier to work with than the abstract parameters *c* and *d*.

5 Life cycle for different products

The growth period ΔT of equipment or products depends of course on the technical development in the different industrial areas. Especially for consumer electronics like mobile phones the lifetime has become shorter and shorter over the last years. If the diffusion curve (S-curve) is used to describe the accumulated growth of a specific series of equipment, say the ZyXEL Prestige 600 series of ADSL modems or the Nokia 7110 Model of mobile handsets, the growth period ΔT of the models is short (1–5 years) due to new models introduced to the market with new capacities and functionality. If the formula is used to describe the accumulated growth of all units in all series of the product, like fixed telephones, the life time would be much longer, as illustrated in Figures 5.1 and Figure 5.2. For example, the growth period of Television in Canada was about 10 years. In general, due to the better production process, the life cycle of the different electronic products has decreased significantly during the last two decades.

In Figure 5.2 we can observe ΔT of more than 20 years for growth of several goods in Finland (all devices and all production series).

6 The extended learning curve

The expression for $n_r(t)$ in (4.10) is now to be substituted into the learning curve formula (4.2) yielding the final expression for cost versus time in closed form (Annex 2). The expression is called *The extended learning curve model.*

$$P(t) = P(0) \cdot$$

$$\left[n_r(0)^{-1} \cdot \left(1 + e^{\{\ln[n_r(0)^{-1} - 1] - [\frac{2 \cdot \ln 9}{\Delta T}] \cdot t\}} \right)^{-1} \right]^{log_2 \cdot K} \quad (6.1)$$

The parameters in the extended learning curve model are defined by:

- $P(0)$ the production cost in the reference year 0,
- $n_r(0)$ the relative accumulated volume in year 0,
- ΔT the time for the accumulated volume to grow from 10 % to 90 %
- K the learning curve coefficient
- 0 is the reference year.

In order to illustrate this relation, and to get a normalised component cost, we put $P(0) = 1$ and $K = 0.90$. By keeping $n_r(0) = 0.001$ constant and letting the parameter ΔT range from 2 to 20 years, we can illustrate the evolution of the normalised cost versus time for different ΔT, as shown in Figure 6.1.

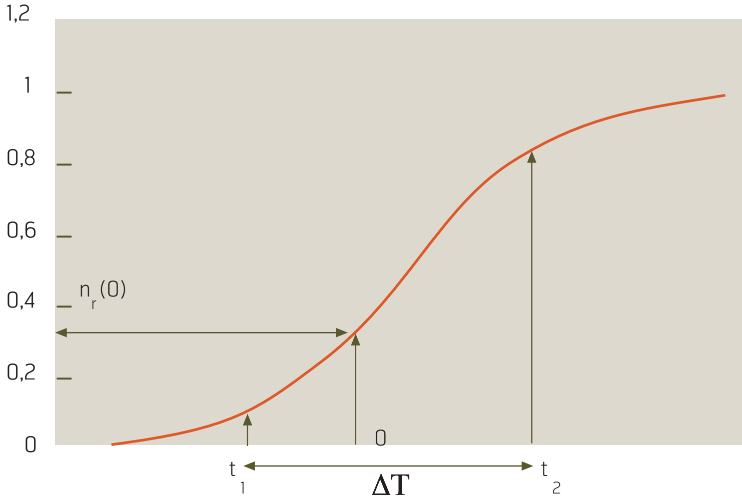

Figure 4.1 The logistic model showing $n_r(0)$ and ΔT

Figure 6.2 shows the impact of $n_r(0)$ on the normalised cost, keeping $\Delta T = 5$ years as a constant.

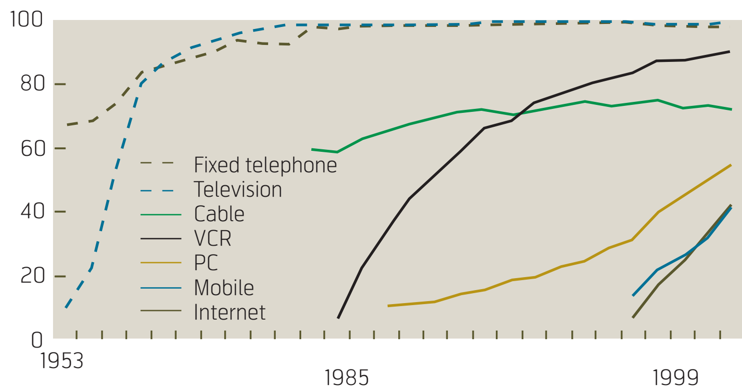

Figure 5.1 Historical diffusion of selected goods in Canada, source: Sciadas 2002b [18]

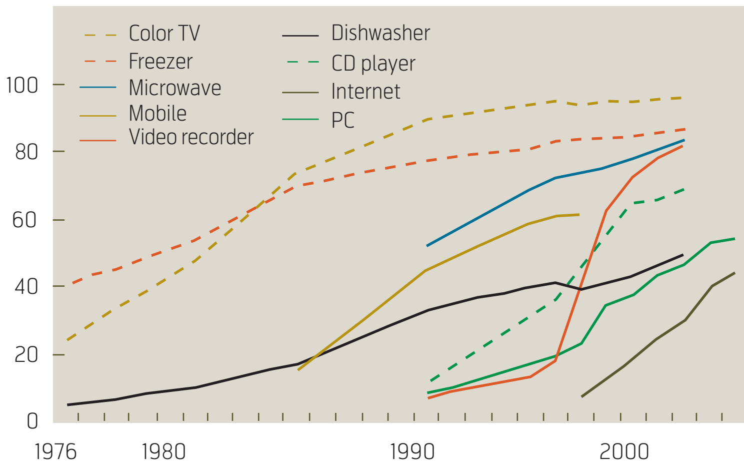

Figure 5.2 Historical diffusion of selected goods in Finland, source: Statistics Finland 2003 [18]

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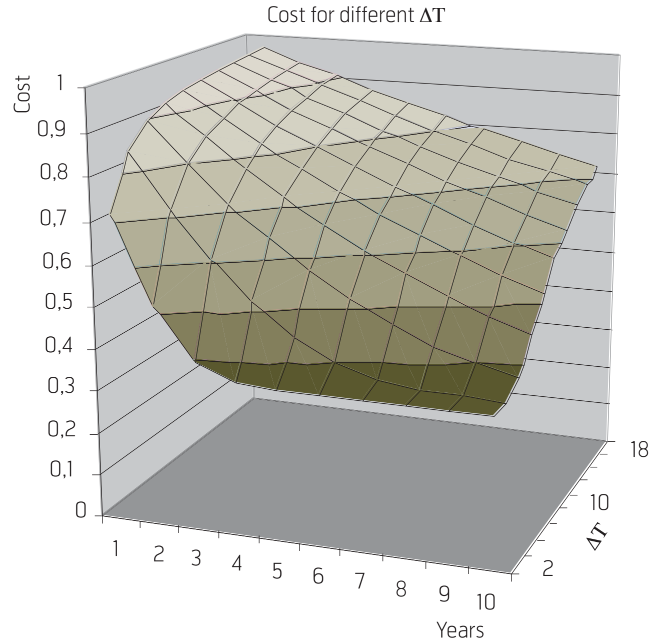

Figure 6.1 The impact of ΔT on the normalised cost, keeping $n_r(0) = 0.001$ and K = 0.9

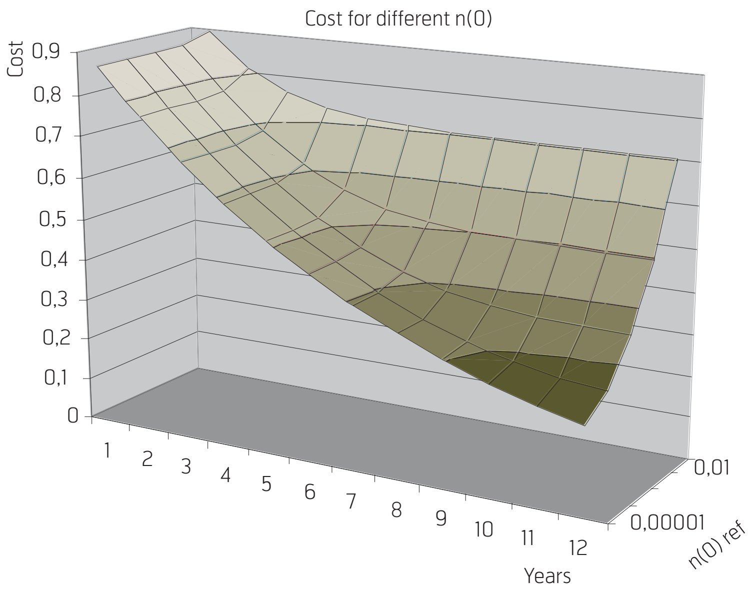

Figure 6.2 The impact of $n_r(0)$ on the normalised cost, keeping ΔT = 5 years and K = 0.9

LearningCurveClass	K_Value
CivilWorks	100.0 %
CopperCable	100.0 %
Electronics	80.0 %
SitesAndEnclosures	100.0 %
FibreCable	90.0 %
Installation (constant)	100.0 %
AdvancedOpticalComponents	70.0 %
Installation (decreasing)	85.0 %
OpticalComponents	80.0 %

Table 7.1 The learning curve classes (Learning curve coefficient)

From the previous expression it is clear that the asymptotic price level when t approaches ∞ does not depend on ΔT, and is given by:

$$P(\infty) = P(0) \cdot \left[\frac{1}{n(0)}\right]^{log_2(K)} \tag{6.2}$$

In addition, for small t the slope of the price curve is proportional to ΔT^{-1}.

7 Volume and learning curve classes

In the practical implementation of the extended learning curve in the tool mentioned in the introduction, the user chooses or estimates values of every cost component among different classes of the learning curve coefficients K and combinations of $n_r(0)$ and ΔT (volume classes). In case the components are new and no historical costs exist, *a priori* values have to be chosen. Illustrations are shown in Table 7.1 and Table 7.2. Typical values of the Learning curve coefficient are from 100 % (meaning no cost reduction) to 70 %, giving 30 % reduction for doubling of production volume.

Typical volume classes are shown in Table 7.2. The grouping can be established by the user of the tool and is not fixed.

The learning curve coefficient K classes and the volume classes are chosen according to a pragmatic choice of granularity and can be changed by the user of the tool. Especially the volume classes are chosen to cover the two aspects of cost components: the type and maturity of cost components. For example the twisted copper pair or civil work costs are Straight Line class, POTS may be Old Very Slow class, Fibre costs can be Mature Slow class and new devices for optical switching can be like Emerging Fast class.

The grouping in classes brings the needed granularity for modelling cost evolution of every cost component. The effect of allocating cost evolution to every component in the business case study make the uncertainty of the overall cost picture smaller due to the "large number law" in statistics. In general, over- and under-estimation cancel out by the large number of components.

8 Forecasts by the extended learning curve – some examples

To illustrate how the extended learning curve methodology can be applied, two examples from the telecommunication area are presented in this chapter. The first example shows how ADSL line costs are forecasted based on collected data. A substantial part of the ADSL line costs comes from the DSLAM and the line cards itself (modem is not included). The second example makes cost forecasts for transmission equipment used in the core network. The described costs are not production costs, but costs the operators have to pay for the equipment.

VolumeClass	$n_r(0)$	ΔT
Emerging_Fast	0.001	5.0
Emerging_Medium	0.001	10.0
Emerging_Slow	0.001	20.0
Emerging_VerySlow	0.001	40.0
New_Fast	0.01	5.0
New_Medium	0.01	10.0
New_Slow	0.01	20.0
New_VerySlow	0.01	40.0
Mature_Fast	0.1	5.0
Mature_Medium	0.1	10.0
Mature_Slow	0.1	20.0
Mature_VerySlow	0.1	40.0
Old_Fast	0.5	5.0
Old_Medium	0.5	10.0
Old_Slow	0.5	20.0
Old_VerySlow	0.5	40.0
StraightLine	0.1	1000.0

Table 7.2 The volume classes

Figure 8.1 shows the development of ADSL line costs in the period 2000–2003. The line costs are shown in brown. Note the significant drop in the line cost from 2001 to 2002. It is difficult to collect international cost data. Some times the data may reflect immediate results from negotiations between manufactures and operators, while some other times there have been no changes in the costs/prices over a long period. The reason can be rather long contract periods. The 2001 cost observation on ADSL line cost is too high compared to both 2000 and 2002 cost, to fit a "natural" decrease during the observed period. The observation has been treated as an outlier. The learning curve model is complex and traditional linear estimation methods cannot be used. The estimation of the parameters is performed by a non-linear estimation procedure, which minimises the root mean square error.

The ADSL line cost forecast modelling gave the estimates:

$P(2000)$ = 212 Euro
ΔT = 8
$n_r(2000)$ = 0.1 %
K = 0.74

Figure 8.1 shows the forecasting results based on the estimation.

The figure shows that ADSL line costs have decreased to about 30 % of the original 2000 costs during a period of only three years. The forecasts also show that there is still a potential for a significant drop in the line costs. The forecasts indicate that the line costs reach a rather stable level after a period of 9–10 years. One reason is the estimated $\Delta T = 8$ years.

It is of interest to evaluate the estimated values. $P(2000) = 212.3$ Euro is one Euro less than the observed value in 2000. The initial production volume in year 2000 is estimated to be 0.1 %. At that time, ADSL was in its initial phase and 0.1 % is a reasonable value. The growth period $\Delta T = 8$ years, from a 10 % production level to a 90 % production level, may be right for ADSL cards with low access capacity. However, if high capacity ADSL cards (up to 8 Mb/s) are included, there is reason to believe that ΔT will be larger. The K factor estimated tells that the cost is reduced by a factor of 0.736 when the production volume on a worldwide basis is doubled. We do not have information about the total international production volume, but the K value seems reasonable.

Figure 8.2 shows the development of SDH equipment costs from 2000 to 2003. The SDH equipment costs are shown in brown in the figure.

The observed equipment costs have a nice reduction. However, we see that the relatively yearly reductions are not of the same size as for ADSL line costs. An interpretation is that the maturity of the SDH equipment in 2000 was much higher than the ADSL equipment. This is true because SDH equipment was put into production many years before the ADSL equipment, meaning that the cost evolution of SDH is closer to the tail of the cost curve.

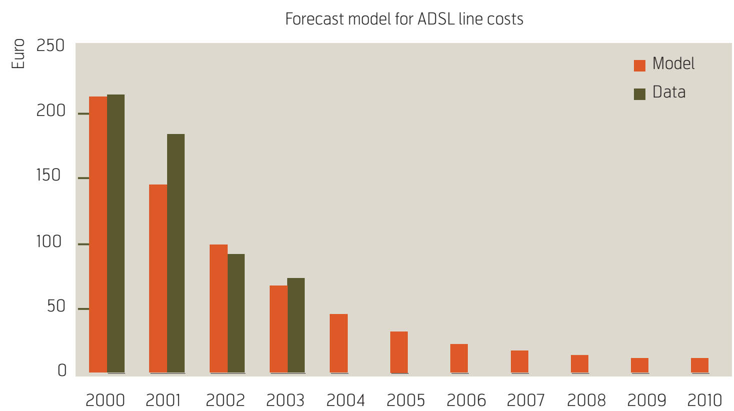

Figure 8.1 Cost observations and forecasts for ADSL line costs

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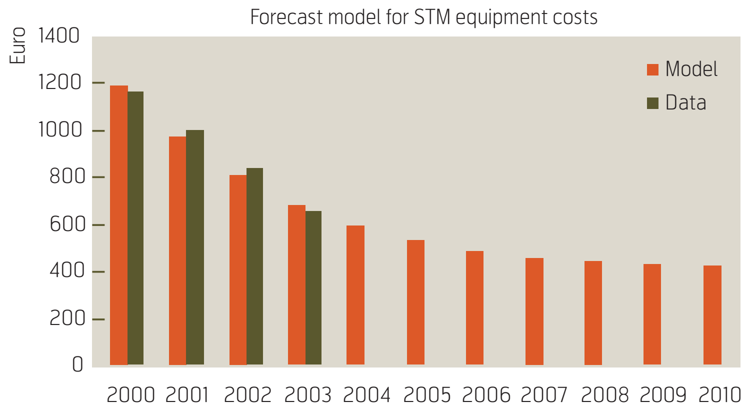

Figure 8.2 Cost observations and forecasts for SDH equipment costs

The same non-linear estimation procedure is performed for the SDH equipment. The estimation gave the following results:

$P(2000)$	= 1188 Euro
ΔT	= 8
$n_r(2000)$	= 7.4 %
K	= 0.76

Figure 8.2 shows the SDH equipment cost forecasts. The figure indicates quite a small future decrease in costs and that the component cost evolution stabilises around 2007. The estimation shows that 7.4 % of the total volume has been produced. The growth period ΔT is estimated to be eight years. The K factor is estimated to be about the same as for the ADSL line costs. This seems to be reasonable, because both types of equipment are produced today with very similar production methods (10 years is very typical for equipment in a series today). Also the estimated initial cost in year 2000 Euro is reasonably good, only 26 Euro from observed real cost value.

It is difficult to evaluate the forecasts, but the fact that the value of the estimates both for the ADSL line cost and the SDH equipment cost is reasonable based on our additional knowledge is of course a positive element in the evaluation.

9 Conclusions

Wright and Crawford have developed the learning curve model for cost predictions. However, their model is not able to predict the costs as a function of time. In traditional business case modeling, cost predictions for a given period is a necessary input for calculations of net present value, pay-back period and internal rate of return.

The extended learning curve model presented in this paper has the ability to predict cost evolution as a function of time. The model extends Wright and Crawford's learning curve by inserting a Logistic forecasting function for number of produced units. The Logistic function includes *three* parameters for flexible modelling of different production volume evolutions. In addition the learning curve is described with *two* parameters.

Hence, the number of parameters that go into the new model is five. The saturation level of the Logistic function, which is the expected total number of units to be produced, is one parameter. This parameter is eliminated through expression of the relative number (percentage) of produced units. Then the resulting number of parameters in the extended learning curve model is only four.

The traditional objective from a statistical point of view is to estimate the parameters. This is of course a reasonable way to perform the modeling when many observations are made. *However, there are possibilities to include even more knowledge into this process.* Therefore substantial work has been carried out to transform two of the parameters (c and d) in the model, to get *interpretative parameters*.

The following interpretative parameters were identified after the transformation:

- Price in the reference year;
- Relative accumulated volume sold today;
- Main part of the life cycle time to the product – the period between 10 % and 90 % penetration of the product (growth period);
- Proportion of cost decrease when the production volume is doubled (the learning curve coefficient).

In many situations, business case modeling for introduction of new products is performed. Then, no data are available of the production evolution of the new product. Even if no data are available, it is possible to use the extended learning curve model for prediction of the costs. And the reason is *the interpretative parameters*. Without observations, there are possibilities to give *a priori* values of these parameters.

Information about a probable price in the reference year of the product can be collected. The relative volume sold today $n_r(0)$ can be almost 0 or estimated on the basis of some country data. There is no need to know the worldwide penetration. The growth period of the product ΔT has to be roughly estimated.

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Remember that the life cycle of the product has decreased significantly during the last two decades (Chapter 5). Based on this type of knowledge it is possible without observations to do some estimates. There exists *a priori* knowledge about the *K* factor for different types of components. This information is available from the equipment provider industry if the component is on the market. The advantage of having *interpretative parameters* in the learning curve model is obvious when cost predictions for new products are developed.

Chapter 8 documented how the extended learning curve model is applied when a set of observations are available. Then, statistical methodology (non-linear estimation) is used to estimate the parameters. Even in this situation, *a priori* knowledge is important. The evaluation of the estimated values turned out to be reasonably good in the two examples presented. However, if for example the main part of the life cycle of those products was estimated to be 40 years, we know that this is completely wrong and we have the possibility to adjust the parameter.

The extended learning curve modeling gives the possibility to include both observations and *a priori* knowledge in the cost forecasts.

The extended learning curve is based on insertion of a three parameter Logistic model which describes a symmetric behavior of the production penetration around a turning point for the function. In Annex 3 a four parameter Logistic model with a non-symmetric pattern is used as input to the learning curve. This variant of the extended learning curve model can give a better flexibility for the estimation of the cost evolution.

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Annex 1 – Relative growth model

We know that the production volume n and the production cost per unit P_n are a function of time. Thus

$$P(t) = n(t)^{-\alpha} \cdot P_0 \tag{A1.1}$$

In principle $n(t)$ is the global accumulated volume for the world production of a component at time t and P_0 is the cost of the very first component.

Both of these inputs are sometimes difficult to obtain. These obstacles are easily removed from the learning curve formulation by using relative values, in which case P_0 does not appear.

$$\frac{P(t)}{P(0)} = \left[\frac{n(t)}{n(0)}\right]^{-\alpha} \tag{A1.2}$$

Furthermore, the global accumulated volume $n(t)$ may be removed from the expression by observing that

$$\frac{P(t)}{P(0)} = \left[\frac{n_r(t)}{n_r(0)}\right]^{-\alpha}$$

holds true since

$$\left[\frac{n(t)}{n(0)}\right]^{-\alpha} = \left[\frac{n_r(t)}{n_r(0)}\right]^{-\alpha}$$

where $n_r(t)$ and $n_r(0)$ are relative values (i.e. normalized to 1). Rearranging the expression gives:

$$P(t) = P(0) \cdot \left[\frac{n_r(t)}{n_r(0)}\right]^{-\alpha} \tag{A1.3}$$

or

$$P(t) = P(0) \cdot [n_r(0)^{-1} \cdot n_r(t)]^{\log_2 \cdot K} \tag{A1.4}$$

$n_r(0)$ is the relative component volume at time $t = 0$. The relative accumulated component volume $n_r(t)$ at time t of the component must be modeled in some way.

In the situation with limited number of observations, it is necessary to make a model of the lifetime of every cost component. To be very general we assume that the best general model to describe the relative accumulated volume produced (sold) of a component $n_r(t)$ is the normalized standard demand logistic curve with four parameters. Hence, the Logistic model is defined by:

$$n(t) = [1 + e^{(c+d \cdot t)}]^{-\gamma} \tag{A1.5}$$

where

- c, d and γ are parameters;
- t is time.

The model predicts the yearly production volume. If the production volume for the last years is known, it is possible to estimate the parameters c, d and γ. However, in new network architectures, there are a lot of rather new or completely new network components. In this case there is no time series of the yearly production volume. Then we need to be able to interpret the parameters and estimate them based on different *a priori* knowledge.

Annex 2 – Reformulation of the Logistic curve in the symmetric case

In general the Logistic curve is described by abstract parameters, which give no direct meaning. In a situation where hundreds of cost components have to be characterized, it is important to be able to have a more direct feeling about the reasonable sets of parameters to be applied. In the following we first make the reformulation in the symmetric case with the γ set to 1.

Instead of using the parameters c and d in the Logistic model, the *growth period* ΔT and the relative production volume $n_r(0)$ at a reference time 0 are introduced. It is easier to understand and also easier to have an opinion about the size of these parameters than the parameters c and d.

$$n_r(t) = [1 + e^{(c+d \cdot t)}]^{-1} \tag{A2.1}$$

c expressed by $n_r(0)$:

Setting $t = 0$ in (A2.1), we get:

$$n_r(0) = (1 + e^{c})^{-1} \tag{A2.2}$$

Some rearrangements give:

$$c = \ln[n_r(0)^{-1} - 1] \quad \text{(A2.3)}$$

which expresses c in terms of the relative accumulated volume at year 0.

***d* expressed by ΔT:**

We define the growth period as the time from the component reaches 10 % of the total production volume (saturation) until it reaches 90 %. Then the following equations are defined:

$$n_r(t_1) = 0.1 \quad \text{(A2.4)}$$

$$n_r(t_2) = 0.9 \quad \text{(A2.5)}$$

Thus

$$\left[1 + e^{(c+d\cdot t_1)}\right]^{-1} = 0.1 \;\&$$

$$\left[1 + e^{(c+d\cdot t_2)}\right]^{-1} = 0.9 \quad \text{(A2.6)}$$

$$1 + e^{(c+d\cdot t_1)} = 10 \;\&\; 1 + e^{(c+d\cdot t_2)} = \frac{10}{9} \quad \text{(A2.7)}$$

$$e^{(c+d\cdot t_1)} = 9 \;\&\; e^{(c+d\cdot t_2)} = \frac{1}{9} \quad \text{(A2.8)}$$

$$e^c \cdot e^{d\cdot t_1} = 9 \;\&\; e^c \cdot e^{d\cdot t_2} = \frac{1}{9} \quad \text{(A2.9)}$$

By dividing the right hand side by the left hand side of (A2.6) we get

$$e^{d\cdot(t_2 - t_1)} = \frac{1}{9^2} \quad \text{(A2.10)}$$

$$d \cdot (t_2 - t_1) = -2 \cdot \ln 9$$

By definition

$$\Delta T = t_2 - t_1 \quad \text{(A2.11)}$$

$$\Delta T = \frac{-2 \cdot \ln 9}{d} \quad \text{(A2.12)}$$

$$d = \frac{-2 \cdot \ln 9}{\Delta T} \quad \text{(A2.13)}$$

which express d in terms of ΔT.

Substitution of the expressions of c and d into the logistic curve gives

$$n_r(t) = \left(1 + e^{\left\{\ln\left[n_r(0)^{-1} - 1\right] - \left[\frac{2\cdot\ln 9}{\Delta T}\right]\cdot t\right\}}\right)^{-1} \quad \text{(A2.14)}$$

where $n_r(0)$ and ΔT are the only parameters.

Annex 3 – The extended learning curve model based on asymmetric production growth

The Logistic curve for various values of the parameter γ is illustrated in Figure A3.1.

The parameters c and d can be derived as in the symmetric case giving:

$$c = \ln\left[n_r(0)^{\frac{-1}{\gamma}} - 1\right] \quad \text{(A3.1)}$$

and by defining δ:

$$\delta = \frac{\left[\left(\frac{10}{9}\right)^{\frac{1}{\gamma}} - 1\right]}{\left[10^{\frac{1}{\gamma}} - 1\right]} \quad \text{(A3.2)}$$

where δ is a function of γ only.

Finally, we get the expression for δ as a function of ΔT:

$$d = \frac{\ln \delta}{\Delta T} \quad \text{(A3.3)}$$

Hence, the final expression for price versus time in general is:

$$P(t) = P(0)\cdot \left[n_r(0)^{-1} \cdot \left(1 + e^{\left\{\ln\left[n_r(0)^{\frac{-1}{\gamma}} - 1\right] + \left[\frac{\ln\delta}{\Delta T}\right]\cdot t\right\}}\right)^{-\gamma}\right]^{\log_2 \cdot K} \quad \text{(A3.4)}$$

The parameters in the formula are defined by:

$P(0)$, the price in the reference year 0;
$n_r(0)$, the relative accumulated volume in year 0;
ΔT, the time for the accumulated volume to grow from 10 % to 90 %;
K, the learning curve coefficient;
γ, the asymmetry of the logistic curve.

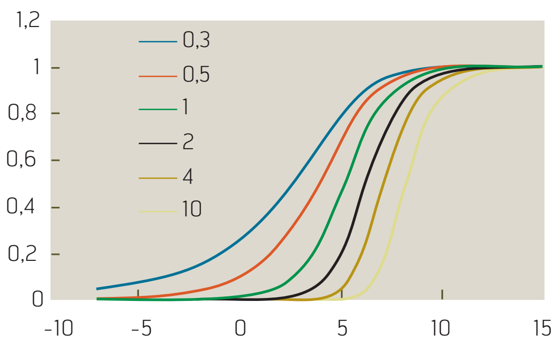

Figure A3.1 Diffusion curves for different values of γ (from 0.3 to 10)

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Borgar T. Olsen received his MSc in physics in 1975 and his DrPhilos degree in 1987 from the University of Oslo. From 1977 to 1983 he was Research Assistant at the Department of Physics, University of Oslo. From 1984 to 1986 he was Research Fellow at Max-Planck-Institut in Bad Nauheim and Munich in Germany. Since 1986 he has had a position at Norwegian Telecom Research Department, now Telenor R&D. Since 1992 he has been involved in European projects RACEII2087/TITAN, AC226/OPTIMUM, AC364/TERA, and IST-2000-TONIC, EURESCOM P306, EURESCOM P413, EURESCOM P614, EURESCOM P901, EURESCOM P1446 and EUREKA/CELTIC ECOSYS. He has been project manager of the AC226/OPTIMUM and AC364/TERA projects. He has published several papers in international journals and conferences and is co-author of the book "Broadband Access Networks" (Chapman&Hall, 1998).

email: borgar-torre.olsen@telenor.com

For a presentation of Kjell Stordahl, please turn to page 2.

Rollout strategies based on adoption forecasts for ADSL2+/VDSL

KJELL STORDAHL AND NILS KRISTIAN ELNEGAARD

Kjell Stordahl is Senior Advisor in Telenor Networks

Nils Kristian Elnegaard is Researcher in Telenor R&D

Different ADSL2+/VDSL roll-out scenarios are examined. ADSL2+/VDSL adoption rate forecasts for the competing operators are modelled. The adoption rate forecasts depend on the roll-out delay to the operators, compared with the entrance to operator No. 1 in various exchange areas. Net present value and internal rate of return have been calculated by use of an advanced techno-economic tool for different roll-out scenarios. Based on analysis of the different scenarios, guidelines for ADSL2+/VDSL roll-out strategies are developed.

1 Introduction

During the last years a significant broadband demand has been generated in Western Europe. The growth was very high in the first part of 2004. Forecasts show that the expected broadband penetration in the residential market will be 20–25 % in year 2005 [1, 4, 6]. The most relevant broadband technologies are DSL, HFC, FTTH, FWA, WLAN, multiple ISDN lines, DTT and also satellite solutions to cover the rest market. The European Commission has recommended a market driven and technology neutral broadband evolution. Only Sweden, Canada and South Korea have used another strategy by supporting part of the broadband deployment with Governmental investments.

The incumbent operators face competition from the LLU operators, the cable operators and to some extent operators using fixed wireless access and fibre-to-the-home solutions [9, 13]. In the rest market with low densities of population the FWA and satellite operators challenge the incumbent operator [3, 5, 10]. Broadband rollouts have been studied earlier [11, 12]. The question is what type of broadband strategy should the incumbent apply in order to secure his market share.

The incumbent operators have started to rollout ADSL. The second step is to use enhanced technologies like ADSL2+ and VDSL with the potential of a much broader spectrum of services.

2 Broadband technology forecasts

Broadband access forecasts for the residential European market have been developed by the European Commission projects RACE 2087/TITAN, AC 226/OPTIMUM, AC364/TERA and IST-2000-25172 TONIC [3, 6, 7, 8, 14, 15].

The broadband forecasts for the different technologies are modelled by starting to develop broadband penetration forecasts for the total broadband demand in the Western European residential market. Several papers show that the aggregated long-term demand for many information and telecommunication services, ICT, has a diffusion pattern. New forecasts are developed in the CELTIC project ECOSYS. A four parameter Logistic model has been applied for forecasting long-term broadband penetration from the Western European market, which is also documented in this issue [1].

The broadband technologies are segmented in four main groups:

- ADSL
- ADSL2+/VDSL
- Cable modem (HFC)
- Other technologies

Other technologies are mainly: Fixed wireless broadband access systems (FWA), Fibre-to-the-home, Fibre-to-the-building systems, Power line systems, Direct-to-the-home satellite with return channel and Digital terrestrial television systems.

Predictions of the evolution of market share between different broadband technologies have been developed based on a set of Logistic forecasting models. Migrations between technologies are handled when ADSL2+/VDSL and other broadband technologies are catching market shares from ADSL and cable modem. Finally, the broadband penetration forecasts for the technologies are found by multiplying the total forecasts with the market share forecasts for the technologies.

The CaTV coverage is very different between countries in Western Europe. Some countries, like the Netherlands and Belgium, have nearly 100 % coverage, while other countries have a more limited coverage. Because of Direct To the Home (DTH) satellites, the CaTV networks are not expanded. However, the CaTV operators are upgrading their networks to HFC. The study presented in this paper analyses areas where there is no competition from HFC.

ISSN 0085-7130

The penetration is a function of deployment and adoption rate. The adoption rate is the genuine demand for broadband. However, the demand cannot be effectuated if the broadband infrastructure is not deployed. Hence, the adoption rate will always be higher than the penetration if coverage is less than 100 %. The penetration for a country is estimated by multiplying the mean adoption rate by the coverage.

3 High capacity broadband: ADSL2+ and VDSL

So far the incumbents have offered ADSL in the residential market and ADSL/SHDSL in the business market. The next step is to extend their broadband offer by ADSL2+/VDSL. Telenor has studied VDSL extensively during the last three years through a large VDSL pilot with 700 subscribers. The technology offers two parallel interactive TV streams and traditional high-speed Internet surfing (like ADSL) simultaneously with 15 Mbit/s capacity up to 1.5 km from the DSLAM. ADSL2+ is predicted to cover distances up to 2 km from the DSLAM with 10 Mbit/s capacity.

The substitution effect between ADSL and ADSL2+/VDSL is a critical factor in the forecast modelling. It is assumed that the sum of ADSL2+ and VDSL in 2010 will catch 40–50 % of the DSL market. The VDSL is delayed in some countries, but ADSL2+ on the other hand will have significant market opportunities because the ADSL2+ line cards in new multi DSLAM equipment can replace traditional ADSL line cards.

A set of different elements is important for ADSL, ADSL2+ or VDSL rollout in various access areas. Important elements are: Size of the access area (number of customers), broadband penetration forecasts, distribution of the copper lines, standardisation of broadband network elements, especially access cards and multi DSLAM, network component prices and functionality, broadband capacity and length capability for ADSL2+ and VDSL and broadband applications offered.

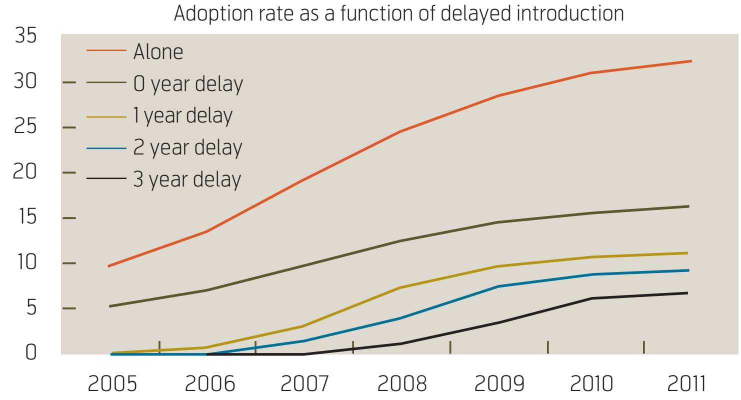

Figure 5.1 ADSL2+/VDSL adoption rate forecasts as a function of delayed introduction

4 Strategic positioning

The challenge for the incumbent operator is to roll out ADSL2+ and VDSL at the right time. The timing for rollout depends on what the LLU operators and other operators using other broadband technology are doing in the same access area.

The broadband operators wait for standardisation of the DSL technology and mass production of new network components to get lower prices, lower investments and lower operational costs. On the other hand, the operators are afraid of losing significant market shares. In Sweden, the operators Bredbandbolaget, Bostream and Bahnhof have announced that they plan to offer VDSL based on hiring the copper lines (LLU) from TeliaSonera. The operators will introduce VDSL in the largest exchanges in major cities in Sweden. The operators plan to use a cherry picking strategy by offering the service to customers who are situated close to the exchange according to the maximum VDSL coverage without doing any infrastructure investments. It is of course a good strategic move to start with the largest exchanges where the investment per customer is small. In addition the operator reduces the other operators' market possibilities significantly in the area.

5 Adoption rate forecasts

In this paper a generic model is used to quantify the market loss for the incumbent by entering the area later than a competitor. The adoption rate is the genuine demand for broadband in an area. The adoption rate will be effectuated if a broadband infrastructure is deployed in the area. The adoption rate for ADSL2+/VDSL has been estimated based on the penetration forecasts and adjustments for deployment coverage.

Figure 5.1 shows the adoption rate for the incumbent as a function of delayed introduction of ADSL2+/VDSL in an area. The upper curve shows the evolution of adoption rate if only one operator offers the broadband services in the area. The next curve shows the adoption rate evolution if both the incumbent and another operator enter the area at the same time. The other curves show the adoption rate evolution based on delayed introductions.

The generic model for reduced adoption rate as a function of delayed introduction assumes that the first operator takes the initial market, while the new operator the first year takes 20 % of the market growth, the second year 35 % of the market growth and from the third year 50 % of the market growth.

6 Business case

The business case studied is a country with 60 million inhabitants and 25 million households.

The market is segmented in five main groups according to the exchange size where the size is defined as number of households with a twisted pair connection to the exchange. Table 6.1 defines the market segments called Area 1, Area 2, ..., Area 5.

Market segment	Exchange size N	Percentage households
Area 1	15,000 < N	10 %
Area 2	10,000 < N = < 15,000	15 %
Area 3	5,000 < N = < 10,000	20 %
Area 4	2,000 < N = < 5,000	20 %
Area 5	N = < 2,000	35 %

Table 6.1 Market segments according to exchange size and volume of households in the segments

The average number of lines per exchange (CO) in Area 1, 2, 3, 4, 5 is assumed to be 12,000, 8,000, 2,600, 1,400 and 400 respectively. The ADSL2+/VDSL coverage within 2 km is assumed to be 75 %. This coverage differs in different European countries because the distribution of the subscriber lines is different.

It is assumed that households in dense areas have a higher broadband penetration and also generate higher Average Revenue Per User (ARPU). The relative weights regarding both penetration and ARPU are 1.2 for Area 1, 1.1 for Area 2, 1.0 for Area 3, 0.95 for Area 4 and 0.90 for Area 5. The value 1.0 corresponds to a monthly ARPU of 100 Euro per month. The ARPU is assumed to decrease by about 20 % in the project period. The most attractive market segment for ADSL2+/VDSL rollout is Area 1, followed by Area 2 etc, because of higher penetration, higher ARPU and lower investment cost per customer.

The sales costs and the content costs are expressed as a proportion of the total (ISP + wholesale part) and ISP part of the revenues respectively. The sales cost are 30 % of the total revenue each year. The content costs are 60 % of the ISP part of the revenues in the first two years of operation, 5 % less in year 3 and 4 and then decreasing 5 % in the following years. The equipment costs are assumed roughly to have 10 % reduction each year. The customer operations and maintenance costs are assumed to be 25 Euro per year, while the installation costs are about 120 Euro.

7 Deployment scenarios

Six different deployment evolutions called Scenario 1, ..., Scenario 6, are analysed. It is assumed for all scenarios that the ADSL2+/VDSL rollout ends with 60 % coverage in year 2010. In addition the investments are based on a cherry picking strategy only offering ADSL2+/VDSL to customers with maximum 2 km copper lines. In this study VDSL is offered to customers with copper lines up to 1.5 km, while ADSL2+ is offered to customers with copper lines in the 1.5 – 2 km range. The cherry picking strategy is based on no additional infrastructure investments.

Year	Incumb.	Other	Overlap	Incumb. Area1	Other Area1	Incumb. Area2	Other Area2	Incumb. Area3	Other Area3	Incumb. Area4	Other Area4
2005	2.5 %	2.5 %	0 %	2.5 %	2.5 %						
2006	7.5 %	7.5 %	0 %	2.5 %	2.5 %	2.5 %	2.5 %				
2007	12.5 %	12.5 %	0 %			5.0 %	5.0 %				
2008	17.5 %	17.5 %	0 %					5.0 %	5.0 %		
2009	22.5 %	22.5 %	0 %					5.0 %	5.0 %		
2010	27.5 %	27.5 %	0 %							5.0 %	5.0 %
2011	30.0 %	30.0 %	0 %							2.5 %	2.5 %
Sum			0 %	5.0 %	5.0 %	7.5 %	7.5 %	10.0 %	10.0 %	7.5 %	7.5 %

Table 7.1 Scenario 1 – Market equality, no overlap

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Year	Incumb.	Other	Overlap	Incumb. Area1	Other Area1	Incumb. Area2	Other Area2	Incumb. Area3	Other Area3	Incumb. Area4	Other Area4
2005	2.5 %	2.5 %		2.5 %	2.5 %						
2006	7.5 %	7.5 %		2.5 %	2.5 %	2.5 %	2.5 %				
2007	15.0 %	15.0 %	5.0 %	2.5 %	2.5 %	5.0 %	5.0 %				
2008	22.5 %	22.5 %	10.0 %	2.5 %	2.5 %			5.0 %	5.0 %		
2009	32.5 %	32.5 %	20.0 %			5.0 %	5.0 %	5.0 %	5.0 %		
2010	40.0 %	40.0 %	25.0 %			2.5 %	2.5 %			5.0 %	5.0 %
2011	45.0 %	45.0 %	30.0 %					2.5 %	2.5 %	2.5 %	2.5 %
Sum				10.0 %	10.0 %	15.0 %	15.0 %	12.5 %	12.5 %	7.5 %	7.5 %

Table 7.2 Scenario 2 – Market equality, 50 % overlap

Year	Incumb.	Other	Overlap	Incumb. Area1	Other Area1	Incumb. Area2	Other Area2	Incumb. Area3	Other Area3	Incumb. Area4	Other Area4
2005	2.5 %	2.5 %	0.0 %	2.5 %	2.5 %						
2006	7.5 %	7.5 %	0.0 %	2.5 %	2.5 %	2.5 %	2.5 %				
2007	17.5 %	17.5 %	10.0 %	5.0 %	5.0 %	5.0 %	5.0 %				
2008	27.5 %	27.5 %	20.0 %			5.0 %	5.0 %	5.0 %	5.0 %		
2009	35.0 %	35.0 %	25.0 %			2.5 %	2.5 %	5.0 %	5.0 %		
2010	45.0 %	45.0 %	35.0 %					5.0 %	5.0 %	5.0 %	5.0 %
2011	52.5 %	52.5 %	45.0 %					5.0 %	5.0 %	2.5 %	2.5 %
Sum				10.0 %	10.0 %	15.0 %	15.0 %	20.0 %	20.0 %	7.5 %	7.5 %

Table 7.3 Scenario 3 – Market equality, 75 % overlap

Year	Incumb.	Other	Overlap	Incumb. Area1	Other Area1	Incumb. Area2	Other Area2	Incumb. Area3	Other Area3	Incumb. Area4	Other Area4
2005	0.0 %	5.0 %	0.0 %	0.0 %	5.0 %						
2006	0.0 %	15.0 %	0.0 %	0.0 %	5.0 %	0.0 %	5.0 %				
2007	10.0 %	25.0 %	5.0 %	5.0 %		5.0 %	5.0 %		5.0 %		
2008	22.5 %	37.5 %	15.0 %	5.0 %		0.0 %	5.0 %	7.5 %	7.5 %		
2009	35.0 %	45.0 %	27.5 %			5.0 %		2.5 %	5.0 %	5.0 %	2.5 %
2010	45.0 %	50.0 %	37.5 %			5.0 %		2.5 %	2.5 %	2.5 %	2.5 %
2011	52.5 %	52.5 %	45.0 %					7.5 %			2.5 %
Sum				10.0 %	10.0 %	15.0 %	15.0 %	20.0 %	20.0 %	7.5 %	7.5 %

Table 7.4 Scenario 4 – Incumbent two years delayed

Year	Incumb.	Other	Overlap	Incumb. Area1	Other Area1	Incumb. Area2	Other Area2	Incumb. Area3	Other Area3	Incumb. Area4	Other Area4
2005	0.0 %	5.0 %	0.0 %	0.0 %	5.0 %						
2006	5.0 %	15.0 %	0.0 %	2.5 %	2.5 %	2.5 %	7.5 %				
2007	15.0 %	25.0 %	7.5 %	5.0 %	2.5 %	2.5 %	2.5 %	2.5 %	5.0 %		
2008	25.0 %	35.0 %	15.0 %	2.5 %		2.5 %	2.5 %	5.0 %	7.5 %		
2009	35.0 %	42.5 %	22.5 %			5.0 %	2.5 %	0.0 %	0.0 %	5.0 %	5.0 %
2010	45.0 %	47.5 %	32.5 %			2.5 %		5.0 %	2.5 %	2.5 %	2.5 %
2011	50.0 %	50.0 %	40.0 %					5.0 %	2.5 %		
Sum				10.0 %	10.0 %	15.0 %	15.0 %	17.5 %	17.5 %	7.5 %	7.5 %

Table 7.5 Scenario 5 – Incumbent one year delayed

Year	Incumb.	Other	Overlap	Incumb. Area1	Other Area1	Incumb. Area2	Other Area2	Incumb. Area3	Other Area3	Incumb. Area4	Other Area4
2005	5.0 %	5.0 %	0.0 %	5.0 %	5.0 %						
2006	15.0 %	10.0 %	0.0 %			10.0 %	5.0 %				
2007	25.0 %	20.0 %	10.0 %	5.0 %	5.0 %			5.0 %	5.0 %		
2008	35.0 %	27.5 %	17.5 %			5.0 %	2.5 %	5.0 %	5.0 %		
2009	45.0 %	32.5 %	25.0 %				2.5 %	5.0 %		5.0 %	2.5 %
2010	52.5 %	37.5 %	32.5 %				2.5 %	5.0 %		2.5 %	2.5 %
2011	55.0 %	40.0 %	35.0 %				2.5 %			2.5 %	
Sum				10.0 %	10.0 %	15.0 %	15.0 %	20.0 %	10.0 %	10.0 %	5.0 %

Table 7.6 Scenario 6 – Incumbent agressive rollout

The tables show for each year the deployment volume proportion (in percentage) of the total number of households both for the incumbent and for other operators. Highlighted figures indicate that the operator is the first one in the given exchange area, and non-highlight figures indicate that the operator is the second one. The deployment strategy for the operators for each scenario is to be the first operator in an exchange area starting with the largest exchanges possible. The operators have to cover Area X+1-1as a second operator before all the Area X is covered by operator number one.

Scenarios 1–3 show competition situations where the incumbent and the other operators take 50 % of the market. Scenario 1 represents a strategy where there is no overlap, i.e. there is no second operator in the areas. In scenarios 2 and 3 there are respectively 50 % and 75 % overlap in the exchange areas. Scenarios 4 and 5 show situations where the incumbent is respectively two and one year delayed in ADSL2+/VDSL rollout compared with the other operators, while Scenario 6 shows an aggressive rollout from the incumbent point of view.

8 Techno-economic assessments

Different deployment strategies are analysed by using a techno-economic tool. The tool developed within the European programs ACTS and IST by the projects AC 226/OPTIMUM and AC364/TERA and IST 25172/TONIC calculates Net Present Value (NPV), payback period and Internal Rate of Return (IRR) for each deployment strategy. The tool contains a cost database with reference costs for network components in 2004 and learning curve predictions of the component cost evolution. The Capital Expenditure

(CAPEX) is calculated based on the forecasts, the dimensioning of number of components and the predicted cost evolution. In addition Operational Costs (OPEX) is calculated based on operation and maintenance parameters for the component and the maintenance system. The revenue in the model is found by multiplying the ARPU with the access forecasts. The discount rate is assumed to be 10 %.

The cherry picking strategy for ADSL2+ and VDSL only offering the access close to the exchange/ DSLAM are examined. The techno-economic tool calculates the economic value of the strategies for different rollout times for the incumbent operator based on deployment strategies to the other operators.

9 Results

The main results are shown in Figure 9.1 where the net present values are calculated for all scenarios. The figure shows that Scenarios 1–3 have rather good net present values for the incumbent and of course also for the other operators (since the incumbent and the other operators use identical rollout strategies). Scenarios 1–3 are described in Table 7.1–7.3. Scenarios 1–3 have a symmetric rollout between the competitors, ending with 60 % ADSL2+/ VDSL coverage in year 2010. Both the incumbent and the other operators benefit by being the first operator to enter new exchange areas. The figure shows that the net present value decreases when the incumbent has to use additional spending to cover the exchange areas as a second operator. The analysis shows that the optimal way for the incumbent and the other operators is to share the market without overlap (Scenario 1). Then the return of the investment is maximised. However, there will be competition in a lot of areas and the operators are not allowed to make such agreements. Scenarios 2 and 3 show the net present value when the incumbent and the other operators have respectively 30 % and 45 % overlap in the rollout.

Scenario 4, "Incumbent two years delayed" is described in Table 7.4. Both the incumbent and the other operators end up with 52.5 % coverage in 2010. However, the incumbent is two years delayed in the rollout compared with the other operators. The consequences are rather dramatic since the other operators enter the largest exchange areas. The incumbent loses the possibility to be operator No. 1 in Area 1 with the largest potential of subscribers and also significant part of Area 2 as the first operator. The move for the incumbent is to concentrate on being the first operator in Area 3 and the second operator in Area 1 and mainly in Area 2. The incumbent has a rather aggressive rollout after the two first years, but it is too late to achieve profitability. The explanation is the loss of initial access subscribers by entering the market too late and lower revenue per subscriber by entering areas with a (much) lower number of lines. The net present value is negative in this case.

Scenario 5, "Incumbent one year delayed" is described in Table 7.5. Now, the incumbent is one year delayed compared with the other operators. The incumbent fails to be the dominant operator in the largest exchange areas, but the handicap is not as significant as in Scenario 4. Figure 9.1 shows that the net present value is positive but less than for the first three scenarios.

Scenario 6, "Aggressive incumbent rollout" is described in Table 7.6. Now both the incumbent and the other operators start the rollout in year 2004. The incumbent has the resources, uses an aggressive rollout and ends up with a higher coverage than the other operators. Hence, the incumbent also gets a better position by entering the largest exchange areas as fast or faster than the other operators. The result is a rather large net present value – also compared to Scenario 1.

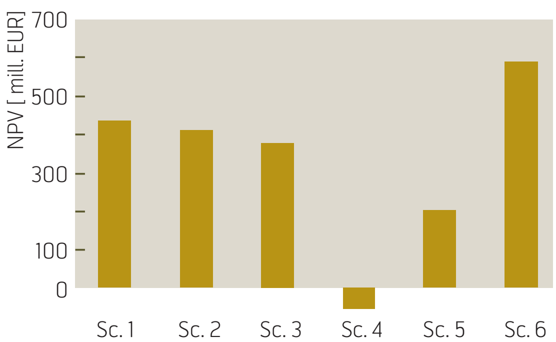

Figure 9.1 Incumbent: Net present values for Scenario 1–6

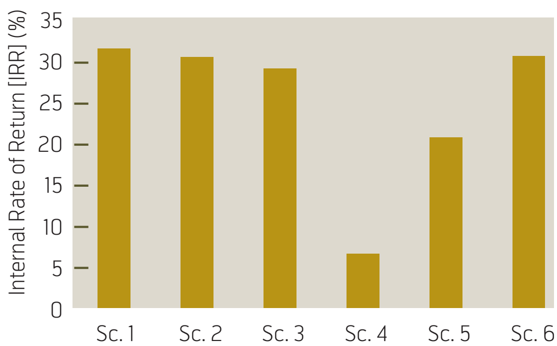

Figure 9.2 Incumbent: Internal rate of return for Scenario 1–6

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The calculation of internal rate of return for the various scenarios confirms the conclusions based on the assessed net present values. The results are shown in Figure 9.2

10 Uncertainties

The rollout strategy is dependent on estimated revenue, expected return on investments and assessed economic risks caused by uncertainties in the forecasts and predictions. Introduction of new technologies, new applications, new network platforms and new architectures depend on the long-term revenue prospects and also on related uncertainties and risks. The preferred alternatives depend on the costs of network components and the cost evolution. Revenue for the given applications depends on investment costs, operation and maintenance costs and revenue considerations. Demand depends on the expected competition, the market potential for the applications, expected market shares, substitution effects between applications, penetration as a function of time, price and service quality.

Therefore, it is important to evaluate the economic value of the rollout based on uncertainties in these factors. The paper *Analysing the Impact of Forecast Uncertainties in Broadband Access rollouts by the Use of Risk Analysis* [2] in this journal shows how risk analysis is used to evaluate ADSL2+/VDSL rollout strategies based on well-defined uncertainties.

11 Conclusions

The operators have limited resources for ADSL2+/VDSL rollout. The question is how to utilise the resources in an optimal way. Analysis in this paper shows that the first step is to enter the exchange areas by the cherry picking strategy.

To optimise the economic value of the rollout, the operators should start to roll out ADSL2+/VDSL in large areas. However, the rollout depends on being the first operator or the second operator in the area. The analysis show that it is better to enter the second best area as the first operator, than to enter the best area as the second operator.

Both the incumbents and the other operators are in fact playing a game to utilise their resources in an optimal way when they are rolling out ADSL2+/VDSL.

This paper also gives some guidelines on how ADSL2+ and VDSL should be rolled out. If the competition is heavy, delay in the rollout causes significant loss.

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For a presentation of Kjell Stordahl, please turn to page 2.

Nils Kristian Elnegaard (38) received his Master Degree in Electronics Engineering from the Technical University of Denmark in 1993. During the last eight years he has been working with techno-economic analyses in the area broadband access network rollout strategies. He has worked in a number of European research projects within ACTS, IST and EURESCOM dealing with techno-economic analyses of broadband rollouts. Mr. Elnegaard has published more than 50 papers in international journals and conferences in this field. His main research interests are new and emerging access technologies, rollout strategies and techno-economic risk analysis.

email: nils.elnegaard@telenor.com

Analysing the impact of forecast uncertainties in broadband access rollouts by the use of risk analysis

NILS KRISTIAN ELNEGAARD AND KJELL STORDAHL

In this paper thorough risk analysis is performed on the rollout investment case described in this journal [1]. The concepts of uncertainty and risk are introduced, followed by an extensive overview of various types of uncertainties and risks in telecommunication investment projects. The next part of the paper describes the risk methodology. The risk and sensitivity analysis performed on the scenarios described in [1] is discussed. The focus is on financial risk in this paper.

Nils Kristian Elnegaard is Researcher in Telenor R&D

Kjell Stordahl is Senior Advisor in Telenor Networks

1 Introduction

There are many complex and interacting factors with an impact on the economics of telecommunication investment projects. The main factors are the evolution of: applications, technologies, network platforms, service quality requirements, cost evolution, demand for new services, price levels, regulatory environment and competition. Telecom projects are influenced by *future forecasts and predictions* of all these factors.

The network operator's strategy is governed by estimated revenue, expected return on investments and assessed economic risks caused by uncertainties in the forecasts and predictions. Introduction of new technologies, new applications, new network platforms, new architectures etc. depend on the long-term revenue prospects and also on related uncertainties and risks. Strategic decisions play an important role in the near term positioning when the competition is increasing. The environment of the telecommunications market is now changing dramatically and will continue to do so in the coming years.

New applications and services can be implemented by using the existing network platform, or by expanding the network platform, or by introducing new technology and new network platforms. The preferred alternatives depend on the cost of network components and the cost evolution. The price of the given applications depends on investment costs, operation and maintenance costs, and revenue considerations. Demand depends on the expected competition, the market potential for the applications, expected market shares, substitution effects between applications, penetration as a function of time, price and service quality. In addition there are interactions between the main factors.

In this paper, thorough risk analysis is performed on the rollout investment case described in this journal [1]. We begin with an introduction to the concepts of uncertainty and risk, followed by a description of the risk methodology. The risk and sensitivity analysis performed on the scenarios described in [1] is discussed. Focus is on financial risk in this paper.

2 Uncertainty and risk

Uncertainty and risk are unavoidable companions in every business case evaluation. Many high level assumption variables in a business case, e.g. service penetration, ARPU, market share etc. of which the default values are chosen from consensus/brainstorming/expert information etc., are inherently uncertain. The variation of these variables may have a vital impact on the whole value of the project, which means the difference between success and failure. The first questions that arise are how do we describe the uncertainty in assumptions, and what is actually the difference between uncertainty and risk?

To illustrate the concepts of uncertainty and risk, let us start with a simple example. We assume that we have two projects, A and B, with their respective distributions as shown in Figure 1 (for example obtained from simulations).

The question is now: Which project is more uncertain than the other, and which project carries most risk? It is immediately seen from Figure 1 that Project B has the highest level of uncertainty due to its higher standard deviation. However, Project A is the riskier of the two projects as the 5 % percentile is negative, and therefore there is a probability of a negative NPV higher than 5 %. For Project B, however, the probability of a negative NPV is 0 as the minimum value is positive. The 5 % percentile (Value at Risk) is therefore also positive.

A "plain" traditional sensitivity analysis is often used, in which each input variable is changed on a one-by-one basis, in order to identify the most significant variables. However, this is not sufficient if a more complete picture of the overall uncertainty is needed. The multivariable sensitivity and risk analysis approach applied in this paper is based on the well-known Monte Carlo simulation methodology. In

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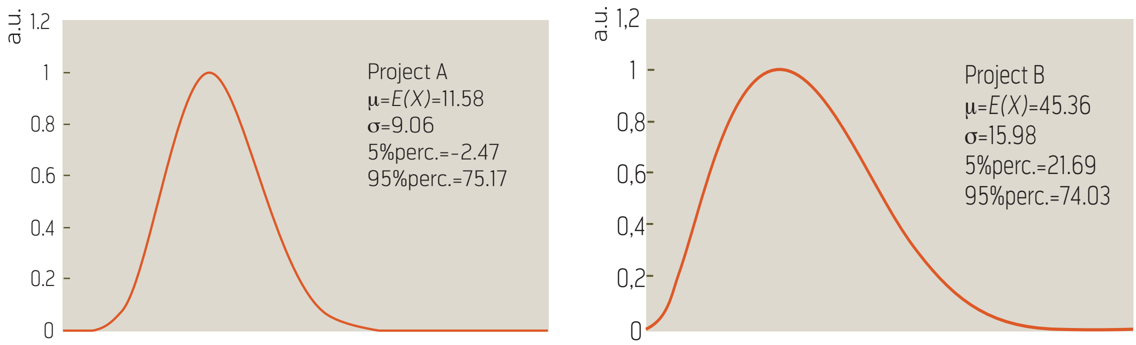

Figure 1 The difference between uncertainty and risk

short, the difference between traditional "plain" sensitivity analysis and risk analysis based on Monte Carlo simulation is that the former only tells you what is *possible*; not what is *probable*!

3 Overview of uncertainties and risks in broadband telecommunication projects

Market uncertainties and risks

Substantial risks are linked to the predicted evolution of the broadband market. A fundament for the evolution is new and enhanced broadband applications. Uncertain demand forecasts generate significant risks influencing the investments and also other costs. One realisation is unexpected delay in the demand. Overestimation of the demand implies overestimation of investment costs, where parts of the costs are bundled and not utilised for a period.

Underestimation of the demand will generate waiting lines and bad reputation and lost market share. Also the problems in the rollout, in component and service supply and in service quality will induce bad reputation.

If some customers are lost to a competitor, it is difficult to win these customers back. This risk problem is denoted as the churn problem. The customer can be lost from specific market segments, specific user groups or in specific geographic areas. The risk of lost market shares may also be caused by substituting applications and services.

Uncertainties are usually expressed by measures like standard deviations and confidence limits. Traditional statistical methods are used to estimate standard deviations and confidence limits for given probability densities. However, the situation is often more complicated when forecast uncertainties are estimated.

Then there are two sets of uncertainties: Uncertainties based on estimation of parameters in the forecasting model and uncertainties caused by the forecasting period. The forecasting uncertainties are either expressed directly from the model when Box Jenkins time series models [3] are used, or in regression models with time, *t*, as explanatory variable. However, when there are additional explanatory variables the situation is more complex. Then, the uncertainty of the forecasts of each explanatory variable also has an impact on the total forecast uncertainty. In such situations it is difficult to model and estimate the uncertainty as a function of time.

Competition, regulatory risks and uncertainties

The main objective for the regulator is to establish a competition regime where newcomers have a fair competition, while the incumbent operator has significant handicap. The European Commission has recommended that the regulators perform market analysis to identify whether the incumbent is dominating the market or not (Significant Market Position).

The effect could be a reduced market share and power for the incumbent operator and a more balanced market between all operators. The risks and the uncertainty are influenced by unpredicted regulations, the number of new competitors, and alliances between the operators and also service providers.

The geographic deployment strategy for rollout influences the market shares as well as the service mix, service quality, customer support and type of billing systems compared with the other network operators. Another important competitive factor is the tariffs and the tariff strategy. Significant risks of losing market shares are linked to the tariff evolution generated by different competitors.

Since the incumbents own large parts of the access network, the European Commission through European regulators have taken actions to generate competition in the access network by introducing Local Loop Unbundling, LLU. However there is a lot of uncertainty connected to the actions of the regulator. The regulator may generate changes in some important parts of the telecommunication law. The regulator controls the number of licenses for the operators. The regulator may prevent the incumbent operator from offering given services. The body influences the interconnect tariffs and may also regulate the ordinary tariffs.

Technology risks

A wide range of technologies are available for transport of broadband communication. In the access network a fibre node structure or a coax structure has to be deployed. The last part of the access network can be covered by ADSL, ADSL2+ or VDSL on twisted pair copper lines, or by the radio solutios such as LMDS, WiFi, WiMax. Other alternatives are satellite systems combined with a wireline return channel or a hybrid fibre coax system, HFC. The technologies may substitute each other or may be deployed as supplements in different parts of the network. In parallel the fibre capacity is extended by introduction of wavelength division multiplexing, WDM and mainly IP in the core network.

There are substantial risks of implementing the wrong technology at the wrong time. Important questions are:

- Selection of optimal technology in different parts of the network;

- Strategies for rollout based on competition in specific areas;

- Strategies for robust upgrading of the upper part of the access;

- Network design giving possibilities for utilising different technologies;

- Strategies for minimising the upfront costs the first period.

In addition specific technology problems may occur. The quality of some components does not satisfy the norms and have to be replaced by other types of components. The selected manufacturer has significant problems and does not satisfy the production specifications. The effect is bad quality for the customers, delivery problems, waiting lists and bad reputation. The same risks can be generated if the demand forecasts, planning, dimensioning, projecting or deployment of the network are pure.

Operational and investments risks

Investment and operational costs can be divided into:

- Investment costs
- Operational and management costs
- Maintenance cost
- Administrative costs
- Costs of support systems
- Customer support costs
- Marketing/sales costs.

Implementation of a new broadband network including new services and applications will generate uncertain cost estimates. The main input is demand forecasts for the total market and estimates for lost market shares because of competition. If the forecasts turn out to be completely wrong, then the investments will also be out of scale. Since forecasts for new services are uncertain substantial cost risks are generated. Important questions are:

- Introduction time for optimal rollout;

- Which geographic areas should be covered at the start;

- Which market segments should be covered at the start;

- The size of the broadband nodes and the structure are of crucial importance;

- Dimensioning of the network and estimated demand controlled expansion.

The network components and the technology standards induce risks when an operator starts a rollout before the standards have been adapted. Additional investments and replacement of rather new components may be necessary. There are substantial uncertainties related to the prediction of component costs. The learning curve forecasts show that the component costs decrease as a function of large-scale production. However, there is significant uncertainty in the predicted component cost evolution.

Revenue and cost risks

To be able to evaluate a broadband network upgrading, the discounted sum of revenues, investments, operations and maintenance costs etc. has to be calculated over a 5–10 year period. The result can be expressed in net present value, payback period, internal rate of return, installation first costs, lifecycle costs, pay-back each year, etc. Important revenue and cost risks are caused by:

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- Lower tariffs than expected;
- Reduction of service mix;
- Loss of market shares;
- Higher revenue reductions due to substitution effect between other services;
- Higher investment costs than expected;
- Higher operational and maintenance costs than expected;
- Higher administrative costs;
- Higher customer support and marketing costs than expected;
- Investments restrictions due to lower profit or new priorities.

4 Risk methodology

The uncertainty in each assumption has to be quantified with respect to a suitable probability density function including "practical limits for variation for performing risk analysis".

Data collection

All relevant information, specific assumptions, natural limits, and types of distribution as well as confidence intervals have to be collected.

Probability distributions

Suitable probability distributions should be identified for each assumption variable. The choice of probability distribution depends on the restrictions on the variable, whether we need some extra degree of freedom such as asymmetry in the distribution etc. In various fields, e.g. physics, economics and social sciences, empirical data or the law of large numbers determine the choice of distribution, e.g. noise in electrical systems, the evolution of stock prices and people's IQ. IQ values are for example modelled by a normal distribution with mean value 100 for a population (age group) and standard deviation 15. However, one should generally be careful using the Normal distribution in simulations if negative numbers are not allowed.

For instance a market share will always be between 0 % and 100 %, the value of a stock is non-negative but can (theoretically) be of infinite value, and penetration and costs cannot be negative, etc.

Usually Beta distribution and Log Normal are used to model important variables in the business cases. Appendix A gives a more detailed description of how the Beta distribution and Log Normal distribution are fitted.

Risk simulation performance

Output variables have to be identified. Usually net present value, internal rate of return and pay-back period are used to evaluate the economic value of investment projects. Also the number of simulation trials has to be decided. Then the number of trials performed in a simulation shows the impact on the output variable.

Thanks to modern easy-to-use software, Monte Carlo simulations can be performed on standard spreadsheet models on a PC. Such software also has splendid report features, in which the user can specify result tables with the complete statistics of the output variables such as mean value, standard deviation, percentiles, etc.

Random numbers are generated in each trial of the simulation according to the selected distributions generated for each of the selected variables for the risk analysis. The simulation therefore calculates a large number (maybe thousands; the number of simulation trials specified by the user) of what-if scenarios. Equally important: the simulation keeps track of the calculations by measuring the impact on the result from the changes in each of the variables.

In the simulation package called Crystal Ball® [2], "normal" Monte Carlo or *Latin Hypercube Sampling* can be used. In Latin Hypercube Sampling, an assumption's probability distribution is divided into intervals of equal probability, whereas in the former approach the random numbers are picked over the entire range for that distribution.

In general, it is difficult to give advice on the number of simulations since there is a dependency of the complexity in each case study analysed. The best way to control the accuracy is to do some test-simulation series and calculate the uncertainty in the output distributions. Based on experience so far, the sufficient number of simulations could be 500 – 10,000.

Figure 2 illustrates the concept of Monte Carlo simulation. The figure shows how random values are drawn from probability distributions representing input variables 1, 2, 3, ... For each trial a value of the output variable, here NPV, is calculated. By repeating this process 10,000 times a frequency chart (histogram) is generated. Figure 2 shows that the histogram forms a probability distribution for the output variable. The final part of the risk analysis is to interpret the information from the input and output distribution.

Risk analysis

When the simulation is finalised, the complete statistics on the output variable distributions, the correlation between output variables is available and can be extracted in a report, which is an Excel workbook with tables. The samples generated for the input vari-

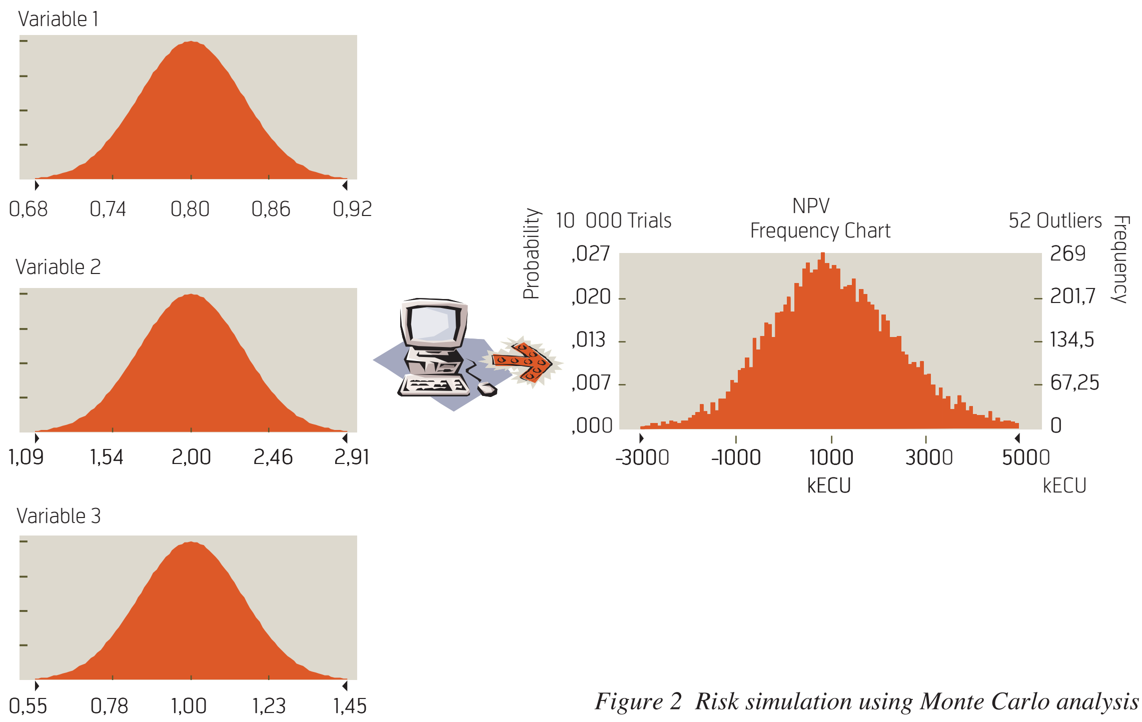

Figure 2 Risk simulation using Monte Carlo analysis

ables can also be saved for further analysis. In addition, the impact of each input variable on the given output variable is measured as well – either in terms of the so-called *Rank Correlation* or the *contribution to the variance*. Both of these metrics will be described in more detail in Appendix B.

An overview of the uncertainties and risks in telecommunication projects is discussed next before moving on to the actual case study in Chapter 5.

5 Risk analysis of ADSL2+/VDSL rollout case study

The six different rollout scenarios described in [1] with different timing and ambition levels of ADSL2+/VDSL rollout are summarised as follows:

Scenario 1: "Market equality, no overlap"
Scenario 2: "Market equality, 50 % overlap"
Scenario 3: "Market equality, 75 % overlap"
Scenario 4: "Incumbent two years delayed"
Scenario 5: "Incumbent one year delayed"
Scenario 6: "Incumbent aggressive rollout "

The base case results [1] are summarised in Figure 3.

To be able to analyse the impact of the uncertainties, the most critical variables have to be identified. In this case study the most important variables are considered to be:

- Adoption rate forecasts
- ARPU
- Broadband content costs
- Sales costs
- Provisioning costs
- Customer operations and maintenance
- Customer installation costs
- Smart card costs
- Line card costs
- Price reduction rate for DSL equipment, i.e. DSLAM rack and linecards.

Table 1 summarises the uncertainty assumptions for each variable. Each selected input variable is described by its default value, upper and lower limit, confidence interval and probability distribution parameters.

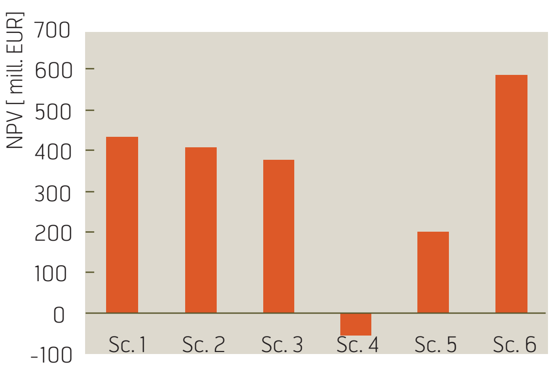

Figure 3 Base case results for the six scenarios

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The broadband demand, the costs and revenues are predicted from 2005 to 2011. The main variables can be grouped by demand, ARPU, which gives the expected revenue, and costs like Capex, Opex and content and sales costs.

Most of the values in the table are specified in EURO. The sales costs and the content costs are expressed as a proportion of the total (ISP + wholesale part) and ISP part of the revenues respectively. The sales costs are 30 % of the total revenue each year. The content costs are 60 % (default) of the ISP part of the revenues in the first two years of operation, 5 % less in year 3 and 4 and then decreasing by 5 % in the following years. Figure 4 shows the default ARPU breakdown.

The demand evolution is based on the adoption rate in year 2011. The adoption rate values in the period 2006 – 2010 are adjusted proportionally according to the simulated 2011 value.

The other variables in the table have reference values for 2005. Based on the reference values, predictions are calculated for the 2006 – 2011 period. In a simulation trial, the reference value has a deviation. Then the predicted values (2006 – 2011) will have a deviation proportional to the predicted size (2006 – 2011) multiplied by the reference value deviation. Since the values of the variables are simulated a large number of times, there will be great variation in the deviations, based on the probability distribution used.

10,000 trials of Hypercube simulation were performed for each of the six scenarios, in order to analyse the impact on the net present value (NPV). The Beta distribution has been used for all input variables. A more detailed description of the Beta distribution is found in Appendix B.

First, three sets of simulations (for each scenario) were carried out:

- All ten variables were simulated;
- Only Adoption Rate and ARPU were simulated (the rest were frozen at default values);
- Only Adoption Rate was simulated (the rest were frozen at default values).

Table 2 summarizes the results for all the three simulation types for the six different scenarios in terms of mean value, standard deviation and 5 % percentile. All values are in mill. EURO.

As can be seen, all six scenarios have negative 5 % percentile values when all ten variables were simulated. The reason is the generally high customer-independent investment combined with high uncertainty

Variable name	Minimum value	5 % percentile	Default value	95 % percentile	Maximum value	α	β
Monthly ARPU	90	95	**100**	108	124.7	5.11	11.16
Line card price	1,200	1,400	**1,600**	1,800	2,000	4.94	4.94
Sales costs	25 %	27.5 %	**30 %**	32.5 %	35 %	4.94	4.94
Provisioning costs	50	60	**65**	70	80	11.77	11.77
Equipment price reduction rate	5 %	8 %	**10 %**	12 %	15 %	8.02	8.02
Adoption rate, final year	26 %	29 %	**32 %**	37 %	42 %	4.02	6.04
Customer installations cost	100	110	**120**	130	140	4.95	4.95
Content costs	50 %	55 %	**60 %**	65 %	70 %	4.95	4.95
Smart card costs	20	25	**30**	35	40	4.94	4.94
Customer operations & maintenance	15	20	**25**	30	35	4.95	4.95

Table 1 Assumptions for probability distributions used in uncertainty and risk calculations

in ARPU and adoption rate. The input variables are independent in the simulations, which means that trials with a combination of a low adoption rate and a low ARPU will give a significantly negative contribution to the NPV.

For all the scenarios it was found that the adoption rate and ARPU in that order were by far the most dominant contributors to the uncertainty in NPV. *The contributions to the NPV variance were in the 48 % – 56 % range for the adoption rate and the 33 % – 38 % range for the ARPU for the six scenarios*. The contributions from the remaining assumptions were therefore small in comparison. Especially the network component costs have a very small impact. This is due to fairly good cost prediction models combined with experiences of cost reduction trends of network components for the last years.

Scenario 6 has the largest NPV and also the highest mean value to standard deviation ratio and is therefore the least risky scenario. Scenario 4 has the smallest NPV (default as well as simulated mean value) and in addition the most negative 5 % percentile (and therefore the highest value at risk; VaR). All the scenarios look quite risky with negative 5 % percentiles in most cases.

As expected, the standard deviation decreases with fewer simulated input variables. As the ARPU and Adoption Rate are the two dominant variables, the most dramatic decrease is seen when going from two variables simulated to only one simulated variable. When only the two dominant variables are simulated, the 5 % percentile turns positive in Scenario 6. When only the adoption rate is simulated, the 5 % percentile also turns positive for the first three scenarios. When only simulating the Adoption Rate, we avoid the negative contribution from trials with low values of both Adoption Rate and ARPU. Therefore the 5 % percentile is improved and the risk therefore reduced even further.

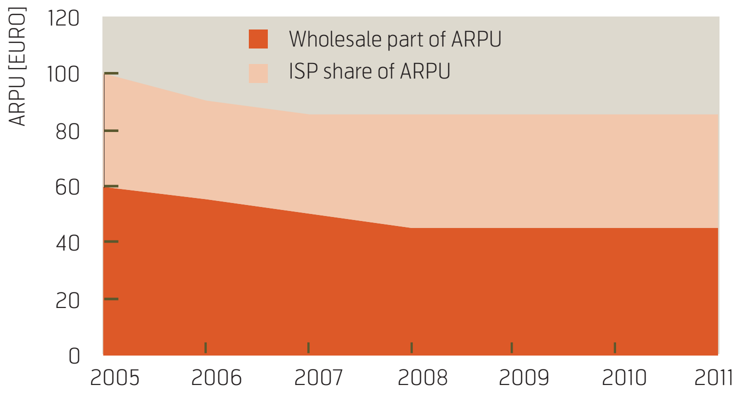

Figure 4 ARPU breakdown

This first batch of simulations was done in order to illustrate that too pessimistic values are generated if we do not take the inherent coupling between ARPU and Adoption Rate into account. This coupling can be modelled by the use of price elasticity models so that the adoption rate will generally increase with a decrease in the monthly tariff. However, such models can be quite complex as other parameters than just price generally influence the adoption rate of services such as brand value, etc. As this kind of price modelling is outside the scope of this paper, we chose to study the impact of introducing a generic negative correlation between the Adoption Rate and the ARPU. The next step was to study the impact of “weak”, “moderate” and “strong” correlation using –0.25, –0.50 and –0.75 respectively for the correlation value. The results are shown in Figure 5 where all variables are simulated.

We see that the risk is reduced remarkably as the 5 percentile is increased significantly due to the reduced standard deviation in each simulation.

Scenario	10 variables simulated			Adoption rate and ARPU			Only Adoption Rate simulated		
	5% perc.	95% perc.	σ	5% perc.	95% perc.	σ	5% perc.	95% perc.	σ
Sc. 1	-48.5	1,155.7	364.1	-5.1	1,114.5	339.5	58.6	928.4	263.4
Sc. 2	-70.6	1,138.4	365.7	-27.4	1,097.3	341.2	37.6	909.7	265.6
Sc. 3	-102.3	1,108.3	366.4	-58.9	1,066.1	341.9	4.3	882.5	266.6
Sc. 4	-376.4	438.5	264.8	-341.4	408.4	227.6	-287.4	261.6	166.7
Sc. 5	-212.0	830.8	315.9	-174.2	795.8	293.8	-112.9	624.9	224.1
Sc. 6	-50.6	1,561.9	487.7	6.0	1,507.2	455.9	90.6	1,256.9	356.1

Table 2 Summary of three types of Monte Carlo simulations – by scenario

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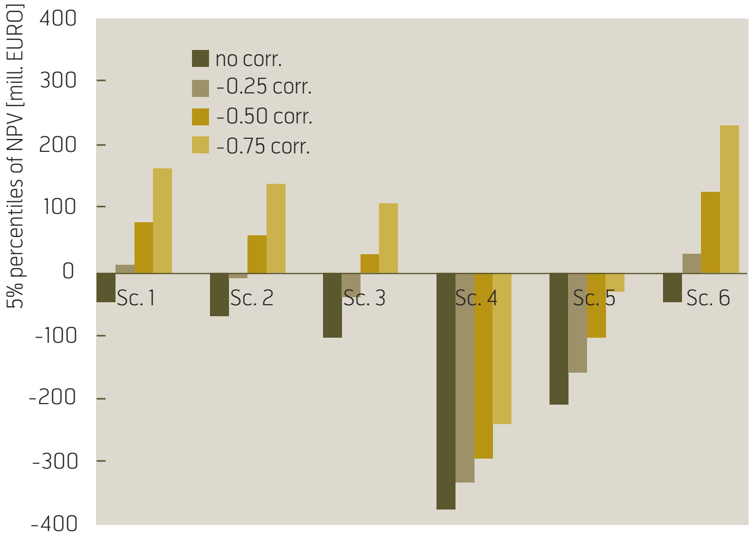

Figure 5 5 % percentiles for various degrees of correlation between ARPU and Adoption Rate. Ten variables simulated

The ranking of the different scenarios with respect to the ranking of NPV and riskiness is however unchanged. Scenario 6 is still the most profitable project and is also the project with the smallest level of risk in terms of mean to standard deviation ratio. Scenario 6 has the highest mean to standard deviation ratio followed by Project 2. We also see that Scenario 4 and Scenario 5 have negative percentiles for all levels of correlation. These two scenarios also have the lowest values of the mean to standard deviation ratio.

For moderate and high correlation, Scenarios 1, 2, 3 and 6 get positive values of the 5 % percentile.

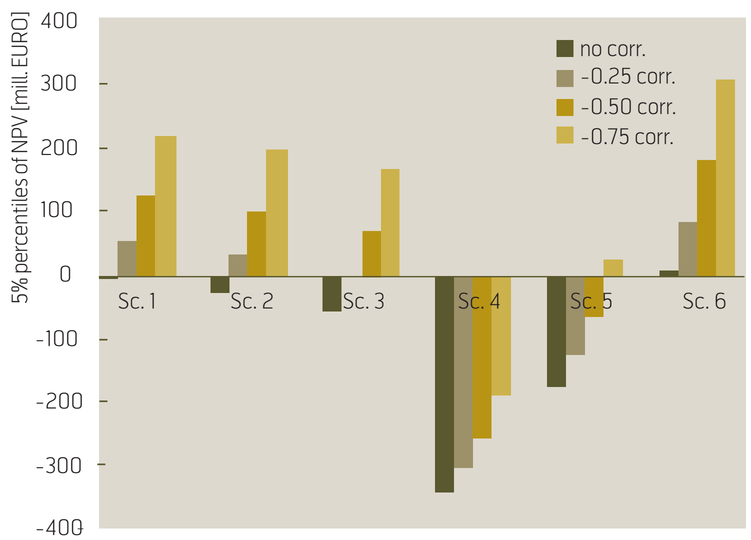

Figure 6 5 % percentiles for various degrees of correlation between ARPU and Adoption Rate. Two dominant variables simulated

The simulation batch with correlation was also carried out where only Adoption Rate and ARPU were simulated. The results are summarized in Figure 6. The same trend and ranking as in Figure 5 are seen but now the standard deviation is even smaller due to the fewer variables simulated.

Scenario 4 and Scenario 5 remain quite risky due to the delay of entry by two years and one year respectively.

It should of course be pointed out that broadband rollouts would be stopped or scaled down if the cash flow is significantly lower than what is expected. Then, the project has to wait until the expected costs decrease or the revenue increases.

For the given assumptions, the strategy of entering the market too late at high coverage as in Scenario 4, is very risky due to lost market shares. The risk picture for Scenarios 1–3 and Scenarios 5–6 is strictly on the pessimistic side, as flexibility in timing is not taken fully into account by considering the given rollout scenarios separately.

An optimal strategy will be to go for a rollout level as in Scenarios 1–3 and scale up the ambition level in coverage as in Scenario 6 only if market conditions are favourable.

6 Conclusions

The objective of the presentation was to show how risk analysis and the related risk framework are used to evaluate business cases on broadband rollout taking the risks into account.

By using Monte Carlo simulations it has been possible to give a more complete picture of the risks in large-scale broadband rollouts. The additional multivariable sensitivity analysis gives the contribution to the NPV variance from all the uncertain assumption variables in the case study. Using the traditional sensitivity analysis concept where all assumption variables are changed one at a time is only useful as a first step in order to pick the dominant ones for further analysis. The reason is that the former concept only shows what is possible – not what is probable.

When not using correlation between variables, all the six scenarios that were investigated had a negative 5 % percentile, i.e. a positive value at risk, and therefore carried significant risk even though four of the scenarios showed a high NPV as well as internal return. By not taking into account the inherent coupling of ARPU and adoption rate what will result is a too high standard deviation and thereby overestimation of the risk. The impact of negative correlation

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between Adoption Rate and ARPU was therefore studied thoroughly. Correlation showed significant impact on the result due to the reduction in standard deviation. For moderate correlation of –0.5, all but the two most risky scenarios (Scenario 4 and Scenario 5) showed positive values of the 5 % percentile. However the ranking of the scenarios in terms of NPV and riskiness remained unchanged. The mean value/standard deviation is a good measure in order to rank projects according to risk.

The risk analysis showed that the adoption rate had the highest impact on risk followed by the ARPU. The prediction of network component costs generated limited risk compared with the adoption rate and the ARPU. The reason is the existence of fairly good cost prediction models combined with experiences of cost reduction trends of network components for the last years.

The methodology described showed its usefulness in identifying the overall uncertainty as well as giving good indications of the ranking of investment projects with respect to risk. We also believe that an extension of the framework taking into account strategic flexibility (if any) would be very useful.

7 Appendix A

In the following, the uncertainty model is described. We give a short description of the Beta and Log Normal distributions and how to calculate relevant parameters from specified values and ranges of the selected uncertainty variables.

Beta distribution:

The Beta distribution has a number of characteristics that makes it useful for most studies:

- It is confined to a specified interval;
- It has sufficient degrees of freedom – it can be symmetric and bell-shaped or asymmetric and peaked.

A Normal distribution is not useful in the modelling of variables that can only have positive values. A Normal distribution with given mean and standard deviation will have a certain probability > 0 that a negative number will be produced. As a result, either meaningless outputs will be generated or the calculation will end with an error message.

The generalised Beta distribution of a variable in the closed interval $[a, b]$ is given by:

$$p(y) = \frac{1}{\mathrm{B}(\alpha,\beta)(b-a)^{\alpha+\beta-1}}(y-a)^{\alpha-1}(b-y)^{\beta-1} \quad \text{(A.1)}$$

where $\mathrm{B}(a, \beta)$ is the Beta function defined by

$$\mathrm{B}(\alpha,\beta) = \frac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha+\beta)} \quad \text{(A.2)}$$

where $\Gamma(z)$ is the gamma function of z, $z \neq 0, -1, -2, -3, \ldots$

In many simulation tools, only the normalised Beta distribution, i.e. $\alpha = 0$ and $\beta = 1$ is available. However, this problem is easily transformed by the linear transformation:

$$Y = f(X) = (b-a)X + a \Leftrightarrow X = \frac{Y-a}{b-a} \quad \text{(A.3)}$$

The most expected value (mode) of the Beta distribution is defined as the value of y for which $\frac{dp(y)}{dy} = 0$. By standard calculus, we get the mode

$$\bar{Y} = (b-a)\frac{\alpha-1}{\alpha+\beta-1} + a \quad \text{(A.4)}$$

and the mode of the normalised Beta distribution

$$\bar{X} = \frac{\alpha-1}{\alpha+\beta-1} \quad \text{(A.5)}$$

It is often easier to relate to a most expected value and a confidence interval of a random variable than the mean value and standard deviation. If q is the confidence interval, Y_L the lower percentile of the confidence interval and Y_H the higher percentile of the confidence interval (by definition $q = H - L$), we must have

$$\int_{Y_L}^{Y_H} p(y)dy = \int_0^{Y_H} p(y)dy - \int_0^{Y_L} p(y)dy = \tilde{\mathrm{B}}(Y_H,\alpha,\beta) - \tilde{\mathrm{B}}(Y_L,\alpha,\beta) = q \quad \text{(A.6)}$$

where $\tilde{\mathrm{B}}(Y,\alpha,\beta)$ is the accumulated Beta distribution of Y with parameters α and β. This function is defined as a built-in function in Excel. When the mode is known, we only get one unknown parameter, namely α. We then have:

$$\beta = \frac{\alpha(1-\bar{X}) + 2\bar{X} - 1}{\bar{X}} = \frac{\alpha(\bar{Y}-a) + 2\bar{Y} - (b+a)}{\bar{Y}-a} \quad \text{(A.7)}$$

α can found by using Solver in Excel.

As an example, we use as default value 15 % for the Beta-distributed variable. The 5 % and 95 % percentiles are chosen as 10 % and 20 % respectively. The minimum and maximum values are set to 5 % and 25 % respectively. Figure 7 shows an implementation in an Excel spreadsheet.

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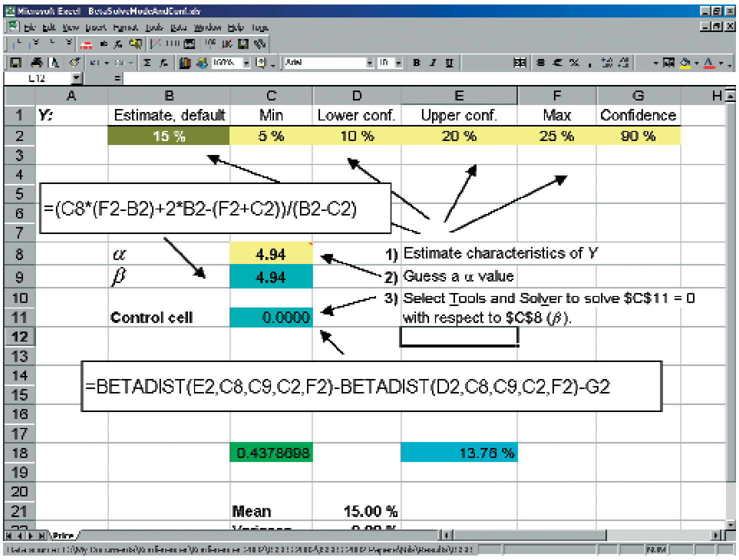

Figure 7 Parameter calculation using Solver and Excel

The Beta distribution can have many shapes depending on the size of the parameters α and β. Figure 8 shows the shapes of the Beta distribution for different combinations of α and β.

The Log Normal distribution:

The Log Normal distribution is often used in modelling random variables that can have non-negative values up to infinity (in principle) as for stock values etc. For a Log Normal distribution, the natural logarithm of the variable is Normal distributed. If the logarithm of the variable of interest, X has a mean and standard deviation of μ_{Log} and σ_{Log} respectively, the probability distribution is defined as:

$$p(x) = \frac{1}{\sqrt{2\pi}\sigma_{\text{Log}}x}\exp\left\{\frac{-[\ln(x)-\mu_{\text{Log}}]^2}{2\sigma_{\text{Log}}^2}\right\} \quad \text{(A.8)}$$

The mode $\bar{X}$, Mean $E(X)$ and variance σ^2 are found by standard calculus as:

$$\bar{X} = \exp(\mu_{\text{Log}} - \sigma_{\text{Log}}^2) \quad \text{(A.9)}$$

$$E(X) = \exp\left(\mu_{\text{Log}} + \frac{\sigma_{\text{Log}}^2}{2}\right) \quad \text{(A.10)}$$

$$\sigma^2 = \exp\left(2\mu_{\text{Log}} + \sigma_{\text{Log}}^2\right)\left(\exp\left(\sigma_{\text{Log}}^2\right) - 1\right) \quad \text{(A.11)}$$

The parameters can be found by using the Solver function, when mode and percentiles, e.g. 5 % and 95 % percentiles are known.

8 Appendix B

In the Monte Carlo simulations approach the input variables are ranked by so-called *rank correlation* or *contribution to variance*.

Rank correlation:

A correlation coefficient measures the strength of the linear relationship between two variables. However, if the two variables do not have the same probability distributions (or at least are very different due to the general non-linear relationships in a model e.g. demand models), *Pearson's correlation* [4] may give misleading results. Therefore the so-called rank cor-

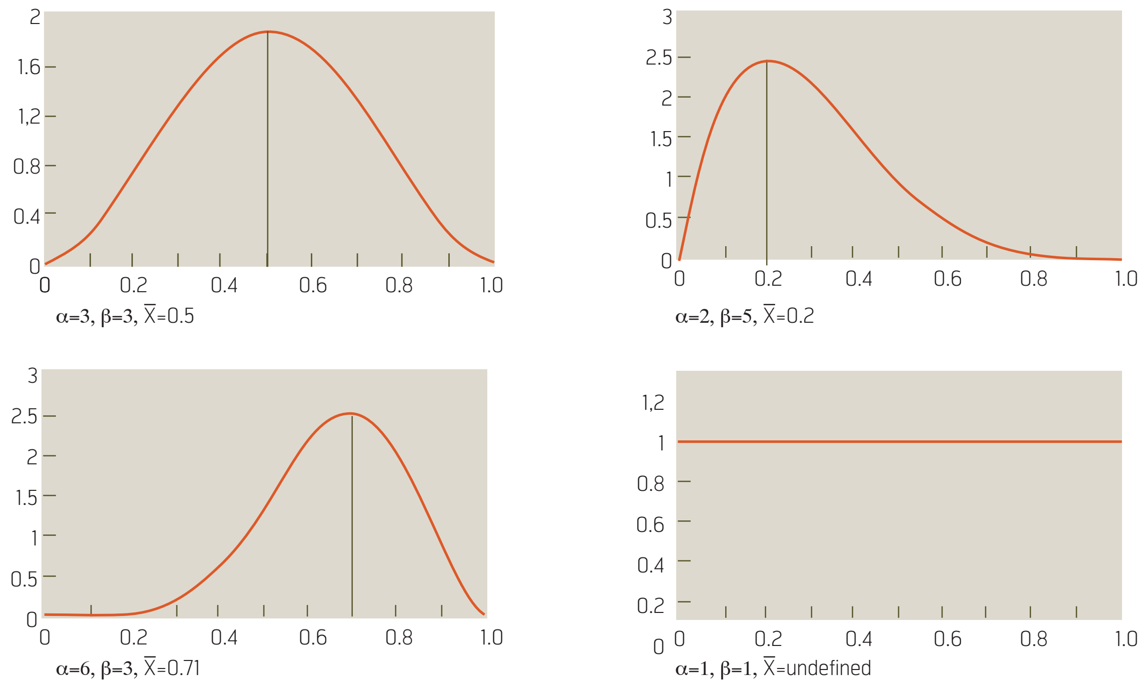

Figure 8 The Beta distribution for various combinations of α and β

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relation or *Spearman rank correlation coefficient* [5] is used. This is the general measure used in most Excel-based commercial software tools. To calculate the rank correlation between two data sample vectors $\bar{A}$ and $\bar{B}$, the data is ranked in order of size using the numbers 1, …, *n*. Rank-correlation is in any case useful when data is not presented in precise samples, which is the case when the number of simulation trials is moderate or small and hypercube sampling (which is more time consuming than standard Monte Carlo sampling!) is not applied.

The rank correlation coefficient is calculated from the following formula:

$$r = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \tag{B.1}$$

where d_i is the difference between ranks of i^{th} sample of $\bar{A}$ and $\bar{B}$ and *n* is the dimension of the arrays. The data can for example be the ranks in two different competitions among five competitors.

Example

$\bar{A} = [5\ 2\ 4\ 1\ 3]$ and $\bar{B} = [3\ 1\ 5\ 2\ 4]$.

We immediately find

$\bar{d} = [2\ 1\ 1\ 1\ 1]$ and $\bar{d}^2 = [4\ 1\ 1\ 1\ 1]$.

$$\sum_{i=1}^{n=5} d_i^2 = 4+1+1+1+1 = 8;\ n^2 = 25$$

We therefore have

$$r_{\text{Rank}} = 1 - \frac{6\times 8}{5\times(25-1)} = 1 - \frac{2}{5} = 0.6.$$

Contribution to total variance:

Crystal Ball® calculates the contribution to variance for variable *i* as

$$C_{Var,i} = \frac{r_i^2}{\sum_{j=1}^{n} r_j^2} \tag{B.2}$$

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For a presentation of Kjell Stordahl please turn to page 2.

Internet traffic dynamics

GARY MADDEN AND GRANT COBLE-NEAL

Gary Madden is a Professor at CEEM, Curtin University of Technology, Perth, Australia

Grant Coble-Neal is a PhD student

The telecommunications industry has evolved at unprecedented rates with current estimates suggesting that seven percent of the world's population now has access to the Internet. However, such growth has stimulated vigorous competition in national and international telecommunications markets leading to a price-cost margin squeeze and unsustainable rates of network expansion. This study demonstrates the reliability of established extrapolation methods for forecasting bandwidth demand and provides network managers with the opportunity to observe Internet traffic dynamics. The ability to anticipate periods of peak use and surplus capacity is likely to pay dividends in terms of a more targeted approach to network expansion plans.

I Introduction

Telecommunications bandwidth has grown at an unprecedented rate in recent years with current estimates suggesting that seven percent of the world's population now has access to the Internet. Indeed, while North America still leads the world in terms of adoption, Table I shows that nearly half of all users now reside outside the Unites States (US). Given the proliferation of telecommunication applications such as Internet browsing, email, Voice over Internet Protocol (VoIP) and video broadband, as well as strong volume growth in the traditional Public Switched Telephone Network (PSTN), it is likely that the growth exhibited in Figure I is likely to continue in the near future. In 1999, for example, standard international telephone traffic grew by over 15 % in 1999 to 107.8 billion minutes. Although VoIP still accounts for only a small fraction of the total voice market, traffic grew tenfold to over 1.7 billion minutes, with the fastest growth occurring in US-developing country outgoing routes (TeleGeography, 2001b).

Not surprisingly, such growth has stimulated vigorous competition in both national and international telecommunications markets. At the national level, countries such as Germany and Israel have experienced spectacular returns to deregulation with long-distance calling market prices dropping 91 % and 94 %, respectively (Newton 2000). Similarly, TeleGeography (2000) global trends suggest that call volume growth has been stimulated largely by successive price cuts. Technology has played a substantial role, initially by least-cost routing arrangements such as callback and traffic refile, and more recently by routing voice and facsimile transmissions through the Internet, thus providing competitors with the means of reducing or avoiding international settlements.

In response, incumbent carriers have sought to increase their scale so as to defend revenues and deter entry by new competitors. According to TeleGeography (2001b), submarine cables increased the aggregate trans-Atlantic bandwidth by a factor of 12 to

Region	Hosts ('000s)	%	Users ('000s)	%
Africa	305.3	0.25	3,337.6	0.77
Asia	10,280.3	8.28	81,733.9	18.73
Europe	23,365.6	18.81	103,827.0	23.80
Oceania	2,297.1	1.85	19,995.1	4.58
Central America	496.0	0.40	1,643.7	0.38
South America	1,367.6	1.10	18,001.1	4.13
North America	86,098.5	69.32	207,734.0	47.62
Total	124,210.3	100.00	436,272.4	100.00

Table I Internet hosts and users by region (Source: Telcordia Technologies, http://www.netsizer.com/)

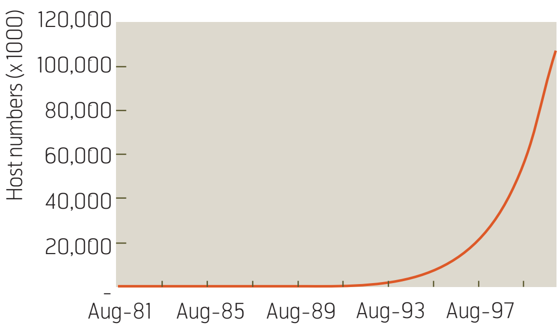

Figure I Internet host growth 1981–2001 (Source: Internet Software Consortium, http://www.isc.org/)

[1] *A terabit is one million million bits.*

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over two terabits per second in just one year.[1)] Overall, telecommunication's three basic building blocks, fibre, digital signal processors and routers, are improving their capacity for throughput ten times faster than the mainstream computer industry (Newton, 2000).[2)] High-speed routers, for example, are now switching terabits of information each second. In addition, laboratory tests show that a fibre strand the width of a human hair can transmit three trillion bits per second, enough to transmit the entire world's Internet (Newton 2000).

However, network expansion is expensive. Construction costs can range from USD 4,000 to USD 3 million per kilometer depending on the choice of upgrade level of dense wavelength-division multiplexing (TeleGeography, 2001a). Similarly, submarine cable installation costs range from USD 0.5 billion for a 10,000 kilometer cable to USD 2.0 billion for 30,000 kilometers. Meanwhile, carriers' mainstream business continues to be cannibalized by the proliferation of Internet Service Providers purchasing flat rate access to upstream network only to offer VoIP to the incumbent carriers' own customer base.

Thus, while telecommunications traffic continues to grow at a rapid rate, networks are expanding at economically unsustainable rates. Such long-term impacts of technological change are always hard to forecast, but that task is especially difficult in the case of e-commerce, where markets are currently very far from equilibrium. In the 'land rush' to secure Internet real estate, to gain first-mover market position and other advantages, many firms are pursuing strategies that are properly interpreted as the payment of one-time, largely sunk entry costs (Borenstein and Saloner 2001).

In this environment, common carriers will need to develop improved forecast models to accurately predict bandwidth demand and target network expansion. This paper uses Internet Traffic Report as a data source that measures Internet bandwidth loads and availability on a continuous basis.[3)] The data is generated by a test called a "ping", which measures round-trip travel time along major paths on the Internet. Several servers in different areas of the globe perform the same ping at the same time and an index based on average response times across test servers is calculated.

The traffic index produces a score in the ranges [0, 100]. A zero score is 'slow' and 100 is 'fast' by comparing the current response of a ping echo to all previous responses from the same router over the past seven days. Response time in reference to Internet traffic is how long it takes for data to travel from point A to point B and back (round trip). A typical response time on the Internet is 200 milliseconds. To be continually accurate and useful, statistics are gathered at many geographically diverse routers and many geographically diverse 'satellite' locations to test from.

This study obtains alternative forecasts of broadband capacity using ARMA, ARARMA, Holt, Holt-D exponential smoothing, Naïve, Robust Trend, as well as a deterministic trend model. The ARMA method is the well-established Box-Jenkins approach to model systematically recurring patterns in stationary data. The ARARMA model, proposed by Parzen (1982), is designed to model long memory processes, using an initial autoregressive specification to filter potentially non-stationary data. Holt's exponential smoothing filters random noise and extrapolates the underlying linear trend contained in the data while Holt's-D models time series as a linear trend decaying towards a constant. Robust Trend essentially models a time series as a stochastic trend with an outlier filter. Thus, the trend is allowed to adapt as observations accumulate while providing a restrained reaction to sudden unexpected pulses in the data. Introduced by Grambsch and Stahel (1990), this technique has been shown to perform best for homogenous telecommunications data by Fildes et al. (1998). Naïve is the simple random walk extrapolation and Trend provides a deterministic alternative to Holt, Holt-D and Robust Trend. Both Naïve and Trend are included as indicative benchmarks with which to compare forecast accuracy of the alternative methods.

The paper is organised as follows: Section II describes sample data, and a discussion of the various forecast models is contained in Section III. Model results are presented in Section IV and concluding remarks are presented in Section V.

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2) *A digital signal processor (DSP) is a specialized micro-processor that performs calculations on digitized signals that were originally analogue (e.g. voice). DSPs are used extensively for echo cancellation, call progress monitoring, voice processing, and voice and video signal compression. Routers are the central switching offices of the Internet and are the interface devices between different network architectures such as x.25, Frame Relay and Asynchronous Transfer Mode. These intelligent devices decide which backbone network to transmit data, monitor the condition of the network and redirect traffic to avoid congestion.*

3) *The Internet Traffic Report URL is http://www.internettrafficreport.com/index.html.*

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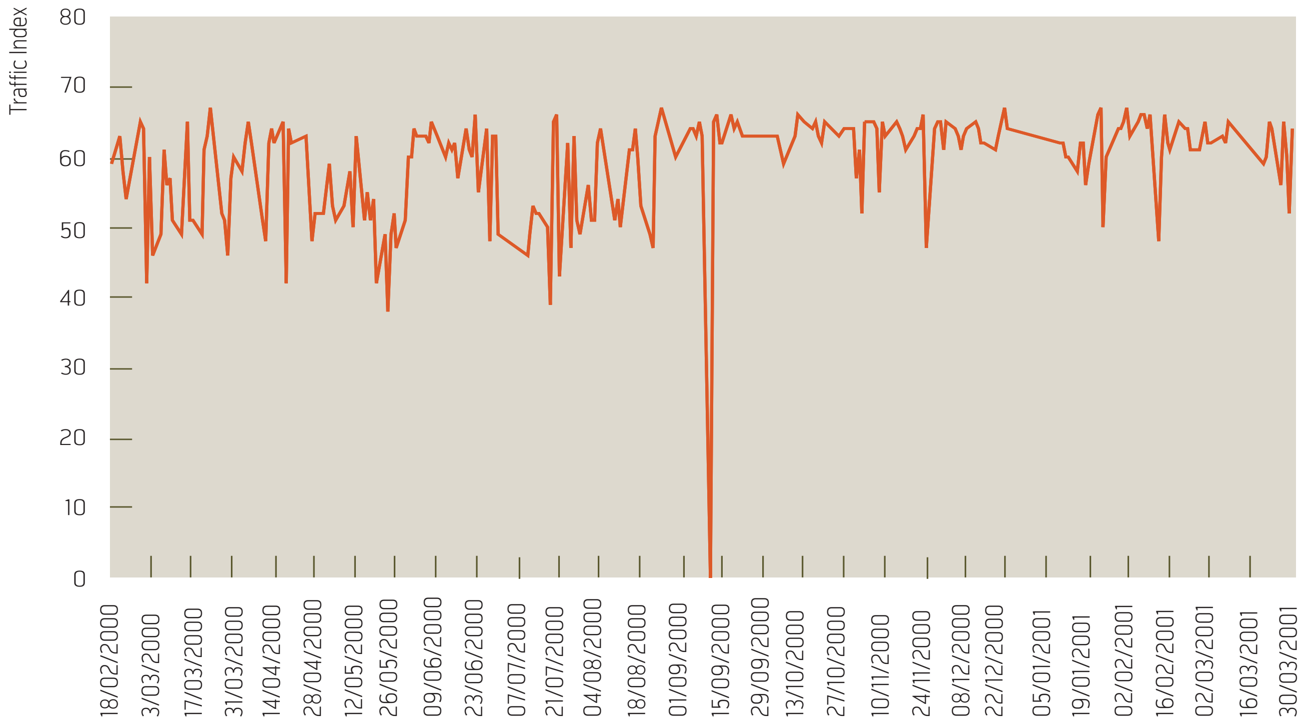

Source: Opinix (2001)

Figure II Japan dm-gw1.kddnet.ad.jp

II Data

The data set described and analyzed in this paper is comprised of 59 time-series, each containing 232 observations. These data are sampled from a continuous data generating process and sampled daily at 7 AM Australian Eastern Standard Time weekdays for the period February 18, 2000 to March 30, 2001. A representative specimen of these data is shown in Figure II. As described, the data oscillate between zero and 100 and appear to exhibit characteristics typical of stationary series. Another feature, which is common to many of the series in this data set, is the sudden downward spike in the series. These spikes indicate brief periods of unusually high congestion and, depending on the motivation for generating forecasts, can either be treated as outliers which are atypical of the series or incorporated in the model as an infrequent but important characteristic of the data generating process.

Summary statistics, reported in Table II, highlight the frequency of the downward spikes with 28 of the 59 routers reporting zero minimum values. Regions represented include East Asia, Australia, Western Europe, Israel, Russia, North America and South America. Absent regions include Antarctica, Africa and most parts of the Middle East. The Denver denver-br2.bbnplanet.net router is recorded as providing the fastest response while AOL1 pop1-dtc.atdn.net has the lowest response time. On average, the Perth1 opera.iinet.net.au router provides the consistently fastest response while Yahoo fe3-0.cr3.SNV.globalcenter.net is typically the slowest.[4)]

Following Fildes (1992) we analyze the series in terms of frequency of outliers, strength of trend, degree of randomness and seasonality, with the results shown in Figure III through Figure V. An observation (X_t) is classed as an outlier if $X_t < L_x - 1.5(U_x - L_x)$ or $X_t > L_x + 1.5(U_x - L_x)$, where L_x denotes the lower quartile and U_x the upper quartile. The strength of trend is measured by the correlation between the series (with outliers removed) and a time trend, with the absolute value of the trend indicating its strength. Randomness is measured by estimating the regression:

$$X'_t = \alpha + \beta t + \delta_1 X'_{t\text{-}1} + \delta_2 X'_{t\text{-}2} + \delta_3 X'_{t\text{-}3}, \qquad (1)$$

where X'_t denotes the series X_t with outliers removed. The adjusted R^2 is used to measure the variation explained by the model. A high R^2 indicates low

4) *Time of day effects and scale of demand may have an impact on router performance. For example, the Perth router services a small market and is likely to have relatively low congestion early in the morning, while in real time, the Yahoo router may be at peak demand in the mid-late afternoon.*

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Router	Average	Std.deviation	Min.	Max.
China2 beijing-bgw1-lan.cernet.net	57.68	10.23	22.00	87.00
HK1 hkt004.hkt.net	58.01	7.54	16.00	72.00
India cust-gw.Teleglobe.net	61.60	8.98	13.00	81.00
Japan dm-gw1.kddnet.ad.jp	58.96	7.54	0.00	67.00
Malay fe1-0.bkj15.jaring.my	56.05	11.53	4.00	79.00
Phil3 tridel-...-inc.Sacramento.cw.net	60.98	5.60	31.00	67.00
Sing1 pi-s1-gw1.pacific.net.sg	58.11	8.39	4.00	69.00
Sing2 gateway.ix.singtel.com	60.81	7.81	27.00	72.00
Taiwan cs4500-fddi0.ficnet.net.tw	59.03	9.06	26.00	77.00
Bris Fddi0-...-core1.Brisbane.telstra.net	61.15	7.92	0.00	69.00
Canb Fddi0-0.civ3.Canberra.telstra.net	61.02	7.55	0.00	68.00
Gosfor Ethernet0.gos2.Gosford.telstra.net	61.44	7.82	0.00	69.00
Melb mc5-a2-0-4.Melbourne.aone.net.au	60.28	7.43	14.00	70.00
Perth1 opera.iinet.net.au	62.63	6.67	0.00	72.00
Perth2 Fddi0-0.wel1.Perth.telstra.net	61.32	8.10	0.00	68.00
Syd1 sc2-exch-fe0.Sydney.aone.net.au	61.04	6.19	27.00	74.00
Syd2 FastEthernet0-...Sydney.telstra.net	60.88	8.03	0.00	70.00
Terri terrigal-gw.terrigal.net.au	52.56	12.99	0.00	69.00
Denmar albnxi3.ip.tele.dk	56.29	9.20	0.00	68.00
Fran1 isicom-gw.iway.fr	53.72	10.68	0.00	67.00
Fran2 rbs2.rain.fr	54.90	8.82	0.00	69.00
Greece athens1.att-unisource.net	60.69	9.79	0.00	71.00
Holl1 amsterdam3.att-unisource.net	58.31	5.83	41.00	70.00
Holl2 hvs01.NL.net	56.23	9.22	3.00	68.00
Ice Reykjavik14ASI.isnet.is	57.81	10.86	0.00	68.00
Israel haifa-rtr.actcom.co.il	61.07	9.26	0.00	75.00
Italy Pa6.seabone.net	60.34	7.47	0.00	70.00
Norway ti09a95.ti.telenor.net	56.32	13.64	0.00	68.00
Russ1 ru-msk-en-1.teleport-tp.net	58.65	11.63	0.00	72.00
Swed1 apv-i1-pos1...-stockholm.telia.net	57.26	10.82	0.00	68.00
Swed2 mlm1-core.swip.net	58.91	6.71	28.00	67.00
UK1 atm0-0-x.lon2gw1.uk.insnet.net	57.92	10.93	0.00	66.00
UK2 access-th-3-e0.router.technocom.net	59.97	8.62	31.00	73.00
AOL1 pop1-dtc.atdn.net	50.04	8.76	15.00	63.00
AOL2 pop1-rtc.atdn.net	50.74	9.22	25.00	64.00
Atlant atlanta1-br1.bbnplanet.net	49.68	10.20	11.00	66.00
Bost1 cambridge1-br1.bbnplanet.net	55.29	11.33	7.00	73.00
Bost2 core3-hssi5-0.Boston.cw.net	49.53	10.58	0.00	65.00
Canad1 core-fa5-0-0.ontario.canet.ca	55.01	8.03	23.00	67.00
Canad2 border6.toronto.istar.net	51.11	15.82	0.00	74.00
Chica1 Fddi0.AR1.CHI1.Alter.Net	53.09	9.19	18.00	69.00
Dallas dallas1-br2.bbnplanet.net	53.25	12.63	0.00	67.00
Denver denver-br2.bbnplanet.net	49.85	13.85	0.00	90.00
Detroi eth1-0-0.michnet1.mich.net	47.91	11.84	2.00	65.00
LA1 borderx2-fddi-1.LosAngeles.cw.net	54.41	9.21	0.00	66.00
LA2 la32-0-br1.ca.us.ibm.net	57.37	6.97	32.00	67.00
Mex4 core2-mexico.uninet.net.mx	54.87	13.09	0.00	69.00
Mex5 dgsca-cs.core-atm.unam.mx	48.60	14.02	2.00	67.00
Mex6 rr1.mexmdf.avantel.net.mx	57.76	10.13	8.00	67.00
NY p2-0-0.nyc4-br1.bbnplanet.net	49.12	9.53	19.00	70.00
Sacram border7-...-0.Sacramento.cw.net	57.30	6.74	28.00	67.00
SanFrn core1.SanFrancisco.cw.net	56.72	7.02	33.00	66.00
Seattl border3-fddi-0.Seattle.cw.net	54.46	9.07	7.00	66.00
Yahoo fe3-0.cr3.SNV.globalcenter.net	46.63	19.09	0.00	67.00
Brazil routrjo07.embratel.net.br	59.67	8.61	15.00	70.00
Chile bwl-gw-net3.rdc.cl	56.88	14.20	0.00	67.00
Colom1 gip-bogota-1-ethernet0-1.gip.net	57.08	11.50	5.00	73.00
Colom2 impsat.net.co	58.85	8.95	13.00	71.00
Venez cha-00-lo0.core.cantv.net	58.63	8.96	0.00	81.00

Table II Summary statistics (Source: Opinix, 2001)

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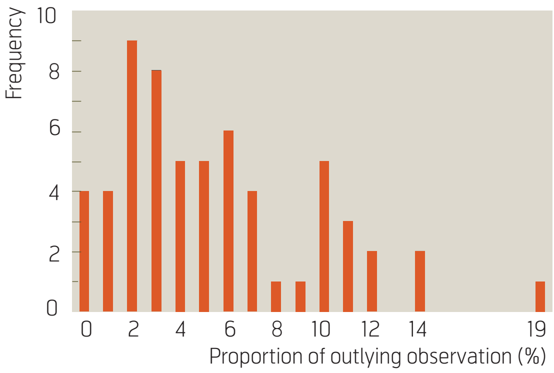

Figure III Outlier frequency

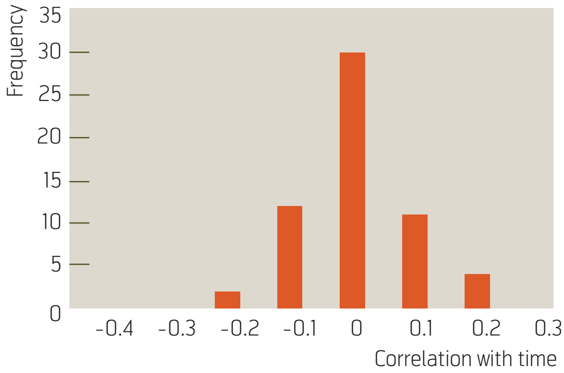

Figure IV Strength of linear trend

randomness while a low R^2 reveals high randomness. Deterministic seasonality is estimated by regressing the series on an intercept and dummy variables which equal one when $t = s$, where t denotes observation X_t's position in time and s corresponds to the frequency of the seasonality. For example, to test the hypothesis that Mondays are statistically different to bandwidth capacity for the rest of the week, $t = \{1, 2, 3, 4, 5, \ldots, T\}$, $s = \{1, 5, 10, 15, \ldots, T\}$ and dummy variable $D_{Monday} = 1$ for $t = s$, zero otherwise.

Figure III reveals that half the series contain between one and five percent outliers. In percentage terms these data appear slightly more heterogeneous than Fildes' (1992) telecommunications data. As indicated in the specimen displayed in Figure II, Figure III shows that the data are generally uncorrelated with time. This contrasts with Fildes (1992) where the data there exhibit strong negative trends. Moreover, the histograms in Figure IV and Figure V reveals the

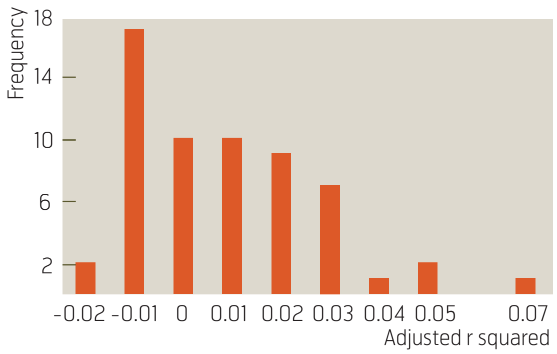

Figure V Variation explained by linear/AR

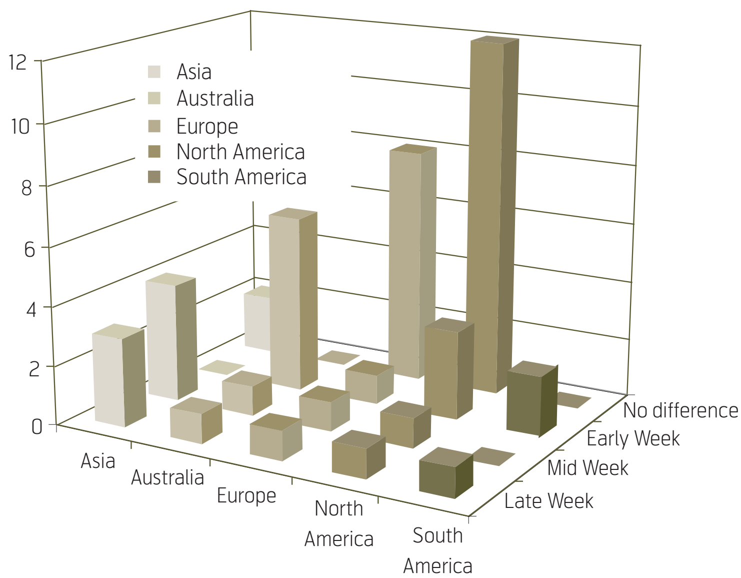

Figure VI Daily variation in capacity utilization

variation in the data presents a high degree of randomness with virtually no serial correlation.

Finally, Figure VI presents some evidence of regularity in weekly capacity variation aggregated by region. As shown, there appear to be regular dips occurring on different days across regions. Asia generally experiences lower traffic volumes across the later part of the week, while the majority of Australian routers have excess capacity in the early part of the week. By contrast, Europe and North America experience relatively smooth traffic flows, possibly reflecting more sophisticated capacity pricing regimes and/or advanced network management systems. Finally, variations in South American Internet traffic are tied to specific routers.

In addition to daily variations in traffic volumes, regressions are conducted to test for regularity in weekly and monthly patterns. Weekly variations are virtually non-existent with only six routers revealing regular spikes across weeks. Surprisingly, given the short time series, significant monthly variation was found in 95 % of routers. Although the sustained increase in traffic is too haphazard across routers to discern a cyclical pattern, most experience statistically significant increases for an average of two months with some routers showing surges of up to three months. Given the nature of the index calculations, this possibly reflects the average lagged response time required before routers are expanded to cope with the increased traffic. Once routers are expanded, the Internet traffic index for the router is likely to increase, reflecting the permanently increased capacity.

Overall, the data series exhibit a high degree of randomness and regular spikes in index scores. Compared to the telecommunications data analyzed in Fildes (1992) and Fildes et al. (1998), these data appear considerably more heterogeneous and less predictable.

III Forecast models and accuracy measures

Forecast models considered are univariate ARMA, ARARMA, Holt, Holt-D exponential smoothing, Robust Trend, with Naïve and Trend benchmarks. All of these forecast methods have been shown to be reliable by Makridakis et al. (1982), Fildes (1992), Fildes et al. (1998) and Makridakis and Hibon (2000) and consistently perform in the annual M-Competition. Implicit in these analyses however, is that the data are nonstationary, while the data analysed here are believed to be stationary. Given this fundamental difference in assumption some of the forecast techniques have been modified to avoid problems associated with over-differencing. For example, the ARMA method is applied rather than ARIMA. ARARMA explicitly questions the practice of differencing to achieve stationarity and has the advantage of utilising information contained in the data normally lost when differencing. Moreover, the approach outlined in Parzen (1982) contains a formal method of determining when it is appropriate to apply the AR filter and hence, the method is adopted intact. Holt and Holt-D methods are techniques for extrapolating the underlying trend that may be present in the data. Although the deterministic trend correlations are mostly zero, short-run trends may prevail and therefore Holt and Holt-D may be appropriate given their simplicity and reliability. However, to ensure the opportunity for accuracy is maximised, the parameter is optimised (rather than being arbitrarily set once) at each time origin as recommended in Fildes et al. (1998). Robust Trend, however, is modified by not differencing the data before calculating the stochastic trend. The perceived advantage in adopting this method is the outlier filter and its use of the median rather than mean in the estimator, which may provide some advantage over the simple random walk extrapolation. Thus for direct comparative purposes, Naïve is included as a benchmark model. If the outliers do not bias the estimates, the forecasts will be hard to improve on, given the reported properties of the data.

The choice of accuracy measures used in this analysis is guided by the recommendations of Armstrong and Collopy (1992). For the reasons outlined in that paper, the Mean Absolute Percentage Error (MAPE), Median Absolute Percentage Error (MdAPE), % Better, Geometric Mean Relative Absolute Error (GMRAE) and Median Relative Absolute Error (MdRAE) are used. Both GMRAE and MdRAE are Winsorized as recommended by Armstrong and Collopy. Mean square error measures are avoided since these statistics are scale dependent and sensitive to outliers.

IV Forecast results

In order to identify forecast methods that perform well four sets of forecasts are created by dividing the data into overlapping time intervals, with each forecast method using 114 observations to forecast over the next 60 observations.[5)] In effect, this approach uses a rolling window beginning at the first observation and steps forward 10 days, re-estimating the forecasts over the next 114 observations. The overall result is 295 forecasts per method with which to judge forecast performance. In evaluating the reliability of the alternative methods, forecasts are compared with actual values retained in the post-sample data.

Table III presents the main results, measuring forecast accuracy in terms of the average absolute error. In general, the various trend extrapolation methods performed better than the more sophisticated ARMA and ARARMA methods while both Holt and Holt-D consistently performed worst.[6)] As shown at the bottom of Table III, the modified Robust Trend method produced the most accurate forecasts approximately 65 % of the time with an average 7.5 % error. Holt-D performed best on a number of occasions, which is probably due to the occasional appearance of weak trends in these data.

5) *60 day forecasts are necessary due to the existence of standard capacity contracts.*

6) *Note that ARMA often provides the same accuracy as the Naïve trend forecast. This is due to the general-to-specific modeling approach that uses the Akaike Information Criterion to identify the best fitting model from a grid of up to six autoregressive and moving average lags. In many cases, this algorithm identified Naïve as the optimal model.*

ISSN 0085-7130

Time origin	Method	Forecasting horizon							
		1	21	41	61	1-6	1-26	1-46	1-61
1	ARARMA	0.04	0.17	0.06	0.17	0.25	0.20	0.14	0.23
	ARMA	0.18	0.13	0.17	0.11	0.12	0.10	0.00	0.05
	Filtered-T	**0.02**	0.18	0.48	**0.02**	0.23	0.20	0.14	-
	Holt	0.23	0.23	0.31	0.34	0.13	0.41	0.49	0.63
	Holt-D	0.07	**0.02**	**0.00**	0.10	0.00	0.19	0.09	0.13
	Naïve	0.18	0.13	0.17	0.11	**0.12**	0.10	**0.00**	**0.05**
	Robust-T	0.03	0.04	0.01	0.05	0.23	**0.02**	0.10	0.05
10	ARARMA	0.26	0.14	0.04	0.19	0.14	0.09	0.08	0.26
	ARMA	0.18	0.13	0.17	0.11	0.12	0.10	0.01	0.04
	Filtered-T	0.06	0.16	0.06	0.07	0.04	0.20	0.00	**0.02**
	Holt	0.05	0.14	0.24	0.52	0.70	0.85	0.92	0.98
	Holt-D	0.07	**0.02**	**0.00**	0.10	**0.04**	0.16	0.06	0.11
	Naïve	0.18	0.13	0.17	0.11	0.12	0.10	**0.01**	0.04
	Robust-T	**0.03**	0.04	0.01	**0.05**	0.23	**0.02**	0.10	0.05
20	ARARMA	0.15	0.04	0.04	0.09	0.31	0.23	**0.00**	0.12
	ARMA	0.18	0.12	0.16	0.11	0.13	0.10	0.01	0.04
	Filtered-T	0.02	0.06	0.05	0.07	0.25	0.20	0.12	0.08
	Holt	141.54	177.14	193.97	233.32	0.97	0.77	1.25	1.34
	Holt-D	2.34	2.61	2.48	2.76	0.13	0.09	0.03	**0.02**
	Naïve	0.16	0.10	0.14	0.09	**0.13**	0.10	0.01	0.04
	Robust-T	**0.03**	**0.04**	**0.01**	**0.05**	0.23	**0.02**	0.10	0.05
30	ARARMA	**0.03**	**0.02**	0.60	**0.04**	0.13	0.24	0.14	0.23
	ARMA	0.16	0.10	0.14	0.09	0.12	0.10	0.01	0.04
	Filtered-T	0.21	0.02	0.00	0.05	**0.00**	0.11	0.07	0.21
	Holt	2.19	2.94	3.61	4.71	311.88	292.82	376.52	392.73
	Holt-D	0.10	0.02	0.04	0.05	0.07	0.15	0.05	0.10
	Naïve	0.17	0.12	0.16	0.10	0.13	0.10	**0.01**	**0.04**
	Robust-T	0.03	0.04	**0.01**	0.05	0.23	**0.02**	0.10	0.05
Mean	ARARMA	0.12	0.09	0.19	0.12	0.21	0.19	0.09	0.21
	ARMA	0.17	0.12	0.16	0.10	0.12	0.10	0.01	0.04
	Filtered-T	0.08	0.10	0.15	0.05	0.13	0.18	0.08	0.08
	Holt	36.00	45.11	49.54	59.72	78.42	73.71	94.79	98.92
	Holt-D	0.65	0.66	0.63	0.75	**0.06**	0.15	0.06	0.09
	Naive	0.17	0.12	0.16	0.10	0.12	0.10	**0.01**	**0.04**
	Robust-T	**0.03**	**0.04**	**0.01**	**0.05**	0.23	**0.02**	0.10	0.05

Table III Mean absolute percentage error. Note: Bolded minimum MAPE statistic indicates best performing method

Further evaluation is provided in Table IV, which presents the GMRAE and MdRAE forecast error measures. Both GMRAE and MdRAE compare each method to a no change benchmark forecast for comparative purposes. Thus, a score less than one indicate the forecast method is at least more reliable than the simplest extrapolation. Using these criteria, it is apparent that both Filtered Trend and Robust Trend consistently outperform the alternatives.

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A factor often considered important is the variation in forecast accuracy over the forecast horizon. For example, evidence from M-Competition results indicates that some methods are better for short-term forecasts, while others perform best over a longer horizon. Examination of Figure VII, which shows forecast errors for the time period with the least number of outliers, indicates that Holt-D reliably forecast variation in bandwidth capacity for period one through 41, closely followed by Robust Trend. Interestingly, ARMA proved most resistant to the disturbance experienced for periods 46 through 60. A possible explanation for this is the ability of the ARMA method to better model periodic spikes in congestion while both Robust and Filtered Trend provide a muted adaptation to sudden large disturbances.

Figure VIII presents MdRAE statistics calculated across all time origins. This statistic provides a measure that is less susceptible to distortion than the MAPE for series where actual values frequently take zero values. As shown, this measure more clearly distinguishes the performance of the alternatives. Holt-D and Holt (omitted due to substantially larger error measures) are by far the worst performers. By contrast, ARMA, Filtered and Robust Trend are clustered closely together ranging between 0.5 and one. Not surprisingly, ARMA indicates greater variability with occasional brief spikes above one and below 0.5 while both trend models produce a more consistent estimate. Of interest is the robustness of these methods with little deterioration as the forecast horizon increases.

Finally, Table V reveals the proportion of times each forecast performed better than the random walk extrapolation across 295 forecasts. Clearly, both Naïve and Robust Trend are the most consistent with the results showing that forecasters can expect these methods to perform better than random walk extrapolation 60 % of the time. As a comparison of best to worst, Robust Trend is on average six times more accurate than Holt.

Overall, the results show that bandwidth capacity can be reliably forecast. The MAPE statistics show that Robust Trend tracks the actual index value with average variation of 7.5 % while ARMA is capable of corroborating long horizon forecasts. The inherent stationarity of these data may explain the relative failure of Holt and Holt-D. Both models work best with non-stationary data with a substantial noise-to-signal ratio. Implicit in the implementation of these models is that model parameters are optimized by first- and second-differencing series. The consequence of over-differencing data is the introduction of a unit-root in the error term and estimation of spurious trends.

	Geometric Mean RAE					
Method	1	12	24	36	48	60
ARARMA	1.24	1.78	1.87	1.24	1.65	1.54
ARMA	0.99	0.80	0.79	1.00	0.93	1.05
Filtered-T	**0.98**	0.57	**0.75**	0.70	0.63	**0.77**
Holt	4.50	5.39	4.79	6.17	5.76	5.61
Holt-D	1.37	1.23	1.11	1.34	1.23	1.24
Naïve	0.99	0.80	0.79	0.98	0.93	1.05
Robust-T	1.10	**0.50**	1.13	**0.67**	**0.50**	1.00
	Median RAE					
ARARMA	1.37	2.10	1.92	1.31	2.02	1.53
ARMA	1.00	0.74	**0.80**	0.99	0.94	1.01
Filtered-T	**0.97**	0.65	0.87	0.91	**0.77**	**0.83**
Holt	7.54	8.19	7.32	8.24	8.20	8.28
Holt-D	2.81	2.88	2.77	3.01	3.14	2.92
Naïve	1.00	0.73	0.81	0.98	0.96	1.01
Robust-T	1.25	**0.56**	1.17	**0.90**	0.64	1.08

Table IV Geometric mean RAE and median RAE. Note: Bolded statistic indicates best performing method

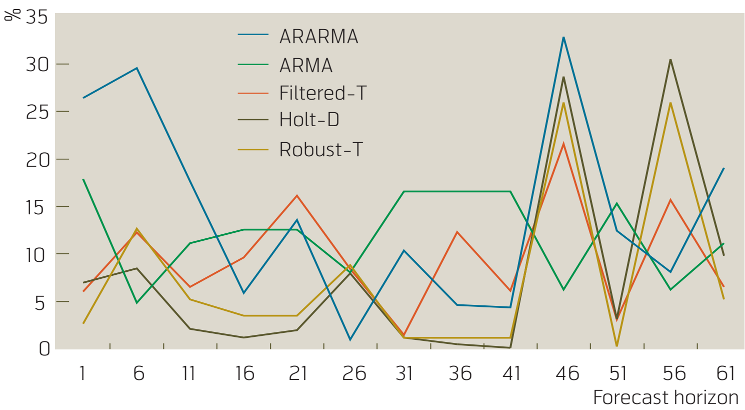

Figure VII Mean absolute percentage error for time origin 10

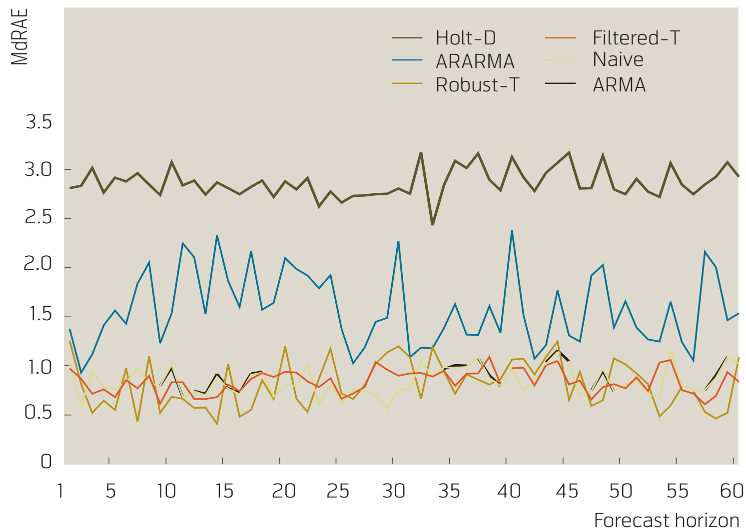

Figure VIII Median relative absolute error across all time origins Note: Holt omitted form chart to show detail

 ISSN 0085-7130

Method	Forecast horizon										
	1	6	12	18	24	30	36	42	48	54	60
ARARMA	37	41	28	43	35	26	44	48	38	41	31
ARMA	51	58	55	54	64	64	51	61	52	46	49
Filtered-T	47	53	62	53	51	41	53	55	59	47	**56**
Holt	11	12	8	14	10	7	6	6	8	6	8
Holt-D	43	48	47	44	55	51	43	53	45	42	43
Naïve	**51**	**58**	55	54	**65**	**64**	51	**61**	51	46	49
Robust-T	32	51	**63**	**56**	32	37	**53**	54	**68**	**63**	36

Table V Percent better. Note: Bold indicates best performing method

V Conclusion

Telecommunications bandwidth has grown recently at an unprecedented rate with current estimates suggesting that seven percent of the world's population now has access to the Internet. However, globalisation of the telecommunications industry has led to unsustainable network expansion. In the future, carriers will need to develop accurate forecasts as an aid to a carefully targeted approach to expansion plans. This study demonstrates that relatively simple extrapolation techniques can provide a useful input into explaining broadband traffic movements.

The forecast techniques adopted here are extrapolation methods that have performed well in the M-Competition and are easily implemented. This study also highlights the need to better understand data generation characteristics, at least in a broad sense, and suggests that mechanically differencing data without reference to the characteristics exhibited data can yield substantially inferior results. Finally, despite the high degree of randomness and the high frequency of outliers, Robust Trend again performed best for telecommunications data.

In general, however, univariate extrapolation techniques can at best provide systematic benchmarks on observed data. For more insightful analysis, it is necessary to develop structural economic models using price, income data and traffic data. Among the benefits of such models are the ability to anticipate cyclical fluctuations due to economic factors external to the telecommunications industry, the estimation of price and income elasticities and as a means of determining the degree of reaction and interaction between competitors. The important distinction in adopting this approach is that economic analysis relates to the market for the service that generates these traffic flows. The release of such competitive intelligence would likely provide carriers with substantially great benefits and help to ensure maximal returns to their increasingly scarce investment funds.

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Appendix AI Routers by geographic region

Router	Location	Current index	Response time (ms)
Asia			
beijing-bgw1-lan.cernet.net	China	66	287
hkt004.hkt.net	HongKong	61	267
cust-gw.Teleglobe.net	India	65	331
tlv-L1.netvision.net.il	Israel	66	471
haifa-rtr.actcom.co.il	Israel	67	262
hfa-L1.netvision.net.il	Israel	61	544
gsr-ote1.kddnet.ad.jp	Japan	66	201
doji-alp2-2-1-3-1.mcnet.ad.jp	Japan	65	216
POS0-2.oskg2.idc.ad.jp	Japan	65	201
fe1-0.bkj15.jaring.my	Malaysia	66	263
pi-s1-gw1.pacific.net.sg	Singapore	66	334
gateway.ix.singtel.com	Singapore	66	285
cs4500-fddi0.ficnet.net.tw	Taiwan	66	264
ntt-pc-communications.Tokyo.cw.net	Tokyo	66	211
Australia			
GigabitEthernet5-1.cha-..brisbane.telstra.net	Brisbane	66	418
Pos6-0.woo-core1.Brisbane.telstra.net	Brisbane	66	427
Fddi0-0.civ3.Canberra.telstra.net	Canberra	64	417
border-gw03-atm301.powertel.net.au	Gold Coast	57	373
Ethernet0.gos2.Gosford.telstra.net	Gosford	66	397
mc5-a2-0-4.Melbourne.aone.net.au	Melbourne	0	0
Pos5-0.exi-core1.Melbourne.telstra.net	Melbourne	66	401
So-0-0-1.XR1.MEL1.ALTER.NET	Melbourne	64	301
opera.iinet.net.au	Perth	63	351
Fddi0-0.wel1.Perth.telstra.net	Perth	66	344
c3600.elink.net.au	Perth	66	328
sc2-exch-fe0.Sydney.aone.net.au	Sydney	65	282
FastEthernet0-0-0.pad8.Sydney.telstra.net	Sydney	66	403
So-3-3-1.XR2.SYD2.ALTER.NET	Sydney	63	296
FastEthernet0-0-0.pad13.Sydney.telstra.net	Sydney	66	400
bb2-gige5-0.rdc1.nsw.excitehome.net.au	Sydney	66	261
terrigal-gw.terrigal.net.au	Terrigal	64	554
Europe			
albnxi3.ip.tele.dk	Denmark	67	189
r3-AT2-0-1-Pas5.Hel.FI.KPNQwest.net	Finland	67	228
isicom-gw.iway.fr	France	64	206
rbs2.rain.fr	France	53	239
feth-0-1-0.cr1.Stuttgart.seicom.NET	Germany	67	243
athens5.gr.eqip.net	Greece	66	264
amsterdam51.nl.eqip.net	Holland	66	180
194.atm1-0-0.hr1.ams6.nl.uu.net	Holland	66	194
Reykjavik14ASI.isnet.is	Iceland	65	196

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Pa6.seabone.net	Italy	66	255
core1-pos8-0.telehouse.ukcore.bt.net	London	66	205
core2-6.csc-1.ldn5.psie.net	London	63	190
zcr1-so-1-0-0.Londonlnt.cw.net	London	65	185
core1-gig2-0.bletchley.ukcore.bt.net	Milton Keynes	65	177
r2-Se0-1-0.0.ledn-KQ1.NL.kpnqwest.net	Netherlands	65	209
ti09a95.ti.telenor.net	Norway	67	257
cisco0.Moscow.ST.NET	Russia	65	241
bgw-ser5-0-0.Moscow.Rostelecom.ru	Russia	65	249
apv-i1-pos1-0-0-int-stockholm.telia.net	Sweden	66	212
mlm1-core.swip.net	Sweden	65	200
atm0-0-x.lon2gw1.uk.insnet.net	UK	63	188
access-th-3-e0.router.technocom.net	UK	65	180
pos3-0.cr1.lnd5.gbb.uk.uu.net	UK	64	180
North America			
pos4-1-0-622M.cr1.ANA2.gblx.net	Anaheim	66	113
pop1-dtc.atdn.net	AOL	65	137
pop1-rtc.atdn.net	AOL	65	137
atlanta1-br1.bbnplanet.net	Atlanta	66	120
cambridge1-br1.bbnplanet.net	Boston	41	178
core3-hssi5-0.Boston.cw.net	Boston	0	0
pos1-0-0-155M.ar1.BOS1.gblx.net	Boston	65	115
core-fa5-0-0.ontario.canet.ca	Canada	66	123
chi-core-03.inet.qwest.net	Chicago	66	80
Fddi0.AR1.CHI1.Alter.Net	Chicago	65	83
c1-pos2-0.chcgil1.home.net	Chicago	66	80
router.mitchell.edu	Connecticut	61	138
dallas1-br2.bbnplanet.net	Dallas	65	105
dllstx1wcx2-oc48.ipcc.wcg.net	Dallas	65	115
denver-br2.bbnplanet.net	Denver	64	106
so-1-0-0-3.mp1.Denver1.level3.net	Denver	0	0
eth1-0-0.michnet1.mich.net	Detroit	53	112
borderx2-fddi-1.LosAngeles.cw.net	Los Angeles	64	119
la32-0-br1.ca.us.ibm.net	Los Angeles	63	109
mae-west.wenet.net	MAE West	0	0
ar8.mexmdf.avantel.net.mx	Mexico	65	154
core2-mexico.uninet.net.mx	Mexico	67	149
rr1.mexmdf.avantel.net.mx	Mexico	66	152
inet-mex-roma-3-g5-0-0.mex.uninet.net.mx	Mexico	65	147
if-9-0.core2.Montreal.Teleglobe.net	Montreal	65	136
vsnl-c-o-cwc.NewYorknyr.cw.net	New York	65	542
p2-0-0.nyc4-br1.bbnplanet.net	New York	64	107
ge12-0-0.access1.hud-ny.us.xo.net	New York	66	100
sl-gw9-nyc-8-0.sprintlink.net	New York	65	114
TelecomItaliaMumbi1.so-...-NYC2.gblx.net	New York	65	330
ix-10-0-1.bb6.NewYork.Teleglobe.net	New York	66	318

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gsr01.spo.embratel.net.br	Brazil	66	246
fast5-cr2-net5.attla.cl	Chile	65	268
telefonica-mundo-chile-no-rev-dns	Chile	65	218
gip-bogota-1-ethernet0-1.gip.net	Colombia	66	223
cha-00-lo0.core.cantv.net	Venezuela	65	190

Gary Madden is a Professor in the Department of Economics and Director of the Communication Economics and Electronic Markets Research Centre (CEEM) at Curtin University of Technology in Perth, Australia. His research is primarily focussed on examining empirical aspects of electronic, information and communications markets. His research funding, which supports CEEM, has come from industry, government and the Australian Research Council. Gary is Editor of the Edward Elgar series, the International Handbook of Telecommunications Economics, Volumes I-III. He is a Member of the Board of Management of the Internatinal Telecommunications Society and a Member of the Editorial Board of the Journal of Media Economics.

email: MaddenG@cbs.curtin.edu.au

Grant Coble-Neal was a Research Associate at CEEM, Curtin University from 1999 to 2003. He is currently completing his PhD under Gary Madden's supervision.

email: CobleG@cbs.curtin.edu.au

Telecommunications demand forecasting with intermodal competition – A multi-equation modeling approach

DAVID G. LOOMIS AND CHRISTOPHER M. SWANN

David G. Loomis is Co-Director of the Institute for Regulatory Policy Studies

Christopher M. Swann is a Senior Economist at Global Insight

The tremendous changes in the telecommunications market have caused new difficulties for the telecommunications forecasting professional. Forecasters have always modeled the impact of economic and demographic variables on their products and services but have largely ignored the influence of technology and policy decisions. Yet these decisions are generating substantial shifts in demand, and forecasts can no longer account for them in an ad hoc manner.

In addition to the impact of technology and policy, consumer behavior itself has changed. Customers are readily substituting wireless phone for wireline service and broadband services for second lines. No longer are forecasters able to produce stand-alone equations that only consider an individual product or service.[1] Important linkages that mimic the convergence that has been long talked about are now critical to the forecasting process. Yet, from a corporate perspective product-specific forecasts are still a necessary input to the business plan and to investment decisions. Thus there is a need to model individual products while directly accounting for intermodal competition.

In this paper, we describe the framework for a forecasting system that explicitly accounts for the linkages between various telecommunications products while retaining the ability to forecast by product line. We also show how this framework can be used to forecast a disruptive technology with serious policy decisions using the example of Voice over IP (VoIP).

Introduction

Changes in industry structure have come from a number of sources including (1) pro-competitive changes in regulatory policy designed to open franchise monopoly markets, stimulate new capital investment and investment in technology, and (2) technology changes for users and service providers. To anyone who has tracked the industry with typical indicators, these changes have obviously manifested themselves in the data.

This modeling effort is an extension of our work that looked at competition in local exchange markets.[2] Initially we were interested in looking at competition in the local loop after the initial deregulation efforts in the US began with the Telecommunications Act of 1996. However it became clear that as digital technology and new entry by PCS carriers into duopoly cellular markets created new price competition in mobile markets, that wireline services, and especially long distance services, were being adversely affected.

With the growth of the Internet incumbent and competitive local exchange carriers began offering high speed service in the form of DSL, while the cable industry pushed ahead with its own cable modem offering.[3] The decline in access lines was an apparent response of substituting these high-speed services for the additional lines used for dial up Internet access. We set about to incorporate intermodal competition into our study and measure the impact of wireless and high speed services on switched access lines.

Typically, telecommunications industry modeling and impact analysis is more of a top-down process with assumptions about prices and economic influences flowing through the telecommunications sector and related sectors. During the 1990s boom period in the US the links *from* the telecommunications services and equipment sector and information technology (computers, software, and premises network equipment) sector to the macro economy became visible. The adoption of the Internet in the consumer market and commercial markets as a new medium for information, communications, and transactions was a profound development. The Y2K equipment build up exceeded the mere replacement of existing information capital. New IT and new network communica-

1) *Loomis, David G, "Forecasting New Products and the Impact of Competition," in* The Future of the Telecommunications Industry: Forecasting and Demand Analysis, *David G. Loomis and Lester D. Taylor, eds., Kluwer Academic Publishers, Boston, 1999.*

2) *Loomis, David G and Christopher M Swann, "Intermodal Competition in Local Telecommunications Markets,"* Information Economics and Policy, *2005, 97–113.*

3) *Loomis, David G, "U.S. Broadband Pricing and Alternatives or Internet Service Providers," in* Forecasting the Internet: Understandng the Explosive Growth of Data Communications, *David G. Loomis and Lester D. Taylor, eds, Kluwer Academic Publishers, Boston, 2002.*

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tions capital accompanied new business processes as the re-engineering of US businesses and the growth in de novo markets developed.

The visibility of those links, however, became all too apparent during the aftermath of the implosion in the technology sector when investment collapsed. This episode – beginning with the acknowledgement of the importance of technology to commerce – makes it important to link changes in service demand and equipment and infrastructure investment to the macro economy.

In this paper we present the framework for a multi-equation forecasting and simulation model for the US telecommunications industry. We present an overview to the model in the next section, in which we show our current model design and several key equations. We follow with an application that traces the path through the dynamic changes.

Description of the model

Model design and key features

There has been and will continue to be enormous structural change in the US telecommunications industry. Legislative and regulatory changes have been the driving forces behind deregulation policies that have been taking place since the Consent Decree of 1982, when long distance markets were opened to competition. The Telecommunications Act of 1996 has similarly spawned a huge reaction to the objective of opening local telecommunications markets and a dearth of alternative communications and network alternatives including mobile wireless, digital communications such as email and online information services, and a growth in local and wide area networks.

Forecasting telecommunications demand, and particularly the demand for any legacy service, in the face of these huge structural changes must take account of important factors and cross-elastic impacts. Single equation estimates necessarily must give way to a total industry, multi-equation approach that can flexibly adapt simulation techniques. The latter approach allows for the interaction of key variables in submarkets, and for new technologies and services for which there is no historical data. Our model is designed to incorporate these features by addressing the industry level, in a multi-equation simulation framework in order to forecast key industry variables, evaluate the impact of alternative technologies and policy, and develop simulations based on alternative paths of variables.

Figure 1 presents an overall schematic for the core model. On the right half of the diagram are three blocks of equations. The core telecommunications markets are represented in three blocks: (1) Broadband Services, (2) Wireless Services, and (3) Wireline Services. Broadband services here include DSL, cable modem, and satellite and other services. Wireless services currently include mobile wireless subscribers and usage only. Both of these equation blocks feed recursively into the wireline services block which includes primary switched access lines, additional access lines, local and long distance switched usage, and business special access lines. These recursive relations add direct intermodal substitution effects to the cross-price impacts in the demand equations for broadband, wireless and switched access lines.

Figure 2 shows explicit variables contained in each of the equation blocks. In the upper left, exogenous demographic variables, national and state economic variables, industry variables feed forward into prices and into fundamental demand blocks. Demographic variables, including household and population levels along with age and income distributions, were obtained through the US Census and Bureau of Labor Statistics. Business formation variables include the number of establishments and level of employment by industry, also from the US Census. Forecasts for all of these variables are taken as exogenous from Global Insight, Inc.

The demand relationships that are estimated at the industry level explicitly account for changes in population demographics and business demographics that include establishments and employment by industry as measures of industry end-user presence. Income levels and distribution and important regional economic variables supplement these fundamental drivers. A list of variables for the core demand equations is contained in Figure 3.

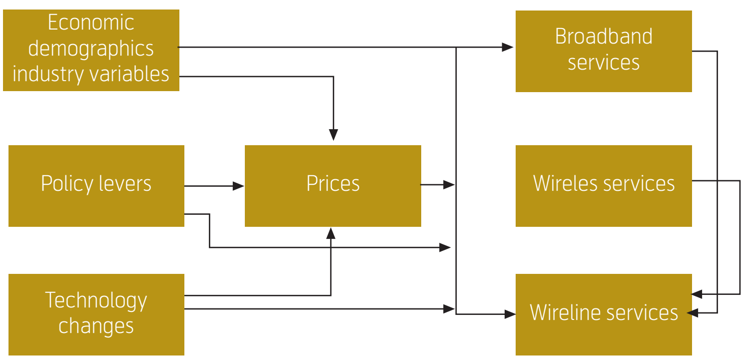

Figure 1 Overall model schematic

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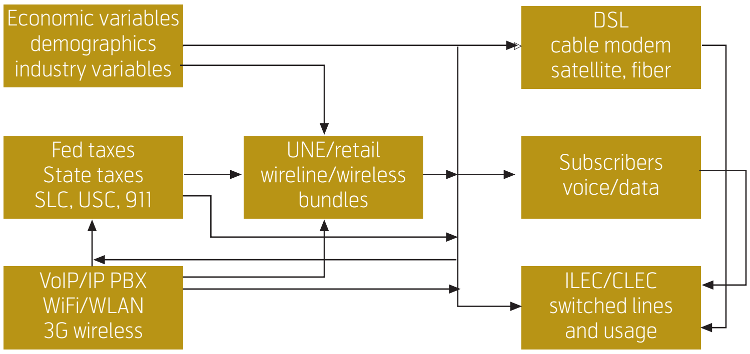


Figure 2 Variable details

Endogenous Variable	Independent Variables
Block: Broadband	
Lines – DSL, Cable Modem	Internet access price Local price Long distance price Income (real)
Block: Wireless	
Subscribers	Population Population age distribution Wireless price Long distance price
Block: Wireline	
Switched lines – ILEC, CLEC	Households Local price Wireless price Long distance price Internet access price Wireless subscribers (lagged) Broadband subscribers (lagged) Density (population per square mile)

Figure 3 Variables and core equations

Policy levers currently include state and Federal taxes, Subscriber Line Charges, Universal Service Charges, and prices for Unbundled Network Elements by state.[4)] The model can be modified to incorporate changes in technology that affect prices and demand for alternative services. For example, Voice over IP (VoIP) is conditional upon the availability of broadband and will likely have a lag relationship to it. Projected adoption of VoIP will put downward pressure on prices and induce cross-elastic substitution from legacy switched services. All of these relationships can be readily adapted to the existing model.

The model is built at the state level in order to incorporate cross-sectional as well as time variation into the estimates. Ultimately this level of disaggregation will permit evaluating the distributional impact of forecasts, competition and policy alternatives. Retail and wholesale prices in wireline services within local markets are still set by regulatory policy, usually at the state level. However the path of prices in many markets – wireless and broadband – is typically subject to market forces and consequently will be constructed to permit endogenously determined by entry conditions and actual number of suppliers. The price block contains exogenous prices and endogenously determined prices as well.

Because technological change plays an enormous role in the telecommunications industry, we are attempting to model major changes on the end-user side and on the carrier side in order to simulate alternative scenarios and measure the impact on the industry. For example, we are currently modeling Voice over IP explicitly based on assumptions about broadband penetration and growth. Figure 4 shows the block flows that are part of our model design and the flows are marked sequentially.

Broadband adoption affects local market competition and ILEC/CLEC shares because of the direct substitution (intermodal competition) of broadband lines for switched access lines. In turn ILEC/CLEC competition affects the broadband choices between the dominant local service carrier and alternative carriers, particularly cable modem. The size of the broadband subscriber base constitutes the addressable VoIP market and therefore we model VoIP adoption conditional upon the broadband base. As voice usage shifts from the switched network to the Internet, revenue shares of carriers will be affected, excess capacity on the switched network will result, and potentially, new equipment investment by users and carriers will be necessary. Finally, since current US regulatory policy exempts VoIP from state and local taxation, state and

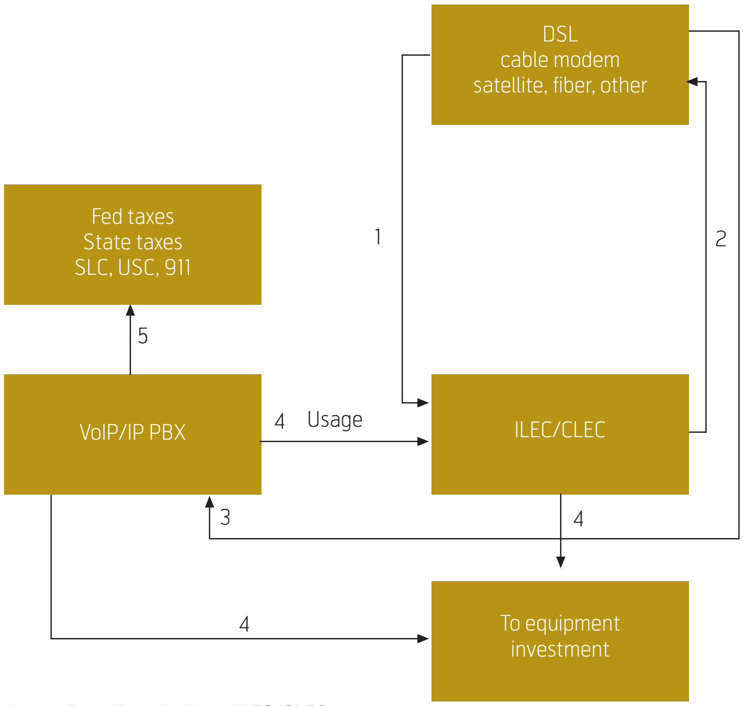
4) *Subscriber Line Charges were created by the Federal Communications Commission after the divestiture of AT&T to replace the cross-subsidies that long distance revenues provided to keep local telephone rates low. Subscriber line charges are billed to the end-user and have risen from $1 in 1985 to over $6 by 2003. Universal Service charges were created by the Federal Communications Commission as a result of the Telecommunications Act of 1996 which required all universal service subsidies to be made explicit. Each telecommunications provider pays into the universal service fund but the method of recovering these charges from end-users is left to the carrier. Some carriers set a per-line fee while others charge a percentage of the customer's total bill. Unbundled Network Elements, also a result of the Telecommunications Act of 1996, allow competitive local exchange carriers to lease parts of the incumbents' network for a monthly recurring charge. Unbundled Network Elements include the local loop, local switching, tandem switching, etc.*

federal revenues will be reduced commensurate with the volume of traffic that is shifted from the switched network to the Internet.

Core relationships

Our previous research addressed competition in local markets between Incumbent Local Exchange Carriers (ILECs) and Competitive Local Exchange Carriers (CLECs) but accounted for the impact of alternative modes of communications access – mobile wireless and broadband – on switched lines.[5] Our results implied that most of the impact of intermodal competition was felt by ILECs on their base of local switched lines. Consequently our forecasting model is centered on the switched, wireline market and the competitive changes induced by exogenous changes and by competitive effects of wireless and broadband alternatives.

Our design addresses the substitution of access lines by wireless subscription and broadband lines. In our initial version we take usage parameters as given and assume a shift of usage consistent with the average usage per line/user and estimate the expenditure shift accordingly. Estimating the traffic shift accordingly will permit the capacity changes and potential change in the mix of supplier network capital. For example, as subscribers shift usage from the switched network to IP or wireless networks, excess capacity in the switched network would be created, along with increased traffic on the alternative network (e.g. wireless). This kind of analysis not only provides information about industry shifts in demand and carrier network but in a broader context provides a link to aggregate business fixed investment in the macro economy as well. VoIP offers an example of shifting switched voice traffic to the Internet but in addition implies additional equipment investment on the part of end-users (e.g. migrating from an existing stock of analog or digital customer provided equipment to IP-based equipment and software).



1. Broadband affects ILEC/CLEC
2. ILEC/CLEC competition affects Broadband choices
3. Broadband level defines VoIP market potential
4. VoIP usage affects provider capacity, revenue, and investments
5. VoIP usage affects Federal and State charges and taxes

Figure 4 VoIP relationships

Suggestions for related research and modeling

We believe that as technology drives new markets to develop and grow, aggregate measures will become less useful in measuring industry bearings as we have already witnessed in many instances. For example, employment has been a reasonable indicator for switched lines because, like telecom services, labor is an input to the end-user's business. In the past the relationship between switched lines and employees moved steadily because the world was driven by voice and not data.

With the growth in data communications and especially web-driven commercial applications in the 1990s, the communications process began changing at business locations and the relationship of switched lines/employees with it. Commercial markets began moving towards LANs, WANs and special access, and away from switched access, particularly in larger enterprises. The flattening of the switched access/employment ratio is apparent from 1997, indicating that fewer switched lines were required relative to rising payrolls. But the growth in special access has been spectacular. The very high special access/employment rate (high capital-labor ratio) suggests telecommunication's contribution to the high productivity derived from IT, is dominated by special access growth. Employment is consequently no longer an adequate indicator of trends in commercial telecommunications access.

This example reinforces the concern that single-equation forecasts of demand at the industry level, and

[5] *Loomis, David G. and Christopher M. Swann, "Intermodal Competition in Local Telecommunications Markets,"* Information Economics and Policy*, 2005, 97–113.*

especially at the level of the firm subject to competition, will not likely be stable. Cross-elastic relationships should form the basis of a model in a multi-equation framework. However research should be directed towards more disaggregated units of observation. Disaggregating across firms to capture inter-firm variation would be valuable.

In many cases there is little or no data, particularly for the introduction of new services. This has always been a problem but quantitative techniques have been applied to successfully address it. Using survey data to determine estimates of demand, or empirical distributions for use in simulation models is an excellent approach. Microsimulation models have been used extensively and successfully in forecasting energy demand for appliances, energy capital and usage. Not only are choices at the extensive margin captured at the user level, but the distributional effects of policy changes are estimable.

David Loomis is Co-Director of the Institute for Regulatory Policy Studies and Associate Professor of Economics at Illinois State University where he teaches in the Master's Degree program in electricity, natural gas and telecommunications Economics. He earned his PhD in economics at Temple University. He is former Chair of the International Communications Forecasting Conference. Prior to joining the faculty at Illinois State University, Dr. Loomis worked at Bell Atlantic (Verizon) for 11 years. He has published articles in the Review of Industrial Organization, Utilities Policy, Information Economics and Policy, *and the* Journal of Economics Education. *He has co-edited two books with Lester Taylor,* The Future of the Telecommunications Industry: Forecasting and Demand Analysis *and* Forecasting the Internet: Understanding the Explosive Growth of Data Communications *and co-authored a chapter in* Principles of Forecasting *by J. Scott Armstrong.*

email: dloomis@ilstu.edu

Christopher Swann is a senior economist, who, since 1997 has made contributions to Global Insight's US Macroeconomic Service, World Service, and Industry Service. His primary focus is the information and communications technology (ICT) sector and he is responsible for telecom forecasting in US markets. Currently, under his direction a multi-equation model of US telecom markets is being developed. Beyond the ICT sector, Dr. Swann has completed studies of the financial services markets and capital-leasing industry, developed US and country macroeconomic forecasts, and has analyzed US labor markets. Dr. Swann holds a BA in Economics from Washington University, St. Louis, and MA and PhD degrees in Economics from Temple University in Philadelphia. He is a past President of the Philadelphia Chapter of the National Association for Business Economics (NABE) and past-Chair of the NABE Technology Roundtable.

email: chris.swann@globalinsight.com

Mind the gap – Linking forecasting with decisionmaking

PATRICK VAN DER DUIN AND RAYMOND KOK

Patrick van der Duin is a research fellow at Delft University of Technology, The Netherlands

Raymond Kok is a Business Analyst for KPN, The Netherlands

Improving forecasting is an essential challenge to everyone who is involved in looking at the future. Therefore, forecasters do everything they can to improve their models and to enlarge their datasets. However, we consider this a one-sided approach to solving the problem. Better forecasting does also mean paying more attention to the user of the forecast, i.e. the decisionmaker. In our view, building models and compiling datasets while being strongly aware of the wishes, needs and circumstances of the decisionmaker will result in better forecasts and subsequently better decisions.

1 Introduction

History has shown that forecasting the future has become a science and perhaps even an art. Probably driven by the expected huge rewards of rightly forecasting the future, many forecasters have developed and experimented extensively with new forecasting methods and relentlessly searched for new and better ways of collecting data to feed their forecasting models. But despite the continuous refinements of models and data collection methods, much research has shown that although forecasts have become more precise, they are also more often wrong. With regard to telecommunication, a famous example from the eighties was McKinsey's advice to ATT not to invest in mobile telephony because by the year 2000 there would be only a few hundred thousand mobile phones worldwide. Or, more recently, the (wrong) prediction that the uptake of SMS services would take place in the business market instead of in the consumer market. And, of course, the huge expectations to UMTS that until now have not lived up to much.

Another tragic situation occurs when the forecast is indeed right but is not used in a decisionmaking process within a telco company. Table 1 shows the different possible combinations of a correct and incorrect forecast, and using and not using the forecast.

And again, the Pavlovian reaction of forecasters to this problem is often to go back to their models and datasets and to make them (again) more advanced and more complex. And does this help? It may not come as a surprise that we think that the answer to this question is no.

So, what to do? This article puts forward the notion that rightly forecasting, that is, producing a forecast that supports a manager, strategists or any other decisionmaker in making good decisions, should not start by building a sophisticated forecasting model that uses the most recent insights from mathematics, computational and statistical sciences. Rather, it should start with analysing the type of question the forecast should address. This has a few consequences. For instance, understanding the nature of the underlying goals to which the question of the managers is related. Or comprehending the professional, scientific, organisational and personal background of the decisionmaker. Or assessing the resources available to the forecaster in terms of time and money.

All this means that the next step after analysing the decisionmaker and his or her questions, goals, resources and/or strategic environment, is building forecasting models that are more aligned with the decisionmaker and the decisionmaking process. We consider the next two general aspects contributing to this alignment:

1) Combining quantitative and qualitative methods and models;

2) Combining predicting (e.g. causal models) and exploring methods (e.g. scenarios).

Quality of forecast / Usage of forecast	Correct forecast	Incorrect forecast
Forecast is used in decisionmaking	Right decision	Wrong decision (type II error)
Forecast is not used in decisionmaking	Wrong decision (type I error)	Right decision

Table 1 Different combinations of forecasts

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Cases:	Case 1	Case 2	Case 3
Combining qualitative & quantitative		X	X
Combining predicting & exploring quantitative	X	X	

Table 2 Relation between the three cases

These two aspects, as well as elements that will be discussed in section 2, will be addressed by describing three different cases in the field of telecommunication (see Table 2).

To sum up, this article claims that better forecasting means reversing the process of making forecasts. It should start with an analysis of the wishes and constraints of the decisionmaker and his or her decisionmaking process. After that, combining different types of models and methods, and different approaches to forecasting can expect to give not only a better answer but also an answer that can be better used in a decisionmaking process. Making models complex and endlessly looking for more and better data might satisfy the forecaster's intellectual curiosity but probably leaves the decisionmaker with still unsolved questions.

2 Forecasting and decisionmaking

Although many forecasts contain a rather high degree of mathematics, the use of those forecasts can be much less logical. That is, forecasts are used by decisionmakers, real people who have a specific commercial and organisational responsibility and use the forecast for a specific purpose. It is beyond the scope of this article to go into the psychology of the decisionmaker, so we address just some elements in the relationship between a decisionmaker and the forecast and that play a role in the decisionmaking process.

1 *Forecasts and their consequences:* Often forecasters just forecast a specific trend and do not pay much attention to the possible consequences of the forecasted development whereas the decisionmaker might be very interested in those consequences. That is, the decisionmaker cannot do much about the forecast (or influence its degree of uncertainty), but he or she is definitely interested in coping with the consequence of the forecasts. If we make a distinction between certain and uncertain forecasts, and between certain consequences and uncertain consequences (of these forecasts), Table 3 can be made. The table shows that although a forecaster can be very certain about a trend, the consequences of that trend might be uncertain. The most extreme situation is when the forecasted trend is uncertain as well as having possible consequences. The point is that the decisionmaker often has no alternative but to accept the forecast (uncertain or not) but his task is to cope with the consequences of the forecast. For example, it is important to know that there will be a millennium-problem in the future, but how to solve the possible problems that it causes? Or, unbundling sounds very interesting, but how sure is this trend, and is it indeed wise to sell your network department and to acquire a foreign mobile service provider?

2 *Uncertainty:* Many forecast assume a certain degree of certainty which largely is based on the idea that history bears very much resemblance to the future. This makes it possible to use historical data as a basis for predictions of the future. Nevertheless, the crucial question is whether this assumption is true and if the forecaster does not have a rather one-dimensional approach to a rather complex phenomenon such as uncertainty. A more nuanced perspective to the concept of uncertainty is given by Courtney, Kirkland & Viguerie (1997). They distinguish between four types of uncertainty that can be placed on a continuum, as shown in Figure 1.

Consequences / Type of trend (forecast)	Uncertain consequences	Certain consequences
Uncertain trend	e.g. 'unbundling' (will it continue and what will be the consequences?)	e.g. 'telecommunication network crash' (it is not known whether or when it will happen but if it does the damage can be estimated fairly well)
Certain trend	e.g. 'Y2K' (it was known that it was coming but it was uncertain to what extent it would cause trouble)	e.g. 'lower investments in telco networks' (very dominant trend with clear consequences)

Table 3 Relation between trends and consequences

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	A Clear Enough Future	Alternate Futures	A Range of Futures	True ambiguity
What can we know	1. A single forecast precise enough for determining strategy	1. A few discrete outcomes that define the future	1. A range of possible outcomes but no natural scenarios	1. No basis to forecast the future
Analytical tools	2. 'Traditional' strategy tool kit	2. Decision analysis, option valuation models, game theory	2. Latent-demand research, technology forecasting, scenario planning	2. Analogies and pattern recognition, non-linear dynamic models
Real-life examples of uncertainty	3. Strategy against low-cost airline entrant	3. Long-distance telephone carriers' strategy to enter deregulated local service market. Capacity strategies for chemical plants	3. Entering emerging markets such as India. Developing or acquiring emerging technologies in consumer electronics	3. Entering the market for consumer multimedia applications. Entering the Russian market in 1992

Figure 1 Four types of uncertainty on a cintinuum

In our view these different degrees of uncertainty have certain consequences for forecasting. That is, it is not very likely that one method of forecasting is suitable in every situation. For instance, when there is 'a clear enough future' forecasting can make valuable use of the historical data available whereas in a situation of 'true ambiguity' using historical data can lead to very wrong conclusions. A forecaster who is not aware of the uncertainty the decisionmakers face will often resemble the handyman with the hammer for whom everything is a nail.

3 *The decisionmaking process:* As said above, most forecasts are made to support a certain decision. These decisions can be about making certain investments (or not), about expected sales, or about which new product or service to develop. Most of these decisions take place within a certain process, just as making a forecast. This means that the process of forecasting should be more or less in line with this decisionmaking process. For instance, if we look at decisionmaking with regard to an innovation process forecasting plays a different role in every phase of that process. Table 4 shows this and is from Twiss (1992).

The table shows that in different stages of an innovation process (left column) different aspects of the forecasts (i.e. importance, accuracy, financial effect of error) have different weights. For the forecaster this means that he should be aware in which phase of the innovation process his forecast is used. Trying to make very detailed forecasts does not make much sense when a decisionmaker only has a rough idea about the innovation he is hoping to develop (i.e the idea generation phase).

3 Three cases

The former two sections have shown that there is more between the forecaster and the decisionmaker than just handing over the Excel file with the forecast. To illustrate how the elements mentioned above play a role in this relationship we describe three cases.

Stage of the innovation process	Technology forecasts		
	Importance	Accuracy	Financial effect of error
Idea generation	High	Medium	Low
Technical feasibility	High	Medium	Low
Design & development	Low	High	Medium
Preparation for production & marketing	Very low	High	High
Post launch	-	-	-

Table 4 Stages of innovation process vs technology forecasts

ISSN 0085-7130

- Case 1 explains, given a forecast question, which type of forecasting model to use.
- Case 2 explains the use of scenario-thinking in forecasting models.
- Case 3 explains that, to make a forecast, other relevant variables have to be included in the forecast.

In this section we only describe the cases very briefly; the linkage of the cases to the concepts discussed in section 2 will be done in section 4, Case summaries and case analyses.

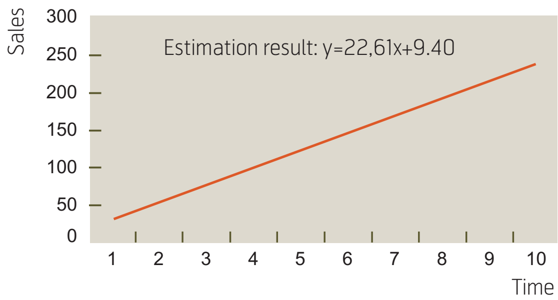


Figure 2 Accumulated sales

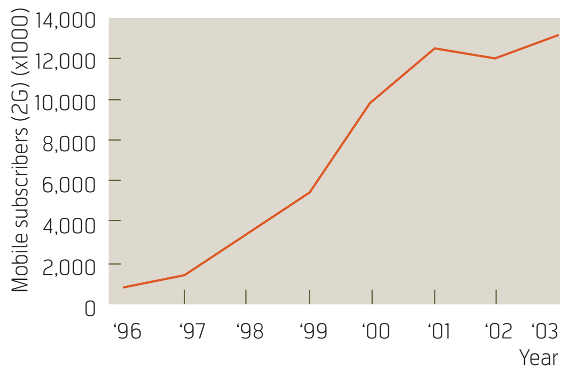


Figure 3 Mobile subscribers in The Netherlands (1996 – 2003)

Which model to use for forecasting an existing or new product?

Additional data available?	Yes	No
New product	Regression models VAR models Fuzzy logic	Diffusion models Monte Carlo simulation Judgemental models
Existing product	Times series (ARIMA) Regression models Data mining	Trend analyses Price elasticity models Judgemental models

Table 5 Different models for new or existing products

Case 1 Forecasting models

Much literature is available about different quantitative methods which can be used for forecasting. Below we briefly describe a typical regression model and a few diffusion models.

Regression model

The easiest regression model is $y = \alpha + \beta x$, see Figure 2. Time is shown along the x-axis, and the y-axis indicates accumulated sales (Sales). Sales (t) equals accumulated sales on time = t. Estimation result is $y = 22.61x + 9.40$.

A line is fitted through the data points and a forecast can be made using the estimated equation (in this example: Sales (11) = 9.40 + 22.61 * 11 = 258.11). This method is useful for identifying the relationship between two (or more) variables and to assess the future course of these variables. Also other relations can be incorporated in this method by introducing additional explanatory variables giving the following model: $y = \alpha + \beta_1 x_1 + ... + \beta_n x_n$.

Diffusion models

Diffusion models are useful when forecasting new products or services with a limited amount of data. Diffusion models are typically S-shaped curves with some parameters in it. These parameters might define the "take-up speed" of the curve and the "ceiling". So, if you know something about the "ceiling" and have some ideas about the take-up, you might experiment with one of these models.

Table 5 shows some forecasting models which could be suitable in situations with different amounts of additional data.

Case 2 Combining forecasting and scenarios

This case shows how forecasting and scenarios can be linked to each other. One should be aware that forecasting is just one approach to looking at the future. Scenario-thinking is a different approach in which the future is not predicted but explored. However, both approaches (and methods) can be combined since they are, to a certain extent, complimentary to each other.

The scenarios

Below are given four scenarios for 2005. These (corporate) scenarios were built in 1999 at KPN Research. The scenarios were constructed on two axes that had a societal nature: 1) the orientation of people towards each other: individual vs. collective, 2) the individual attitude of people: active vs. collective. By crossing the two scenario-axes four scenarios (different possible stories about the future) can be constructed, see Figure 4.

The forecasting model

The model shown in Figure 5 is a market-potential model based on product substitution and is applied to the expected usage of ADSL (i.e. broadband) in the Dutch business market.

We explain the (rise in) demand for ADSL by four factors:

1 The probability ‘p’ that current users of PSTN (‘normal’ telephony) switch to ADSL;

2 The probability ‘q’ that current users of ISDN (digital lines) switch to ADSL;

3 An ‘autonomous’ increase in the number of users of ADSL (‘new connections’);

4 Closings of ADSL lines (negative effect!).

The connection between the scenarios and the market potential model

The difference in the probabilities ‘p’ and ‘q‘ in the matrix below the model is the result of the different scenarios. That is, in the different scenarios businesses and their employees have a different attitude towards the adoption and use of (new) telecommunication services. These different attitudes influence, for example, the extent (or probability) to which current users of PSTN will switch to ADSL. Below it is briefly explained how (and why) the ‘p’ and ‘q’ differ in each scenario:

- *Adventure:* In this scenario, the majority of companies in the industry can be characterized as ‘early adopters’. They are constantly searching for new products and services, and are also willing to pay for them (the prices of products and services in this phase of their life cycle are usually higher than in later phases). The diffusion curve is therefore very steep and companies truly believe that purchasing new products and services as quickly as possible will give them a competitive advantage. Their strong wish to be innovative is directly reflected in a rapid uptake of new telecommunication products and services.

- *Budget:* New products and services are introduced at a very slow pace in this scenario. Companies follow an operational excellence strategy and are satisfied with their existing products. Therefore the penetration rates of new products and services are rising only very slowly. Companies do not immediately see the added value of new products and tend to stay with their current investments.

- *Comfort:* Companies exert a strong influence on their suppliers to come up with products and services that are highly standardized. Only then does the uptake of new products and services accelerate rapidly. The diffusion curves are rather steep

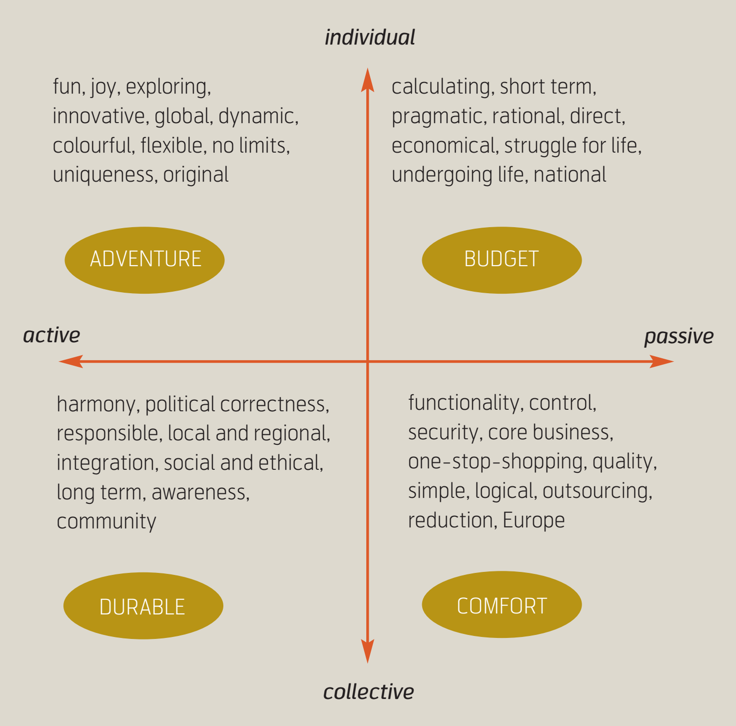
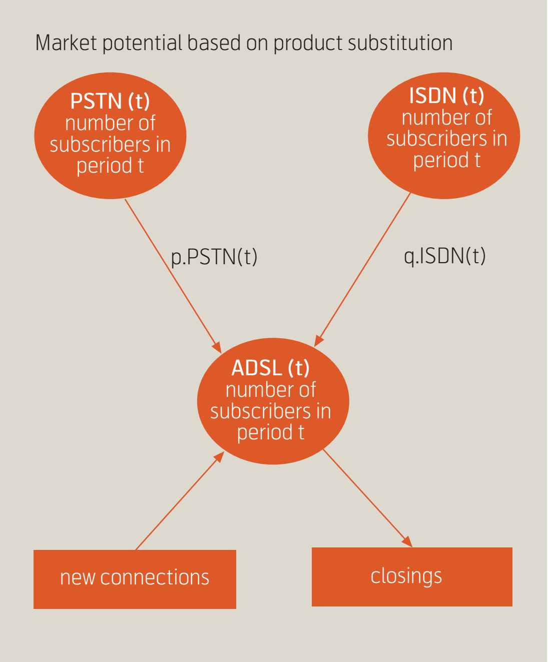


Figure 4 Scenarios for 2005



Scenarios:	p	q
Reference Scenario	0.20	0.20
Scenario 1: Adventure	0.20	0.40
Scenario 2: Budget	0.10	0.10
Scenario 3: Comfort	0.25	0.50
Scenario 4: Durable	0.30	0.30

Figure 5 Market potential model for ADSL with transition probabilities

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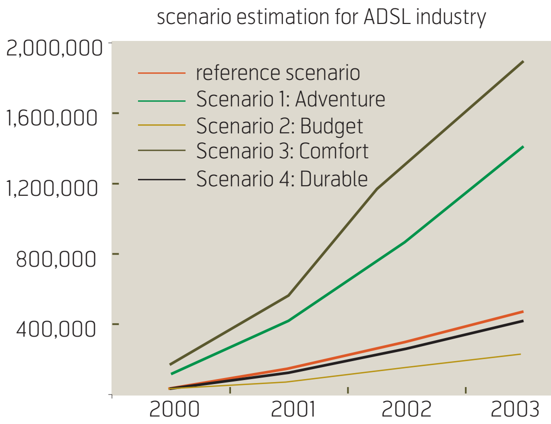

Figure 6 Estimation results for scenarios

(but not as steep as in 'Adventure') because companies can afford new technologies, and intermediaries are doing a good job in advising them which new equipment to buy. This increases the companies' trust in new technologies, which, in turn, stimulates sales of new products and services.

- *Durable:* It is difficult to make a general statement about the diffusion curves in this scenario. However, it can be assumed that the only successful products and services will be those that meet a company's ethical and social requirements. For example, ICT that enables employees to combine their work and private life more easily will sell well. In practice, this means that ICT oriented to teleworking will be successful. Furthermore, ICT that takes the 'human element' into account (as opposed to anonymous, impersonal ICT) will be very attractive to companies and their employees. The diffusion curve of new telecommunication products and services in this scenario is in between 'Budget' and 'Durable'.

Running the model on the basis of the scenarios
When the model is fed with data and run with the adjusted parameters (determined by the scenarios), it produces the outcomes shown in Figure 6 (note that we also show the 'reference scenario', which can be interpreted as the 'normal' forecast, i.e. an extrapolation). Accumulated sales of ADSL is shown on the y-axis and years on the x-axis.

Adventure and Comfort have the highest and fastest-growing number of ADSL users because the pace of technological advance in those scenarios is high, and business users value the benefits of a new technology such as ADSL. Business users in the Budget, Durable and reference scenarios are more skeptical towards new technology and tend to adopt a 'wait-and-see' approach.

These forecasts and scenarios were created in 1999, when no relevant data were available. However, now we know the realisations: End 2003 there were some 750,000 ADSL lines in The Netherlands. This is above the reference scenario; two scenarios are above the realisation and two below. The lesson learned here is to pay more attention to the bandwith (range) of the different scenarios.

Case 3 Forecasting fixed voice traffic

This model attempts to make a one-year ahead forecast of the fixed voice market in The Netherlands. The number of mobile subscribers is as an additional variable included in our forecast, because it can be assumed that there is a relation between the decline of the fixed voice market and the growth of the mobile market. This is a fixed-to-mobile substitution. Of course, there is also an effect on voice traffic from migration from narrowband to broadband internet. However, this is not included in this analysis. Table 6 shows the data that have been used for the forecast.

The mobile base in the Netherlands has grown in the last five quarters from 12.0 million to 13.4 million users, as the total number of fixed minutes has declined from 8.8 billion to 7.8 billion. This relationship is shown in Figure 7.

	Q1'03	Q2'03	Q3'03	Q4'03	Q1'04
Market share base KPN	41 %	41 %	41 %	40 %	39 %
Customers KPN (x 1000)	4908	4919	5038	5205	5269
Total mobile market (x 1000)	12,059	12,086	12,409	12,948	13,373
National KPN (x 10^9)	6.16	5.47	5.02	5.29	5.23
National market share KPN	70 %	69 %	68 %	67 %	67 %
Total fixed national voice (x 10^9)	8.80	7.93	7.38	7.89	7.81

Table 6 Input data for traffic forecast

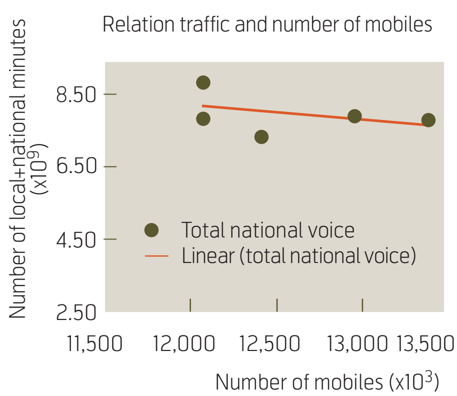

Figure 7 Relation between voice traffic and # mobiles

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	Q1'03	Q2'03	Q3'03	Q4'03	Q1'04	Q2'04	Q3'04	Q4'04
Market share base KPN	41 %	41 %	41 %	40 %	39 %			
Customers KPN (x 10^3)	4908	4919	5038	5205	5269			
Total mobile market (x 10^3)	12,059	12,086	12,409	12,948	13,373			
National KPN (x 10^9)	6.16	5.47	5.02	5.29	5.23			
National market share KPN	70 %	69 %	68 %	67 %	67 %			
Total national voice (x 10^9)	8.80	7.93	7.38	7.89	7.81			
Extra mobiles (#)						1000	1000	1000
Effect per mobile	–400							
Effect of mobiles (x 10^9)						0.40–	0.40–	0.40–
Total national voice (x 10^9)	8.80	7.93	7.38	7.89	7.81	7.41	7.01	6.61
Market share						66 %	65 %	65 %
KPN	6.16	5.47	5.02	5.29	5.23	4.89	4.55	4.29

Table 7 Results of fixed voice forecast

The estimation results are: $y = -0.0004x + 12{,}479$. It can be seen that an additional mobile phone will cause a decline in the number of fixed minutes of 400 minutes per quarter. This is equal to about 133 minutes per month.

Now let us assume that

- This relation between fixed and mobile holds for the next quarters;
- There will be no other effect.

Then all that is needed is an estimation of the number of additional mobiles. Let us assume that the number of mobiles will grow by 1000/quarter. It can easily be calculated (as shown in Table 7) that this will lead to a decline of the fixed voice market of 0.4 billion minutes per quarter.

Now let us introduce some scenarios in which the growth of # mobile subscribers will vary (Figure 8). The x-axis shows the mobile penetration (how many people have mobiles) and the y-axis shows the difference between the fixed and mobile traffic tariffs. (If the difference is great, the premium is high, and vice versa.) P stands for the price, compared to the current price (90 % means the price will be 90 % of the current price). ΔMob stands for the change in the number of subscribers compared to the current number.

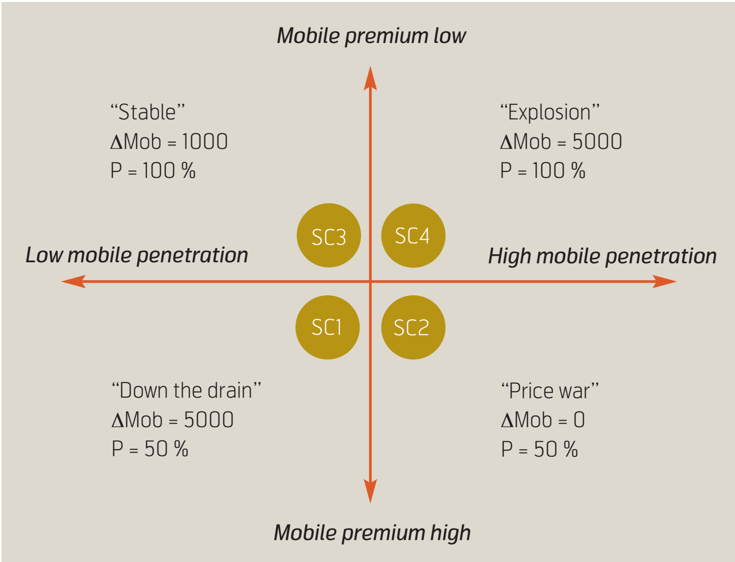

Figure 8 Different scenarios used for forecast

	Q2'04	Q3'04	Q4'04
Change in number of mobiles:			
Scenario 1	5,000–	5,000–	5,000–
Scenario 2	–	–	–
Scenario 3	1,000	1,000	1,000
Scenario 4	5,000	5,000	5,000
Total fixed market:			
Scenario 1	9.81	11.81	13.81
Scenario 2	7.81	7.81	7.81
Scenario 3	7.41	7.01	6.61
Scenario 4	5.81	3.81	1.81

Table 8 Results of fixed voice forecast per scenario

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4 Case summaries and analyses

In this concluding section we want to discuss how the three cases from section 3 are examples of how forecasting and decisionmaking can be better aligned by using the concepts presented in section 2. All the cases described are small parts of forecasting projects at KPN Research and at KPN in the period between 1999 and 2003.

Case 1

Case 1 was a small part of a (basic) fundamental research project at KPN Research in 1999 that had the goal of categorizing the most important methods of forecasting. Instead of doing that by looking at the mathematical characteristics of the different forecasting models it was decided to look at the models from the perspective of a (potential) user (in case of KPN Research the user was KPN). Since users are mainly interested in the output of the model the different categorisations were made from the view of how a user might want to use the forecast. However, it was very common that the client of the forecasting project also had access to the main data needed to feed the forecasting model. Therefore, one categorisation was made according to the data available. Based on the amount of data available different forecasting models (regression/diffusion) could be categorized so that a specific forecasting model could be related to the amount and type of data. It showed that the type and amount of data was strongly related to the type of question to be addressed. That is, for a question about the possible future market share of a specific product of KPN different data was needed and available than for a question about the possible uptake of a product that was being developed. More specifically, questions about new products that were in their developing process (or innovation process) were often segmented on the basis of which phase of the innovation process they were in. To decide this the table of Twiss from section 2 came in very handy. In each phase of the innovation process different information is available for the product or service that is being developed. This information can be linked to the product or service itself or to the (market) environment into which it will be ultimately introduced. It will not come as a surprise that in the first phases of the innovation process not much information is known, neither about the new product/service itself nor about its future environment. A forecasting method such as a 'traditional' regression has then very limited value and it would be wiser to use a method such as Monte Carlo which copes better with the lack of information.

This case aims to show that the decision to use a specific forecasting method (or not) should not only be dependent on its inherent mathematical qualities or elements but rather be subject to the question it addresses and the available data.

Case 2

This case shows very simply how to combine scenarios and forecasting by adjusting the different parameters in the forecasting model on the basis of the four different scenarios. To connect scenarios and forecasting the following two steps have to be taken:

1. Establishing the same level of detail. The scenario stories contain descriptions of possible social, economic and technological trends but it is also possible, on that basis, to determine the effects of such trends on the attitude and behavior of different businesses.

2. Pointing out where they intersect, i.e. where the scenarios enter the model. In the example it was possible to change the parameters, i.e. the probability 'p' that business users switch to ADSL, on the basis of the scenario stories. For example, in the Adventure scenario, business users are enthusiastic about new technologies and will be very quick to adopt new broadband applications. They will do this more readily and at a faster pace than in the other scenarios.

Once these connections are established, it is possible to supplement a forecast with scenarios so that more outcomes are generated. The added value of a greater number of outcomes lies in the insight they provide into possible developments that can easily influence the *assumed* parameter values of a model.

The case shows that combining a predictive method (such as a specific forecasting model) and a more exploratory method (such as scenario-thinking) gives the client the flexibility to think in multiple futures instead of just one, but the combination with the forecasting method makes the outcome much more specific (in terms of, for example, number of ADSL subscribers) than using scenarios only.

Case 3

Case 3 attempts to show that a forecast should incorporate also other variables than just the variable the forecast is about. That might sound obvious but be aware that a client (a product manager, for instance) is mainly interested in the future course of his own product. A consequence might be that he is blind to the development of other, possibly competing products or services and only has access to data about his product. If this is the case with only one product-manager there is no big problem. But if a company has too many short-sighted product-managers things can go worse, that is, the different forecasts made by a company are not consistent with each other. This can result in a situation where after adding up all the forecasts residential users spend about 2,000 euro on telephony per month and/or 38 hours per day telephoning! A short study at KPN indeed showed that the total of all business cases was more than the total market.

The lesson that can be learned from this is that the forecaster should have a broader view than his client, and he should be aware that there are other variables out there, of which his client may know nothing, but that indeed can affect the product or business case of the client very heavily. In the case we have described a simple example of how the forecast of the total national voice traffic (in terms of minutes) of a fixed operator is influenced by developments in the mobile business. By distinguishing different scenarios the effect of these developments on fixed also becomes clear. Things get more complicated when the fixed operator also owns a mobile operator. In that case, the operator will try to maximize its profits over both the fixed and mobile networks.

With respect to the concepts presented in section 2, this case tries to show that there is more than just the forecast, but that the consequences, either certain or uncertain, of the forecast about a different but relevant variable (product/service) are very important for the consistency of the forecast. Especially, a telco company operating in many different parts of the telco industry this linking of different forecasts is very important. A company can never be bigger than the total market even if the telco company in question is an incumbent one.

5 Concluding remarks

In this article we have tried to bridge the gap between the forecaster and the decisionmaker by introducing some concepts that can be helpful in closing it. Of course, we do not claim that this gap is very wide in every organization, but the problem of forecasting cannot be solved only by making ‘better’ models. Rather, forecasting needs an innovation in terms of how it is used in practice by clients. Being more aware of the wishes, needs, and situation of the client and incorporating that into the practices and models of the forecaster will, in our view, not so much result in better forecasts (i.e. forecasts that are more accurate) but rather in forecasts that are ‘better’ used. In that case, the client is more aware of the uncertainty that surrounds every forecast, he has a more comprehensive view of the consequences a specific forecast might have for his product or business, and can more easily asses whether the level of detail of the forecast and the position of his innovation in the innovation process is in balance. But more importantly, both forecaster and client should first of all be aware that they have different backgrounds, expertise, and interests: mind the gap!

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Patrick van der Duin currently works as a research fellow at Delft University of Technology, faculty of Technology, Policy and Management, in the Netherlands. His PhD deals with the use of qualitative methods of futures research in commercial organisations and its relationship with innovation management. Before that he worked at KPN Research where he did studies about scenarios and forecasting with regard to topics such as telecommunication services, communication needs and patterns of large businesses and consumers. Patrick studied macro-economics at the University of Amsterdam.

email: p.vanderduin@tbm.tudelft.nl

Raymond P. Kok is Business Analyst for KPN, Consumer Intelligence and Analysis department. He started working for KPN Research in 1998 in the department for Business Modelling where he was involved in research work as well as project leadership. He moved on to KPN headquarters after about three years – to Corporate Marketing and to the Strategy department. Before joining KPN Raymond studied econometrics specializing time-series forecasting.

email: r.p.kok@kpn.com

Broadband in Norway – Policy and status, August 2004

KJELL OVE KALHAGEN

Kjell Ove Kalhagen is Senior Advisor in the Ministry of Trade and Industry

The Norwegian Government's vision for broadband rollout is that the electronic infrastructure shall cover all parts of the country, provide competitive advantages for Norwegian industry, foster growth among knowledge-based businesses and contribute to modernisation of the public sector. Private and public enterprises need good access to the electronic infrastructure and they need to be able to exploit the opportunities offered by broadband. Content and services must be developed in step with market developments, and organisations and individuals will require expertise in order to reap the benefits of this new technology.

Use of information technology[1)] has spread rapidly over the last 20 years, driven in particular by market conditions and new technological innovation. The convergence of different technologies has facilitated new applications and services, while at the same time users have called for and needed ever newer, faster and more tailored services. This has created a demand for, and provided new conditions for technological developments. IT has become increasingly important for fostering innovation, improving efficiency and restructuring of the private and public sector. Increased transfer capacity in the electronic communications infrastructure will play an increasingly important role for innovation, efficiency and value creation in society and in industry. Just as it has done for road, sea and air transport, the electronic infrastructure is becoming indispensable for most people.

In the strategy document "*e*Norway 2005", which was presented in May 2002, the Norwegian Government set three goals for its IT policy:

Creating value in industry
The expansion and use of information technology shall pave the way for creating value through enhanced innovation and competitiveness in Norwegian industry.

Efficiency and quality in the public sector
Information technology shall be used to make the public sector more efficient and at the same time offer new and improved services to users.

Involvement and identity
Everyone shall be able to exploit opportunities within information technology, and IT shall play a role in the preservation and further development of our heritage, identity and our languages.

The Government submitted a White Paper on broadband to the Parliament in September 2003. The objectives stated in the White Paper were as follows:

- Good offers for broadband shall be available in all areas of the country;
- Access shall be offered to a wide variety of electronic quality content tailored to Norwegian conditions;
- Enterprises shall have sufficient skills to avail themselves of and realise the benefits of broadband communication.

The specific objectives laid down in *e*Norway 2005 remain in place: All primary and lower secondary schools, public libraries and local authority administrative services shall be given the option of broadband communication at a competitive price in the course of 2005. By the end of 2003, all colleges of secondary education shall also be offered an equivalent scheme. One additional objective stated in *e*Norway 2005 was that all health enterprises should have a broadband connection in the course of 2002. This goal has now been achieved.

1 Broadband is useful

The starting-point for the White Paper on broadband is that electronic communications networks with sufficiently high transfer capacity are playing an increasingly important role in the global economy. Use of information technology in general and broadband in particular can lead to increased competitiveness for Norwegian industry, by, among other things, fostering creativity and enhanced productivity. Broadband facilitates the organisation of production in new ways

1) *The terms "information technology" (IT), "information and communication technology" (ICT) and "information society technology" (IST) are considered to be synonymous. The term "information technology" is used in this paper.*

ISSN 0085-7130

and the development of new products and services because among other things it facilitates automation and communication with customers. Investments in broadband and broadband applications will not necessarily provide benefits for industry, the public sector or the consumer market, however. One important prerequisite is that organisations and individual users have the skills necessary to avail themselves of the technology and to realise the benefits it offers. This applies both in respect of cutting-edge technological expertise regarding the choice of solutions and knowledge of the applications of broadband and in respect of new organisational solutions and ways of working. Management in the private and public sector must be aware of, and capable of exploiting the opportunities available. Furthermore, it often takes time to realise such major benefits. The rollout of broadband is part of a general technological development and is one element of a process that will continue for many years. Broadband represents increased transfer capacity and thus increased opportunities for exploiting the electronic infrastructure. The usefulness of broadband and the savings it offers to individuals, and to the nation as a whole, will increase as more and more people access the Internet, and when more activities can be carried out electronically over the Internet. The OECD has pointed out that Norway reaps small but growing benefits from IT.[2)]

2 Both the broadband market and needs are developing

Norway's geography and its demographic patterns present challenges when it comes to the development of modern infrastructure. Furthermore, the present financial situation facing the IT industry only invites players to a limited degree to make strategic investments regarding the rollout of the network. This is a pattern that is evident not only in Norway, but also in most other industrialised countries.

Precisely what constitutes broadband capacity will depend on user needs. For example, schools and private and public enterprises, with many simultaneous users and a need for different types of applications, will require higher transfer capacity than private households. Many of today's electronic services do not require high transfer capacity on their own, but when many users use such services at the same time, high bandwidth will be needed. Broadband technologies are still at an early stage of development, and the pattern of needs is in many ways uncertain. Needs are expected to shift in the direction of

- more extensive use of services and applications based on multimedia and live images requiring faster transfer capacity;

- more simultaneous users; and

- users who will increasingly wish to *send* information, not only *receive* it.

This will increase the need for higher transfer capacity in the network. Part of the need for higher transfer rates will probably be covered by the new compression technology, which means that more information can be transferred at the same bandwidth.

Owing to uncertainty concerning bandwidth development and needs, the term broadband has not been defined in this document as having a minimum transfer capacity. In this context, *broadband is taken to mean two-way communication that can transfer different forms of data and text, audio and video. The network should be able to carry new services and allow many people to use the network at the same time*.

In connection with the White Paper last autumn, statistics for broadband development were presented. These data have now been updated. It is interesting to observe that significant changes have taken place in terms of broadband coverage since the White Paper was submitted. From February 2004 to August 2004, broadband coverage in Norway increased from 77 % to 81 %. This implies that today over 1.5 million households have the possibility to subscribe to broadband from at least one broadband provider at competitive terms.

As of August 2004, 81 % of Norwegian households had a broadband offer from at least one ISP (Internet Service Provider), an increase of 17 percentage points since May 2003.

Figure 1 shows broadband coverage in the private market by municipality as of May 2003 and August 2004. The number of "white municipalities", meaning municipalities where there is no broadband coverage at all, has been reduced from 215 in May 2003 to 28 in August 2004. Every part of the country has benefited from large growth in broadband coverage.

There are now approximately 130 broadband players in the Norwegian market, compared to only 50 in 2001. Most of the players focus on the local and regional market and represent joint efforts between municipalities, power utilities, and local enterprises.

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2) *OECD 2003: Seizing the benefits of ICT: Comparative country performance and policies for review.*

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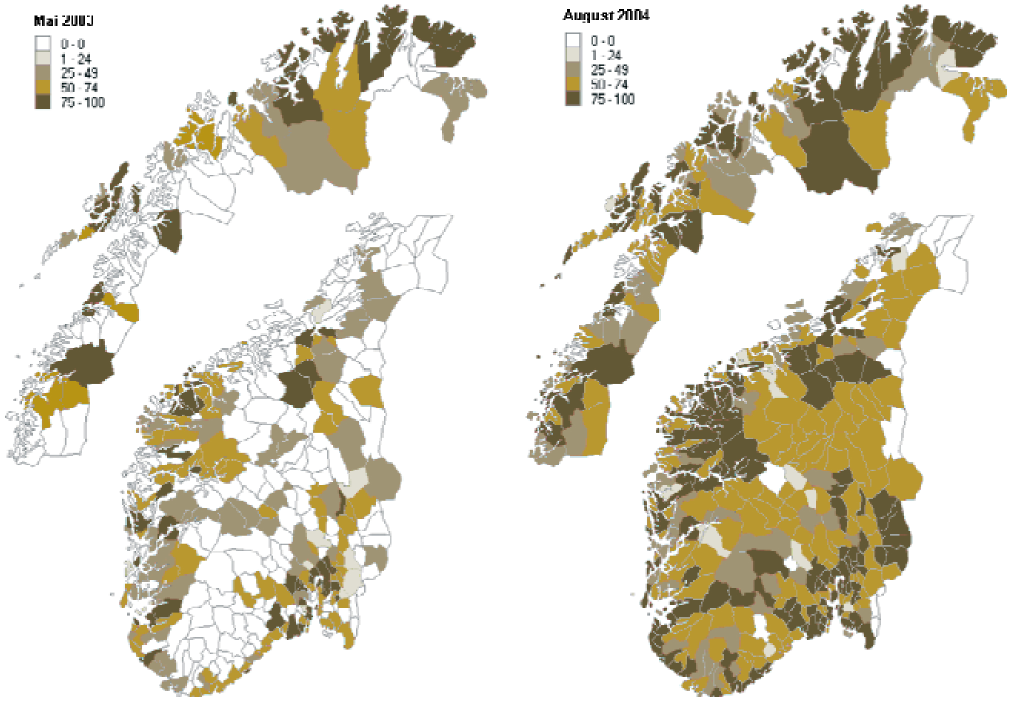


Figure 1 Broadband coverage in the private market as of May 2003 and August 2004 (Teleplan 2003 and 2004)

DSL still remains the most important broadband technology. In addition to Telenor's extensive DSL-rollout, we observe a great number of local players providing DSL-based solutions to municipalities and regions. We also observe that cheaper DSL-equipment combined with higher take-up rates has made it profitable to upgrade smaller exchanges to broadband. About 12 % of the households are covered by radio-based broadband technologies. Broadband over radio are applied by a number of players in rural and remote areas. Both licensed and unlicensed frequency bands are used. Within the unlicensed band WLAN-based technology is dominating. Within the licensed band Nera's 3.5 GHz equipment has been chosen by many municipalities.

The consultancy company Teleplan also expect significant growth in the broadband coverage and further reduction in the number of municipalites without coverage in 2004 and 2005. According to Teleplan it is realistic to expect that about 90 % of households will have the possibility to connect to broadband by the end of 2005. Furthermore, the incumbent operator, Telenor, has announced that they alone will cover 92–93 % of the population with ADSL by 2006. In addition Telenor will deliver xDSL solutions to every municipality/local government administration during 2005. Thus there will be no "white" municipalities by the end of 2005. Telenor will also offer broadband to schools and libraries according to the ambitions stated in the Government's strategy document *e*Norway 2005.

The growth in broadband connections this year is higher than previous years. Teleplan estimates that there were 475,000 broadband connections in the private market by the end of June 2004, compared to 358,000 by the turn of the year 2003/2004. The growth is in particular driven by increased demand for ADSL, but there has also been significant increase in demand for fibre and radio. According to Teleplan the single most important reason behind this growth

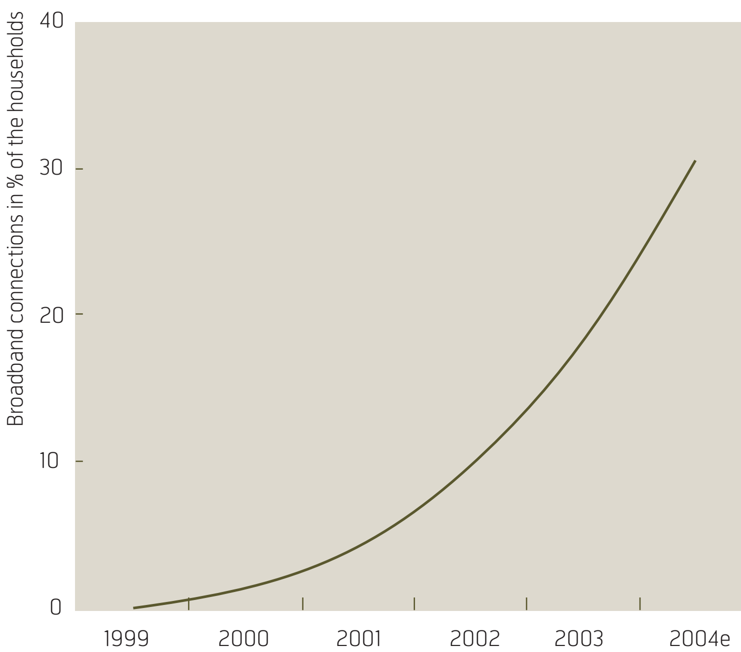


Figure 2 The development of broadband connections in the private market

ISSN 0085-7130

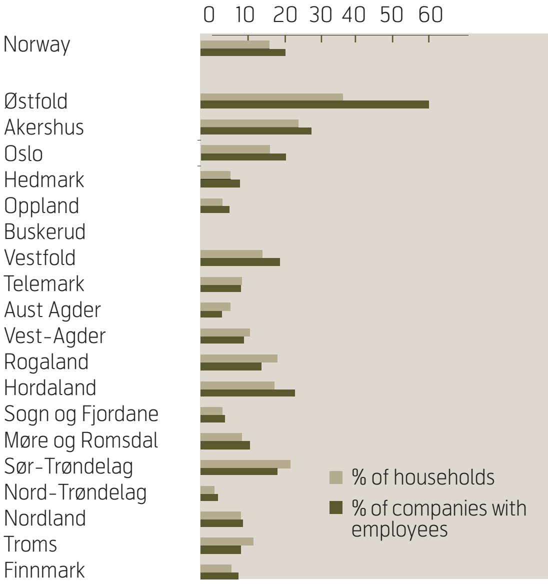


Figure 3 Broadband penetrations as of December 2003 per county, Norsk Telecom, January 2004

is stiff competition amongst the broadband providers. Teleplan still expects strong growth in the number of broadband connections during the coming years due to a highly competitive broadband market. In addition the introduction of IP-telephony as a replacement for fixed telephony probably further increases the demand for broadband as households are seeking to minimize the total costs of broadband and telephony. Teleplan expects that by the end of 2004, over 30 % of the households will have a broadband connection.

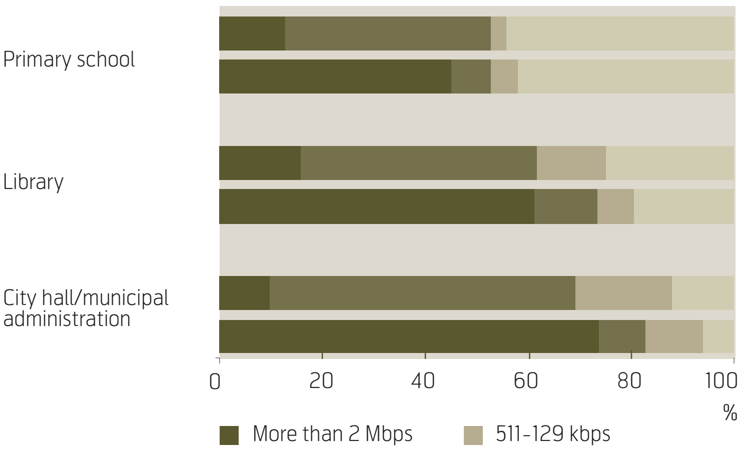


Figure 4 Subscribers connected to the Internet as of May 2003 and March 2004 (Teleplan 2003 and 2004)

There has also been a significant growth in the number of businesses connected to broadband. Figure 3 illustrates broadband penetration by businesses and households by county per December 2003.

Broadband penetration in the business market increased from 15 % to 22 % from August 2003 to December 2003. Figure 4 illustrates broadband penetration in the private and business market for different counties.

Figure 4 summarises the transfer capacity on the Internet available to various public institutions in Norway as of May 2003 and March 2004. We observe an increase in public institutions with broadband connections from 2003 to 2004. In March 2004 83 % of local government administrations were connected to broadband, compared to 69 % in March 2003. For libraries the number of broadband connections has increased from 62 % to 76 %. For primary schools the share of broadband connections has been relatively stable.[3)]

An interesting observation is that out of the institutions that already had a broadband connection in 2003, many of them have upgraded to higher broadband capacities. Particurly we observe that several institutions that had a downstream capacity within the 512 kb/s – 1.99 Mb/s interval have upgraded to capacities larger than 2 Mb/s.

The overall picture therefore indicates that current broadband coverage (offer) and expected broadband in 2005 appear to be good. Thus, it may be concluded that the Government's strategy of a market-based rollout has been a success. Actual connections have lagged behind in the private sector and in parts of the public sector, however, but now appear to be developing more rapidly. Owing to uncertainty regarding technological developments, however, it is still uncertain how large a part of the country the market will eventually cover.

There has been a large growth in broadband connections in all Nordic countries. However, the growth in Sweden has been lower than in the other Nordic

3) *In the Teleplan report, broadband technology is defined as ADSL, SDSL, leased lines, fibre optics or wireless (radio or satellite), with downstream capacities larger than 511 kb/s. These figures include transfer capacity (bandwidth) that would not normally be considered to be broadband bandwidth, but they have been included because the institutions can easily upgrade to broadband if they wish to do so.*

countries in the last year. Denmark, on the other hand, has experienced a higher growth than the other countries. Figure 5 illustrates the development in number of broadband connections per 100 inhabitants in each of the Nordic countries. The numbers include connections based on cable modem and connections based on other technologies such as radio, fibre, satellite, etc.

A forecast (see Figure 6) for the period up until 2008 produced by the analysts Forrester shows that in Norway around 45 % of households will have a broadband connection by 2008. According to the prognosis, this will be the highest connection rate in Europe.

All Nordic countries are now experiencing a broadband coverage of 80 % or more. The growth in coverage has been larger in Norway than in the other Nordic countries. The Norwegian coverage is now on the same level as Finland. Norway has earlier experienced a significantly lower coverage than the other Nordic countries. Both Denmark and Iceland have since 2003 had a coverage above 90 %. This can be explained by a high population density and a high degree of urbanization in these countries. In Denmark population density is high, while in Iceland a large share of the population lives in the Reykjavik area.

In all the Nordic countries with the exception of Iceland, xDSL and cable have a strong market position (see Figure 7). In Sweden competition from the company Bredbandsbolaget has meant that fibre optics has also achieved a sizeable market share (around 20 %). None of the markets have seen a particularly large rollout of wireless access, but Norway leads with a market share for wireless access of 1–2 %, due to the fact that Norway's topography is well suited to wireless access.

Figure 8 illustrates that among the Nordic countries, Norway is the country where the old national monopolist has the lowest market share for DSL. In Denmark TDC has a market share as high as 79 %.

Norway and Finland have the highest share of LLUB. In Finland one particular reason for this is TeliaSonera and Elisa's deployment of ADSL in areas where traditionally there has been a local monopoly. In Norway the LLUB share is high, because this regime is regarded as well-functioning. The largest LLUB-operator NextGenTel has also announced that the LLUB-regime established in Norway has been a success.

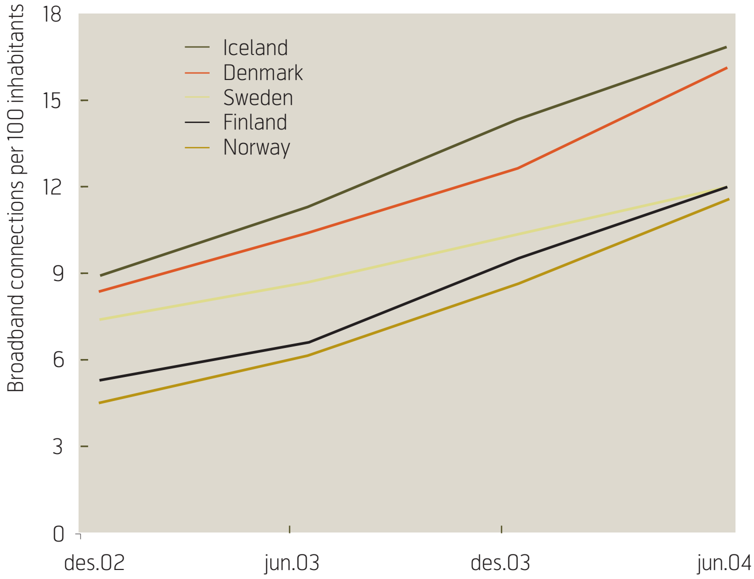
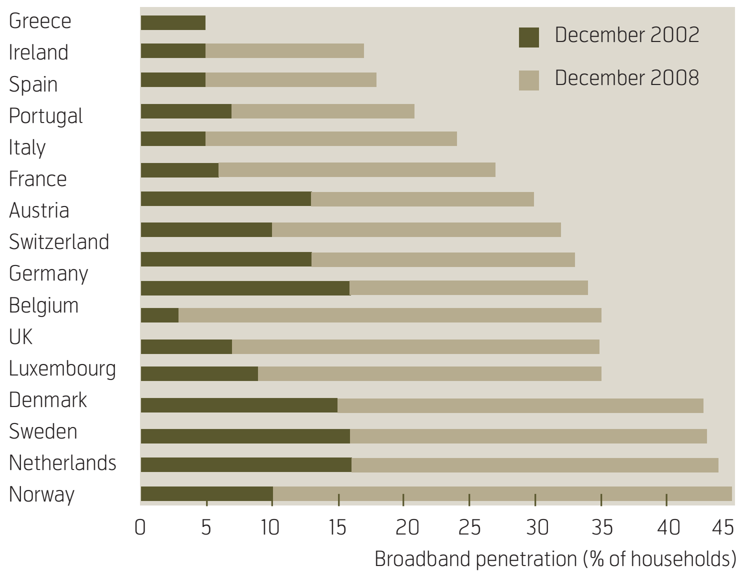


Figure 5 Estimated broadband penetrations in Nordic countries, (Teleplan, EU, NPT, operator information)



Figur 6 Actual and expected broadband connections in Europe, 2002 and 2008 (Forrester Research 2003)

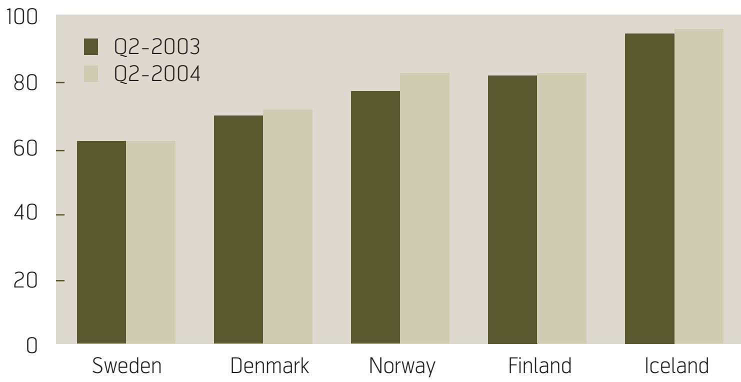


Figure 7 DSL-share in the Nordic countries (EU, NPT, Operator information)

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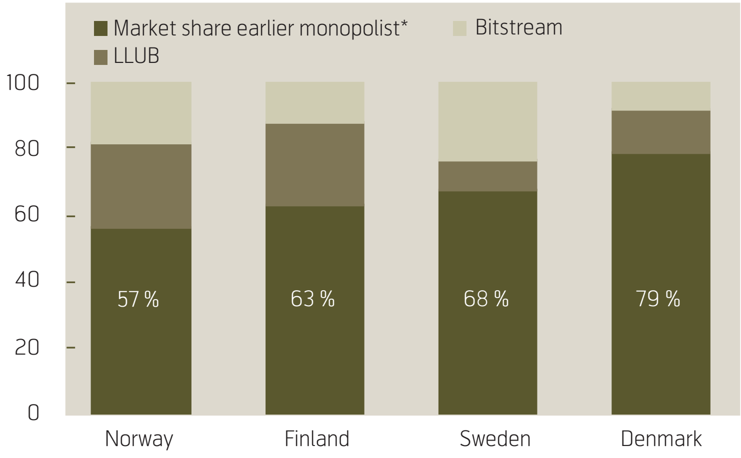

*Figur 8 Market shares for DSL, 2003 (*Telenor, TDC, Telia Sonera and local Finnish operators, EU, NPT and Teleplan)*

3 Network, content and skills should be seen in context

The rollout of broadband should be seen in the light of more conditions than network infrastructures, such as the telecoms and broadcasting networks. On the one hand, huge investments are required for the rollout of *broadband infrastructures*, and the companies involved in this process wish to wait until demand is sufficiently high. On the other hand, it takes time to create *services* with *content*, and it takes time before users have understood the opportunities and defined their needs so that they demand new services. In addition, industry and the public sector must have sufficient *competence* regarding the opportunities and applications for investing in broadband solutions. It is important that the infrastructure should be seen in connection with the development of services, content and skills.

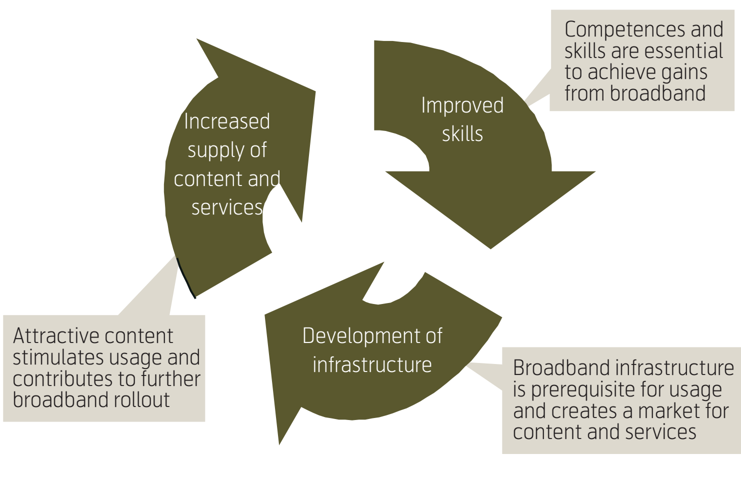

Figure 9 Network skills and content must be seen in context

Communications networks must be designed so that they can both transport the services that are available today and be flexible enough to provide room for future services requiring greater transfer capacity. Broadband is supplied through a variety of competitive technologies, and new technologies are constantly being introduced at the same time as those that are currently available are being developed. It is important that the authorities pursue a policy that does not favour one technology over any other, and which paves the way for competition between and within different technologies. The development of new technologies within the fields of, for example, radio and satellite may prove to be important in providing broadband to a large part of Norway's population on a commercial basis. The rollout of broadband means that society's need for information technology will increase beyond current levels. Communication networks with a constant online presence also mean greater vulnerability. Security, planning, accessibility and a need for additional capacity (redundancy) need to be well planned. There are plans to develop different communications networks for a variety of purposes, including emergency communication. In connection with the development of public networks, the benefits of coordination should be realised.

The demand for broadband is to a large extent driven by growth in *services and content* requiring high transmission rates that are offered by the private market and the public sector. Developments are not wholly clear, however. Today we lack business models for the distribution of revenues between content and service providers and network operators. The value chains are complex and are being developed and changed in line with the introduction of new products on the market, and as technologies converge and branches of industry are restructured. Many business players have problems finding good business models. In the value chain for production and distribution of electronic content, there are also bottlenecks where monopolistic situations can arise. These include requirements concerning the use of software from a dominant supplier, requirements to sell content through specific payment schemes or requirements that content and sources must be approved by specific controlling bodies.

The public sector has an important role to play in the development of services and content, both by offering services and by creating good framework conditions for the production of content. In many areas, the public sector administers basic data that are important for private enterprises wishing to develop services and content. It is important to ensure that these players will also have access to basic public data in the future, and that the organisation of central govern-

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ment does not have an inhibiting effect on the business activities of private enterprises.

Competence is an important prerequisite for realising the benefits of broadband. This applies to both user-skills and leading-edge expertise. Many people acquire IT skills at work. Those without access to the Internet at home or at work may encounter problems as an increasing number of essential tasks such as banking and postal services, information collection and the submission of tax returns are carried out electronically.

Schools and libraries play a key role in the task of strengthening the population's IT skills and in ensuring that pupils have the necessary background when it comes to acquiring new knowledge in new ways. It is a condition that new technology is seen in connection with organisational changes, new ways of working and skills networks. There is a need for skills with a focus, among other things, on organisation, technology and new business strategies. Norway has some of the most prominent environments in Europe in respect of e-learning. Broadband creates entirely new opportunities for interactive e-learning, which to a large degree can contribute to the development of the adult population's IT skills. Universities and university colleges will become central partners in respect of the development of leading-edge skills and applications. With the public sector as a demanding customer in terms of targeted training and education, Norway has an opportunity to create a strong and viable e-learning industry with an international potential.

4 Local initiatives are important for broadband rollout

In different parts of Norway, a wide variety of projects have been initiated in companies, local authorities and public bodies to speed up the rollout of broadband. Local initiatives of this nature help roll out and finance broadband and provide increased competition in areas where telecoms companies do not initially find it profitable to roll out broadband. Financing will primarily be from local sources (local authorities, county municipalities, local businesses, organisations), alternatively with some external support for the financing of pilot projects.

In several instances, various public enterprises in one region, often in collaboration with local businesses, have joined forces to purchase broadband services at a regional level. This allows infrastructure costs to be shared and creates a larger customer base for inhabitants. Local authorities and county municipalities

Digital Regional Agder

In the county municipalities of Aust-Agder and Vest-Agder, 18 outlying municipalities in three inland regions established the cooperative project "Digital Regional Agder" (DRA). These municipalities represent just under 60,000 inhabitants, where the smallest municipality has under 900 inhabitants and the largest over 13,000. The objectives of DRA are: 1) that the regions shall have a competitive offer of broadband on competitive terms, and 2) that the municipalities shall use broadband to enhance the efficiency and quality of their own organisation and range of services.

The DRA project has by means of invitations to tender and negotiations put in place an agreement for the supply of broadband to all 18 municipalities at competitive prices. Under the terms of the agreement, all local government administrations will be supplied with 24 Mb capacity in fibre cable, with the opportunity of additional connections to other public buildings, private industry and to households. Under the agreement, the three regions, consisting of three, five and five municipalities, respectively, will each have their own shared connection point to the Internet, which will increase capacity and reduce costs. As a result of the broadband agreement, 12 upper secondary schools in Aust-Agder will have a connection with a capacity of 10 Mb at competitive prices. All schools will be connected by means of a new fibre cable. Once the broadband connection is in place at the end of September 2003, the stage will be set for continued development and the enhanced efficiency of municipal and inter-municipal cooperation.

The DRA project can be characterised by shared funding by central government, county municipalities and municipalities, which has been the key to realising the project which is budgeted to cost NOK 27 million; the combined purchasing power of 18 municipalities has yielded interesting results compared to what they would have achieved had they each stood alone; the project has been rooted at the level of mayor/chief financial municipal executive in all 18 municipalities; the project has been based at all times on the principles of equality and solidarity between the municipalities – each municipality pays the same and receives the same capacity, regardless of number of inhabitants and geographical location; there has been a large degree of co-determination from all municipalities in budget and activity processes; the county municipalities have played an active role in initiating the project and in acting as a driving force.

Digital Regional Agder 2003

may also take the initiative to coordinate and plan infrastructure in the municipality or region and manage broadband roll-out by stipulating where ditches are to be dug and cables are to be laid. Local authorities and county municipalities may either involve themselves directly in the supply of services, or they may leave this to commercial players in the market.

The Norwegian Government is positive to these local initiatives, provided that the rollout of broadband is organised so that it has as little adverse effect as possible on market competition.

In southern Norway, a collaborative project called "Digital Regional Agder" has been established between local authorities and county municipalities. The local authorities that have been involved in the project have received a better offer as regards coverage and capacity/transfer rates than they would if they had purchased broadband individually. For many municipalities, cooperation has been essential in order to establish an offer of broadband.

5 The authorities will encourage continued development

It is the responsibility of businesses to upgrade their skills and pave the way so that they can use the technology effectively and reap the greatest benefits possible from their use of broadband. Continuous training, new opportunities and enhanced efficiency are also important for other parts of the private sector.

Like most other OECD countries, Norway has chosen a market-based strategy for the rollout of broadband, in line with OECD recommendations. The market players stand for development of the infrastructure for electronic communication and appurtenant services, and for the choice of technology. The Government will pursue a *neutral policy as regards technology* in order to secure competition within and between different technological platforms. Central government has no capability to choose between technologies and shall therefore not do so. The Government's strategy for broadband rollout is to

- *Pave the way for effective competition* in the rollout of the communications network and development of services and content;

- *Encourage public demand for broadband* and pave the way for the development of services and content, skills development and the dissemination of experiences;

- Evaluate *initiatives in areas where there is no commercial basis* for broadband rollout.

One central initiative for strengthening competition in the telecoms market is the new Act on Electronic Communication, which replaces the previous Telecoms Act. The new Act provides the authorities with instruments with which to strengthen competition in the market. At the same time the Act contains instruments that are flexible enough to both stimulate and regulate the emergence of new markets. The new Act continues the principle of a sector-specific regulation, but it also paves the way for a gradual transition to regulating the sector with a basis in general competition law. Other initiatives are aimed at improving the use of current and new telecom networks, publication of reports concerning matters relating to price and competition and to make available radio frequencies for the production of radio-based communications networks for use by market players.

The public sector is responsible for comprehensive service production and many supportive activities such as administration of basic data and information in respect of the general public. It is the Government's wish that the total thrust of public demand shall be utilised more systematically in order to enhance efficiency in the public administration, i.a. through applications that require broadband. Such applications improve the quality of services and provide room for enhanced efficiency and cooperation. The health and education sectors are two of the most important sectors in this respect.

The Government also paves the way for improving conditions for private development of content and services based on basic data owned by the public authorities. One example of basic material with a large potential for cooperation between public and private enterprises is geographical data in the form of electronic maps. The purpose of providing tax exemptions for home PCs is to increase general IT skills. This exemption also extends to broadband connections.

The Government will strengthen its efforts in respect of providing guidance by stepping up and improving the coordination of support services. The Government will pave the way to enable the support service apparatus to assist in processes whose aim is to gather local demand for broadband communication.

The HØYKOM programme, which enters the last year of its second three-year period in 2004, has so far had a major triggering effect. The overall objective of the HØYKOM programme is to stimulate the dissemination of broadband communication in Norway, especially in remote areas. The programme runs for a six-year period, starting in 1999 and ending in 2004. At the end of the ordinary programme in 2004, a total of 400–500 projects will have received support at a total cost of around NOK 250 million, which in turn has triggered investments totalling almost NOK 1 billion. The programme has good geographical distribution and has been the source of extensive cooperation in the public and private sectors. The programme is due to be evaluated in the autumn of 2003.

Effective from 2002, a schools programme was established (HØYKOM School) to investigate future needs and specifications for broadband in the education sector, to provide initiatives to stimulate infrastructure and the development of content and services. A preliminary evaluation of the HØYKOM School programme has shown that this scheme has been in demand by school owners. The Government will therefore propose that the Høykom School programme should be continued in 2004.

The broadband market is still in an early phase. One challenge is to trigger investments in sparsely populated areas of Norway. In the Norwegian State Budget for 2004 it will be proposed that the programme be expanded by introducing HØYKOM Region aimed at rolling out broadband in outlying areas.

The Parliament gave their official response to the Governments White Paper on broadband March 9, 2004. The Parliament specifically asked the Government to closely examine the broadband market, and in connection with the budgetary processes allocate resources for broadband development, so that all households, companies and public institutions will have a broadband offer during 2007.

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Kjell Ove Kalhagen (31) graduated with a Master in Economics from the University of Oslo in 1998. He has worked as Research Scientist in the Strategic Network Development group of Telenor R&D. The main activities have been techno-economics and risk analysis of broadband access rollout. Kalhagen has participated in international IST projects and was leader of one project focusing on the provisioning of broadband services to rural areas. He is author or co-author of several articles in journals and conferences.

Kalhagen joined the Ministry of Trade and Industry in January 2003, where he is working as a Senior Advisor in the Department of IT-policy. The Department is responsibe for coordinating the Government's broadband policy. He made a major contribution to the White Paper on broadband that was submitted to the Parliament in September 2003. Kalhagen is also working with issues related to information economy, including e-business and e-government projects.

Kjell-ove.Kalhagen@mod.dep.no

The Telenor Nordic Research Prize

TERJE ORMHAUG

Terje Ormhaug is Senior Research Scientist at Telenor R&D and Secretary for the Research Prize

Telenor has since 1997 granted a Nordic Research Prize in information technology and telecommunications, to underline the importance of research and innovation in the development of the information society, and to support Norwegian and Nordic efforts in this area. The prize consists of a diploma and NOK 250,000, and may be given for work within a broad range of professional fields. These may encompass areas like technology, networks and service development, economy and markets, and user behaviour, as well as new areas that may appear to be of importance in the future. For each year, however, Telenor chooses a more narrow scope for the prize, which for 2004 was:

> *"SW of importance for the creation or improvement of communication services"*

The winner in 2004 was professor Claes Wohlin at Blekinge Technical University in Sweden. The jury made their choice on the following grounds: Profesor Wohlin has in a short period of time managed to establish himself as a leading researcher internationally in the field of SW engineering, with particular focus on telecom. His work has covered both research and industrial practice within methods, tools and infrastructure in developing telecom software, and process improvement methodology. The view is the full life cycle of SW systems, with the objective to have right SW at right time, with right quality and cost. Professor Wohlin has also been very active in his teaching, and has an impressive list of publications.

Themes and winners of previous years have been:

1997	Video Coding Dr. Gisle Bjøntegård (N)
	SW tools and languages Birger Møller-Pedersen, Dag Belsnes and Øistein Haugen (N/DK)
1998	Development of internet technology Professor Stephen Pink (S)
1999	Advanced applications of communications and information services The Telepathology group (N)
2000	Enabling technologies for advanced ICT systems and services Professor Peter Andreksson (S)
2001	Research in socio-economic impact of ICT Professor Jon Bing (N)
2002	Mobility and wireless access to Internet. Technologies, new services and applications Professor Christian S. Jensen (DK)
2003	Technologies and systems enabling new communication services Dr. Haakon Bryhni (N)

Claes Wohlin being congratulated by Morten Karlsen Sørby, Executive Vice President of Telenor, on winning the Telenor Nordic Research Prize in 2004

Telenor spends huge amounts of money every year on investments and operation of big SW systems, which are crucial for our businesses. Claes Wohlin has made important contributions to improve the quality and value of what we will get for that money in the future.

For 2005 Telenor and the jury agreed on the following theme:

> **Enabling technologies and communication based value added services for the home, leisure and professional environments.** The research cited may include aspects of the technology, services, user acceptability and business opportunities.

According to the statutes the prize can be awarded to individuals or research groups for work that has been carried out in the Nordic countries, or by citizens from these countries. Anyone may nominate candidates for the prize. For 2005 proposals must be submitted to the secretariat at Telenor. The deadline will be announced on our website. Criteria and procedures for entering proposals can be found on: http://www.telenor.com/rd/research_award/. The members of the jury are:

- *Berit Svendsen*, Executive Vice President and CTO of Telenor ASA
- *Peter T. Kirstein*, Professor at University College in London
- *Erik Bohlin*, Ekonomie Dr. at Chalmers Tekniska Högskola in Gothenburg
- *Mads Christoffersen*, PhD, Associate Professor at the Center for Technology, Economics and Management at the Technical University of Denmark
- *Gunnar Stette*, Professor at the Norwegian University of Technology and Science in Trondheim
- *Olli Martikainen*, Professor at the University of Oulo

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Engineering software qualities in telecommunications – Three cases from industry

CLAES WOHLIN

Claes Wohlin is Professor of software engineering at Blekinge Institute of Technology, Sweden

Software has become an integral part of telecommunication systems over the last 30 years. The relative cost for software in the systems has increased continuously over these years. This increase has meant that there has been a need to also focus on evaluation and prediction of different software qualities of the systems. This paper presents three studies evaluating software qualities in different ways. The first study focuses on performance and touches upon reliability. The reliability aspect is discussed in more detail in the second case study. Finally, the third study presents methods to estimate the fault content from software inspections. These studies are presented as representative examples of the work that resulted in the author of this paper receiving the Telenor Nordic Research Prize in 2004. Some ongoing research on engineering software qualities is also briefly presented.

1 Introduction

The importance of software and its development has grown over the last 30 years. A major shift (at least) in the Nordic countries occurred in 1976 when the first AXE system was run on trial basis in Södertälje in Sweden. AXE was one of the first digital public telephone switches on the market. The first digital AXE exchange was installed in Turku, Finland in 1978. The proportion of cost devoted to software research and development in telecommunications has grown considerably over these years. Telecommunication systems have become more complex as new technologies have been developed since the mid 70s, including analogue mobile telephony, digital mobile telephony (GSM), Internet and broadband services. At the same time the functions and services provided by the systems have exploded. A number of services that would have been regarded as science fiction 30 years ago are a reality today. Internet is ten years old and is already taken for granted as part of the infrastructure on which a large part of society depends.

The speed of change is tremendous and software is in many cases becoming the competitive advantage in different types of products. Software was initially developed for specific customers, but today it is a natural part in many mass-market products. More and more products have software embedded into them and the systems should be connected and hence be able to work together in a distributed environment. These changes have of course had a major impact on society and completely changed businesses.

The introduction of digital solutions and an increased use of software have transformed telecommunications. For example, Ericsson is the largest software development company today in Sweden, and a large proportion of their R&D is devoted to software. The introduction of software has led to new possibilities, but also to new challenges. Software is different from hardware. The difference manifests itself in terms of invisibility, changeability, conformity and complexity [Brooks87]. These inherent problems (or challenges) of software means among several other things that engineering of the qualities of the software becomes a challenge. It is easy to determine whether a specific delivery date or the budget has been met, but it is much more difficult to address product qualities such as performance, reliability and maintainability.

The challenge of engineering and managing different quality aspects (or qualities) of software has led to an increased research into these aspects of software. The objective of this paper is to briefly present some of the research that has been conducted by the author of this article and which formed the basis for receiving the Telenor Nordic Research Prize in 2004. The presentation is by no means exhaustive, and hence the aim is primarily to provide a glance of some of the research on software qualities in relation to telecommunication systems.

The research related to engineering of software qualities is illustrated with three studies conducted together with different industrial partners. The following studies are reported:

- Section 2: A study of estimation of performance and reliability from software design descriptions using simulation is presented briefly. The study was conducted together with Telelogic AB.
- Section 3: The experience from simulating usage in Section 2 is used in the study reported here. The objective of this study is to certify software reliability using a statistical approach to testing, in particular in acceptance testing. The study was conducted together with Telia AB.

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- Section 4: The work on reliability led to a study of software faults. The objective was to capture faults before testing. The focus was on software inspections and fault content estimations. This research project was conducted together with Ericsson AB.

Thus, the three studies reported show how experiences from one study help form the basis for new studies. These three studies are reported briefly here to give a flavor of the research. More details of the studies can be found in the references provided. The report from the studies is followed by a presentation of a current research project, in Section 5, where several qualities are addressed. Finally, some general conclusions and an outlook are given in Section 6.

2 Performance and reliability estimation

The main objective of this work was to formulate a general (independent of software description technique) method for functional, performance and reliability evaluation at an early stage of software development. The long term objective was to formulate a method that can be applied throughout the software life cycle to evaluate and assess the quality attributes of software systems. The objective was that the principles presented can be used throughout the software life cycle even if the actual level of detail in the models used may vary depending on available information.

The aim was to provide a method for evaluation of functional real time behavior, performance (in terms of capacity) and reliability of software design descriptions. The method is based on the software design descriptions being specified with a well-defined language, for example SDL (Specification and Description Language), which can be transformed automatically into a simulation model of the software design. A tool prototype, performing the transformations of SDL descriptions into a simulation model of the software, was implemented at Telelogic. The underlying method is presented in [Wohlin91]. Some initial ideas were presented in [Wohlin89]. It must be stressed that SDL is used as an example assuming that SDL is the normal software development method at the company applying the proposed evaluation method.

Transformation rules were formulated for SDL, hence showing that it is possible to actually use the design in the evaluation of quality attributes instead of formulating a separate simulation model of the behavior of the software. The transformed model is then distributed on a simulation model of the architecture. The input to the system (transformed software design distributed on a simulation model of the architecture)

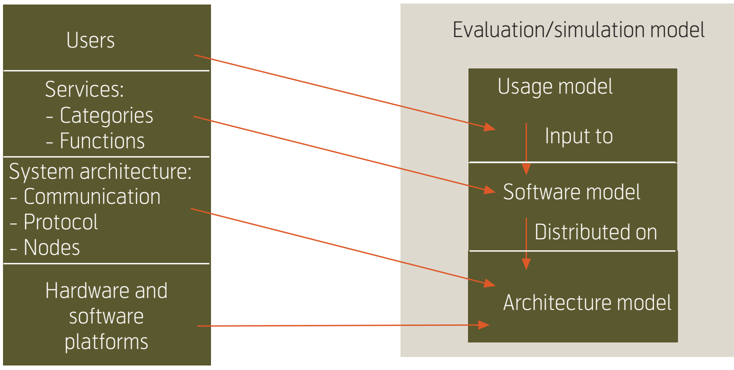

Figure 1 Mapping of the layers of uses and system concepts on the modeling concepts

is then modeled in a usage model, which is a simulation model of the anticipated usage of the system. The method consists hence of three separate models: software model, architecture model and usage model, as is shown in Figure 1.

The software model is a direct transformation of the actual design of the software to be used in the final system. The usage model and the architecture model are formulated in the same language as used in the software design, but these two models are supposed to be simulation models of the actual architecture and of the anticipated behavior of the users of the system. The three models are hence described with the same description technique which is the same technique as the software is being designed in. The strength of the method is its opportunity to combine the actual software design with simulation models.

The usage model is used as a traffic generator to the system, i.e. it sends signals to the system in a similar way as expected when the system is put into operation. The reliability of the software can be evaluated since failures occur as they would in operation, since the usage model operates with a usage profile which describes the anticipated usage in terms of expected events. This type of evaluation is further discussed in a testing context in Section 3. The capacity of the system is determined based on the inputs coming into the system and measurements on loads and throughputs. The analysis allows for identification of bottlenecks in the system as well as delays. The real time functional behavior is analyzed in terms of locating unexpected functional behavior. In particular, it is possible to find functional behavior that is a direct consequence of the delays in the system. The linkage between reality and the models as well as the relations between the models is depicted in Figure 1.

The difference between the work presented here and other approaches is the opportunity to combine the

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software design with simulation models described in the same description technique as the software design. The idea in itself is general and no direct limitations have been identified concerning which design techniques this approach can be applied for. The objective has neither been to formulate a tool set nor to advocate the use of SDL. The major difference with existing approaches is that a special notation has not been used and hence the method is believed to be general and the method aims at more than one quality attribute. This implies that it should be possible to adapt the general idea and formulate transformation rules etc. for other design techniques as well. The aim is to provide a framework and a method supporting early evaluation based on the actual software design as well as other description levels in the future.

The advantages of the proposed scheme can be summarized as:

- The evaluation of quality attributes can be performed at an early stage, i.e. during the design (cf. below with for example statistical usage testing);

- The concepts are general even though transformation rules have to be formulated for each specific design language;

- The actual software design is included in the evaluation method hence allowing for a good basis for decisions regarding the quality of the software;

- The method aims at analyzing performance, reliability and real time functional behavior, hence no separate analysis has to be performed for each quality attribute.

Reliability estimation is also of major importance in testing. The next section highlights this further.

3 Reliability and statistical testing

Testing may be defined as any activity focusing on assessing an attribute of capability of a system or program, with the objective of determining whether it meets its required results. Another important aspect of testing is to make quality visible. Here, the attribute in focus is the reliability of the system and the purpose of the testing is to make the reliability visible. The reliability attribute is not directly measurable and must therefore be derived from other measurements. These other measurements must be collected during operation or during tests that resemble the operation to be representative for the reliability. Reliability is often viewed as one important attribute of dependability. The latter is discussed in more detail in, for example, [Helvik04].

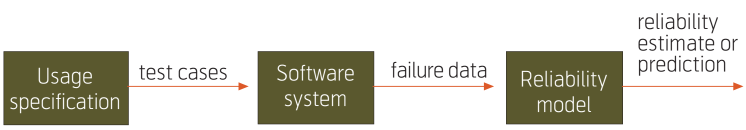

Figure 2 Reliability estimation from failure data

The difficulty of the reliability attribute is that it only has a meaning if it is related to a specific user of the system. Different users experience different reliability, because they use the system in different ways. If we are to estimate, predict or certify the reliability, we must relate this to the usage of the system.

The reliability attribute is complex. Reliability depends on the number of remaining faults that can cause a failure and how these faults are exposed during execution. This implies two problems:

- The product has to be executed in order to enable measurement of the reliability, although it may be estimated earlier. Furthermore the execution must be operational or resemble the conditions under which the software is operated.

- During execution, failures are detected and may be corrected. Generally, it is assumed that the faults causing the failures are removed.

In order to solve these problems, two different types of models have to be introduced:

- *A usage specification*. This specification, consisting of a usage model and a usage profile, describes the intended software usage. The possible use of the system should be specified (usage model) and the usage quantified in terms of probabilities or frequencies (usage profile). Test cases to be run during software test are generated from the usage specification. The specification may be constructed based on data from real usage of similar systems or on application knowledge. If the reliability is measured during real operation, this specification is not needed.

- *A reliability model*. The sequence of failures is modeled as a stochastic process. This model specifies the failure behavior process. The model parameters are determined by fitting a curve to failure data. This implies also a need for an inference procedure to fit the curve to data. The reliability model can then be used to estimate or predict the reliability.

The principle flow of deriving a reliability estimate during testing is presented in Figure 2.

Failure intensity is an easier quantity to understand than reliability. Failure intensity can in most cases be derived from the reliability estimate, but often the failure intensity is used as the parameter in the reliability model.

As indicated by Figure 2, the measurement of reliability involves a series of activities.

The process related to software reliability consists of four major steps:

1. *Create usage specification*
   This step includes collecting information about the intended usage and creation of a usage specification.

2. *Generate test cases and execute*
   From the usage specification, test cases are generated and applied to the system under test.

3. *Evaluate outcome and collect failure data*
   For each test case, the outcome is evaluated to identify whether a failure occurred or not. Failure data is collected as required by the reliability model.

4. *Calculate reliability*
   An inference procedure is applied on the failure data and the reliability model. Thus a reliability estimate is produced.

If the process is applied during testing, then process steps 2–4 are iterated until the software reliability requirement is met.

Additionally, it is possible to use attribute models to estimate or predict software reliability. This means that software reliability is predicted from other attributes than failure data. For example, it may be estimated from different complexity metrics, in particular in the early phases of a project. Then the estimates are based on experience from earlier projects, collected in a reliability reference model as outlined in Figure 3.

The reliability measurement can be used for different purposes in software project management. First of all we differentiate between reliability estimation and reliability prediction:

- Reliability estimation means assessment of the current value of the reliability attribute.

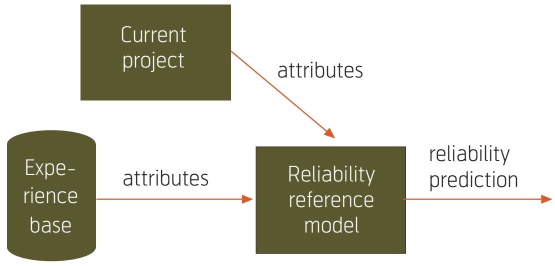

Figure 3 Reliability prediction from failure data

- Reliability prediction means forecasting the value of the reliability attribute at a future stage or point in time.

Reliability measurements can be used for different purposes. One of the most important is certification:

- Certification means to formally demonstrate system acceptability to obtain authorization to use the system operationally. In terms of software reliability it means to evaluate whether or not the reliability requirement is met.

The certification object can be either a complete product or components in a product or in a component library. Component certification is discussed in [Wohlin94]. The certification can be used for internal development purposes such as controlling the test process, by relating the test stopping criteria to a specific reliability level as well as externally as a basis for acceptance (as in the case with Telia).

Reliability predictions can be used for planning purposes. The prediction can be used to judge how long time is remaining until the required reliability requirement is met.

Predictions and estimations can both be used for reliability allocation purposes. A reliability requirement can be allocated over different components of the system, which means that the reliability requirement is broken down and different requirements are set on different system components.

From the usage specification, test cases are generated according to the usage profile as mentioned above. If the profile has the same distribution of probabilities as if the system is used during operation, we can get a reliability estimate that is related to the way the system is used, see Figure 4.

To evaluate whether the system responses for a test case are right or wrong, an oracle is used. The oracle uses the requirements specification to determine the right responses. A failure is defined as a deviation of

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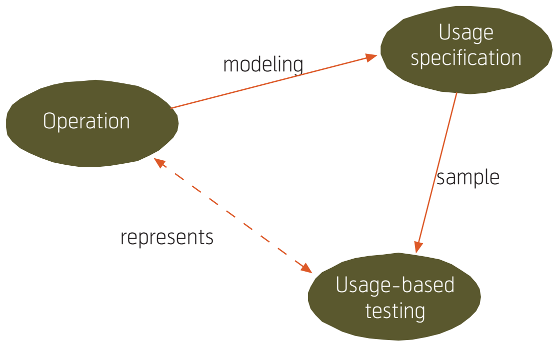

Figure 4 Relationship between operation, usage specification and usage-based testing

the system responses from its requirements. During the test, failure data is collected and used in the reliability model for the estimation, prediction or certification of the system's reliability.

The generation of test cases and the decision whether the system responses are right or wrong, are not simple matters. The generation is done by "running through" the model and every decision is made as a random choice according to the profile. The matter of determining the correct system responses is to examine the sequence of user input and from the requirements determine what the responses should be.

Statistical usage testing or operational profile testing is one of the few methods to actually predict the expected reliability during testing. Statistical usage testing was initially proposed as part of Cleanroom Software Engineering [Linger95]. Some extensions to the original approach are presented in, for example, [Runeson92]. In parallel to this work, operational profile testing was developed as a best practice at AT&T. More information about the approach used at AT&T can be found in [Musa93]. An introduction to software reliability can be found in, for example, [Wohlin01].

Reliability is clearly related to the faults in the software, although the actual relationship depends on the usage of the software. Thus, one way to get in control of reliability is to start managing software faults early. In particular, it is important to find ways of estimating fault content early. The next section addresses this challenge.

4 Fault content estimation

Inspections are used as a way of controlling quality, in terms of faults, but it is mostly done rather informally. The procedure is informal in the sense that we do not normally have any method or model to objectively judge the quality of the document or code being inspected. A capture-recapture method has been proposed to overcome this problem [Eick92], which is a method that is also used in biology to estimate animal populations. However, it was suggested as a method in software engineering in [Eick92]. The method is based on the inspection information from the individual reviewers and through statistical inference conclusions are drawn about the remaining number of faults after the inspection. Informally, the estimate is obtained based on the amount of overlap between findings of individual reviewers. More overlap means that fewer faults are probably remaining and vice versa. This is illustrated in Figure 5 with the help of bugs. In Figure 5, it is shown how three reviewers find different sets of faults. Moreover, the overlap between their findings is shown together with some faults that have not been found.

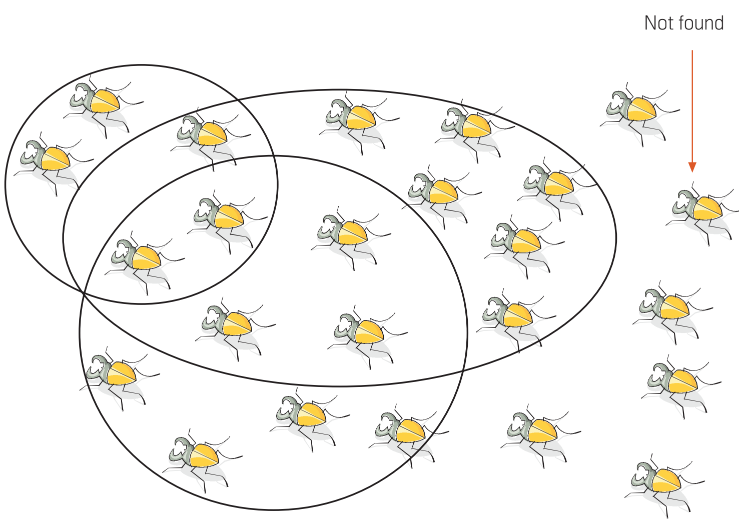

Figure 5 An illustration of the principle behind capture-recapture

This would allow us to make informed and objective decisions regarding whether to continue, do rework or inspect some more. The capture-recapture approach is based on applying a statistical method to the collected data. Three methods have been applied for this purpose: the maximum-likelihood estimator, the jacknife estimator and the Chao estimator. The maximum-likelihood method has been applied in, for example, [Eick92, Runeson98], and the jacknife method has been compared with the maximum-likelihood method in [Briand97]. The Chao estimator has also been examined and some results are presented in [Briand97].

In [Eick92, Wohlin95], it is reported that both the maximum-likelihood method and the jacknife method seemed to consistently underestimate the number of faults. This result is contradicted by [Runeson98], where the maximum-likelihood method overestimates the number of faults by approximately 10 % on average. An experience-based approach is also presented in [Runeson98]. This method is based on historical data, and it does on average as well as the maximum-likelihood method, but it seems a little less sensitive to variations in the data. Based on the difficulty to achieve good and consistent estimates, two new methods were proposed in [Wohlin98].

The novel idea behind the new approaches is that we start from a plot of the actual data (inspired by software reliability models), and through the plot we are better able to understand the data. Thus, we are also able to understand how the actual data deviate from the assumptions in using, for example, a capture-recapture approach.

The two methods identified were:

- *Detection profile method*
  In this method, the data are plotted with fault number on the x-axis and the number of reviewers that found a particular fault on the y-axis. The ordering of the faults on the x-axis is done based on the number of reviewers that found a specific fault. The data are plotted in a bar graph, and it is assumed that the data can be approximated with a decreasing exponential function which then is used to estimate the total number of faults, and hence the number of remaining faults as the inspections is done.

- *Cumulative method*
  This approach is based on the cumulative plot of all faults found by the reviewers. The data are plotted with the faults on the x-axis and with the cumulative number of faults found by the reviewers on the y-axis. This means that the first bar gives the number of reviewers that found the fault found by most reviewers, the second bar adds the number of reviewers that found the next fault to the first bar and so on. The y-axis is simply the cumulative number of faults found. It is assumed that the bars can be approximated with an increasing exponential curve. The exponential curve is then used to estimate the total number of faults, and hence the number of remaining faults.

The objective of the detection profile estimation method is to estimate the number of faults using the information of how many reviewers that found a specific fault. The method is based on sorting and plotting the number of reviewers that found different faults, and then estimating the total number of faults approximating the data with a mathematical function.

Based on the studies we have conducted [Runeson98, Wohlin95], we have here found it suitable to use an exponentially decreasing function. It should be noted, however, that we would in particular recommend to sort and plot the data, and then choose an appropriate function based on the plot.

A fictitious data set resembling the form we have observed from real inspection data is given in Figure 6. The objective is to illustrate the form of the plot underlying the detection profile estimation method. It should be noted that we have assumed eight reviewers (J = 8) and ten faults (K = 10), which is rather unrealistic but convenient for illustration purposes. In Figure 6, we can see that the first fault is found by all eight reviewers, the second fault is found by six reviewers and so forth. An alternative interpretation is to view it as fault number one occurred eight times. The basic idea behind this method is that the data should be sorted according to the number of occurrences.

In plotting the data according to Figure 6 it can be noted that it should be feasible to approximate the plot with an exponentially decreasing function. This can be used to estimate the total number of faults, if assuming:

- Adding more reviewers means that more faults will be discovered and finally all faults will be found.

- The data resemble an exponential distribution when plotted. The fulfilment of this assumption is probably dependent on the applied inspection method.

- The total number of faults is estimated from the function, assuming there is an additional fault if the function has a value greater than 0.5 for integers above the number of faults already found. Thus, the total number of faults is estimated as

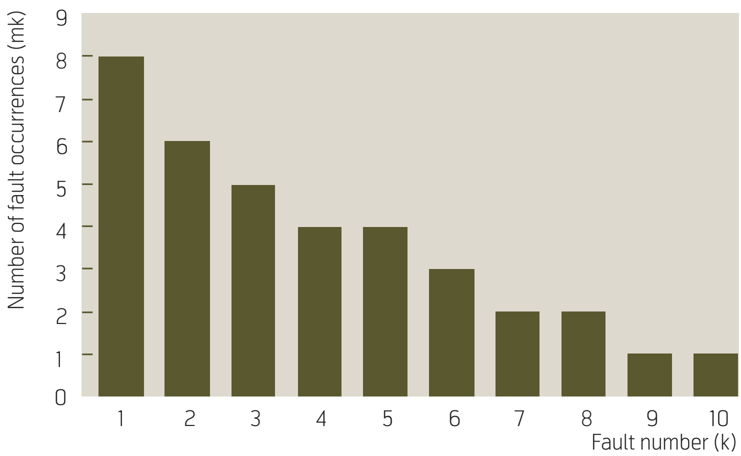

Figure 6 Fault content estimations from fault data in inspections

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the last integer value which results in the function being greater than 0.5.

- Furthermore, it is assumed that transforming the exponential function and the data into a linear model does not considerably affect the estimate. Basically, it is assumed that this transformation does not affect the estimate more than the actual uncertainty in the data.

This method has no explicit assumption about independent reviewers, although it is assumed implicitly through the assumption of an exponentially decreasing function, where it is expected that at least some faults are found by a single reviewer.

In conclusion, these types of methods, capture-recapture estimations or fault content profile methods provide an opportunity to get an estimate of the remaining fault content after an inspection. Normally, the found faults are noted, but the number of remaining faults is unknown, which may not be the best situation to base the further development on. A more in-depth introduction and overview of these types of methods are provided in [Petersson04]. An overview of software inspections in general can be found in [Aurum02].

The three studies have shown some of the work conducted with respect to software qualities. The next section gives a brief introduction to some ongoing research.

5 Current main project

Software products should fulfill several quality requirements that may be divided into three main areas (related to user, developer and manager). These three areas are: operational qualities (for example performance, reliability and usability), development or evolution qualities (for example maintainability), and business qualities (for example lead time, effort and cost). Any software project needs to trade-off between different qualities. Based on this need a major research project was launched called "Blekinge – Engineering Software Qualities (BESQ)". The vision of the project can be summarized as "Quality-balanced software". The overall objective of the research is to provide methods, techniques and tools to engineer the different qualities and the trade-off between them through the software life cycle from requirements to acceptance testing via design and implementation.

To achieve the above objective expertise in the following areas is joined:

- *Processes and methods for development and management*
  The research in this area is concerned with methods and techniques to improve the work process of developing software. The research includes several subprojects related to requirements engineering. One of these is focused on improving impact analysis from a requirements level. This includes supporting both managers and developers in predicting system impact. Another study is aimed at requirements prioritization of dependent software requirements. The objective is to develop a method to allow for the best possible subset of requirements to include in, for example, the next software release. Other studies in this area include software faults, methods to control faults and the faults' relation to software reliability.

- *Software architecture*
  Research in this area is aimed at design and use of software architecture. The focus is also on software architecture in industrial use, including both software product lines and evaluation of software architecture. Issues of particular interest are methods, techniques and mechanisms for addressing: variability of a software product line architecture, evolution of a software product line architecture and its derived software product architectures. Software architecture evaluation methods and techniques are of importance since they can be used for a number of objectives: predict quality levels of quality attributes, decide about trade-off between different qualities and assess the architecture's suitability in a software product line. The objective is to develop and validate usable software architecture evaluation methods.

- *Performance and availability aspects*
  This area includes investigating techniques, methods and guidelines for obtaining acceptable performance and availability without sacrificing other qualities, e.g. maintainability and usability. Design techniques which minimize maintainability may result in unacceptable performance due to excessive dynamic memory management. Software architectures for high availability often contain redundant components, which may increase the maintenance cost. The objective is to identify where such conflicts occur and then attack them. This can for example be done by providing guidelines on how to obtain reasonable trade-offs, or by providing new technical solutions in the form of resource allocation algorithms, etc. (e.g. dynamic memory algorithms for object-oriented programs) that will remove the performance and availability penalties of some popular design styles.

- *Use orientation in software development*
  The research in this area is concerned with methods and techniques supporting the development of socially embedded systems. The focus is both on the software development process – evolutionary co-development of work practice and the supporting software – as on product qualities – changeability, maintainability, and user tailoring. For example, in an ongoing project the focus is on techniques to allow for user tailoring and the implication of the development of such techniques on software development, maintenance and "Design in use". An empirical approach is used that facilitates, on the one hand, to explore the use and situated adaptation of methods and techniques in an industrial context. On the other hand, the objective is to (further) develop these methods and techniques in participation with practitioners.

The BESQ research environment was launched in July 2002. The Knowledge Foundation (KK-Stiftelsen) is the main initial sponsor of the initiative together with matching funds (in kind) from industrial partners. The initiative is initially run as a research project with a total funding exceeding 85 million Swedish kronor for the first six years. The objective is to create a strong research environment within Software Engineering during these six years to enable a successful continuation of the research beyond 2008.

There are six companies actively involved at the moment. The project is conducted together with Ericsson, UIQ Technology, Danaher-Motion Särö, ABB, Sigma Exallon and Vodafone. During 2004 two subprojects ended, one with Volvo IT as industrial partner and one with the Swedish Nuclear Power Inspectorate, a government authority, as co-operation partner. There are eleven subprojects running and as many PhD students involved. Among these eleven PhD students, two doctoral students are industrial PhD students who are located at their respective companies. In total around twenty people work in BESQ.

6 Summary and outlook

The importance of understanding software qualities in telecommunications has become more and more important over the years. Software is and will be for a foreseeable future a core component and asset in telecommunications. The challenge of managing qualities of software to handle trade-off and prioritization of different aspects is an important aspect of developing software for telecommunications.

This paper has briefly presented three different studies conducted together with industrial partners from the telecommunication domain. The studies have illustrated that some methods and techniques are available today, and research is continuing. A key problem in research is that in many cases, also in the reported cases, the focus is on individual quality aspects. This is good, but not sufficient. In an industrial situation these qualities have to be traded against each other. The paper has reported on a major research project trying to address some of these challenges.

In addition, different initiatives try to address how software should be developed. This implies improvement of software development processes, including different methods, techniques and tools. This challenge relates to all aspects of software development, including how to handle distributed software development and outsourcing. The leading software research organization world-wide, Software Engineering Institute, has launched an initiative to formulate a roadmap for the future research into the software process [SEI04]. Important aspects that will be discussed and most likely included in the roadmap are issues related to: component-based processes, flexible processes, process verification and validation, process simulation, and empirical validation of changes. Bottom-line is that the development process has to be adapted based on the needs, for example, in terms of which software qualities are important for specific types of products. One-size processes do not fit all projects due to different requirements and expectations on the qualities of the software.

Acknowledgment

First of all, I would like to express my sincere thanks to Telenor for awarding me their Nordic Research Prize in 2004. It underlines the importance of software engineering as a crucial aspect of the development and evolution of telecommunication systems. I would also like to thank former and current colleagues at companies and universities for many interesting and fruitful discussions and collaborative projects over the years.

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Dr Claes Wohlin is a professor of software engineering at the School of Engineering at Blekinge Institute of Technology in Sweden and he is also pro vice chancellor for the Institute. Prior to this, he has held professor chairs in software engineering at Lund University and Linköping University. He has a PhD in Communication Systems from Lund University. Dr Wohlin has five years of industrial experience as software developer, quality manager and project manager. He is co-editor-in-chief of the journal of Information and Software Technology published by Elsevier. Dr Wohlin is on the editorial boards of Empirical Software Engineering: An International Journal, and Software Quality Journal.

email: Claes.Wohlin@bth.se

Terms and acronyms in Telecommunications Forecasting

2G	Second Generation (mobile network)	Refers to the family of digital cellular telephone systems standardised in the 1980s and introduced in the 1990s. They introduced digital technology and carries both voice and data conversation. CDMA, TDMA and GSM are examples of 2G mobile networks.
3G	Third Generation (mobile network)	The generic term for the next generation of wireless mobile communications networks supporting enhanced services like multimedia and video. Most commonly, 3G networks are discussed as graceful enhancements of 2G cellular standards, like e.g. GSM. The enhancements include larger bandwidth, more sophisticated compression techniques, and the inclusion of in-building systems. 3G networks will carry data at 144 kb/s, or up to 2 Mb/s from fixed locations. 3G will standardize mutually incompatible standards: UMTS FDD and TDD, CDMA2000, TD-CDMA.
3GPP	Third Generation Partnership Project	Group of the standards bodies ARIB and TTC (Japan), CCSA (People's Republic of China), ETSI (Europe), T1 (USA) and TTA (Korea). Established in 1999 with the aim to produce the specifications for a third generation mobile communications system called UMTS. A permanent project support group called the "Mobile Competence Centre (MCC)" is in charge of the day-to-day running of 3GPP. The MCC is based at the ETSI headquarters in Sophia Antipolis, France. http://www.3gpp.org.
4G	Fourth Generation (mobile network)	Term often used to denote future broadband mobile communications systems or standards with high mobility and bit rates up to 100 Mb/s to follow 3rd generation. Often referred to as "systems beyond 3G" (B3G).
ACTS	Advanced Communications Technologies and Services	Thematic Programme of the Fourth Framework Research Programme funded by the European Union. It ran from 1994 to 1998 (the last project ended 2000) with a total funding from the EU of 681 million Euro. http://www.cordis.lu/acts.
Adoption rate		See take rate.
ADSL	Asymmetric Digital Subscriber Line	A data communications technology that enables faster data transmission over copper telephone lines than a conventional modem can provide. The access utilises the 1.1 MHz band and has the possibility to offer, dependent on subscriber line length, downstream rates of up to 8 Mb/s. Upstream rates start at 64 kb/s and typically reach 256 kb/s but can go as high as 768 kb/s.
ADSL2+	Enhanced Asymmetric Digital Subscriber Line	The access utilises the 2.2 MHz band and has the possibility to offer considerably higher speed than ADSL, up to 25 Mb/s downstream.
AIC	Akaikes Information Criterion	A "goodness of fit" measure for comparing different forecasting models or other statistical models.
Analogy methods		The analogy methods attempt to compare historical patterns with existing situations in order to model and forecast future evolutions.
API	Application Program Interface	A set of routines, protocols, and tools for building software applications. Most operating environments, such as MS Windows, provide an API so that programmers can write applications consistent with the operating environment.
AR	Autoregressive model	A forecasting model where the dependent variable is related to past values of itself at varying time lags. The model expresses the forecast as a function of previous values.
ARIMA	Autoregressive Integrated Moving Average model	Time-series models which are transformed to stationary ARMA models by differencing.

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ARMA	Autoregressive Moving Average model	Time series forecasting models consisting of Autoregressive (AR), Moving average (MA), or a combination of the two (ARMA). The forecasts are expressed as a function of previous values of the series (autoregressive terms) and previous error terms (the moving average terms).
ARPU	Average Revenue Per User	
ASTN	Automatic Switched Transport Network	
ATM	Asynchronous Transfer Mode	A high-bandwidth, low-delay, connection-oriented, packet-like switching and multiplexing technique. ATM allocates bandwidth on-demand, making it suitable for high-speed connections of voice, data and video services. Access speeds are up to 622 Mb/s and backbone networks currently operate at speeds as high as 2.5 Gb/s. Standardised by ITU-T.
Bass model		A forecasting model in the class of diffusion models.
BJ	Box Jenkins methods	Box Jenkins (1970) developed their well-known Box Jenkins approach to identify and fit autoregressive-integrated-moving average (ARIMA) models to time-series forecasting problems.
Busy hour		A one-hour period within a specified interval of time (typically 24 hours) in which the traffic load in a network or sub-network is highest.
Cable modem		Broadband access modem used in Hybrid Fibre Coax (HFC) networks.
CAPEX	Capital expenditure	
CaTV	Cable Television	
CDMA	Code Division Multiple Access	Digital cellular technology that uses spread-spectrum techniques. Allowing for multiple transmissions to be carried simultaneously on a single wireless channel (same time slot and carrier frequency). This is done by spreading the signal across the frequency band using one of a set of spreading codes such that one user's signal appears as noise/interference for other (non-intentional) receivers. CDMA is used in certain cellular systems, like e.g. cdmaOne/IS-95, and is also in 3G systems like UMTS and CDMA2000.
CDN	Content Distribution/ Delivery Network	A collection of network elements arranged for more effective delivery of content to clients. Typically, a CDN consists of a request-routing system, surrogates (a content server other than the original server), a distribution network, and an accounting system.
CELTIC	Cooperation for a European sustained Leadership In Tele-communications	CELTIC is a five years EUREKA cluster project, which started work in November 2003. The initiative is supported by most of the major European players in communication technologies. The main goal of CELTIC is to maintain European competitiveness in telecommunications through collaborative R&D. CELTIC projects are characterised by a holistic approach to telecoms networks, applications, and services. Like all EUREKA cluster projects, CELTIC is open to any kind of project participants from all EUREKA countries. http://www.celtic-initiative.org/.
CLEC	Competitive Local Exchange Carrier	Telephone company that competes with an incumbent local exchange carrier (ILEC) such as a Regional Bell Operating Company (RBOC), GTE, ALLNET, etc. In Europe the term OLO (other licensed operator) is used more often than CLEC.
CNM	Customer Network Management	
Coverage		Proportion of number of units (e.g. persons, households, firms) who have got a service divided by number of units in the area. Broadband coverage is widely used for comparing the broadband rollout in various countries. Coverage is also used for smaller areas and for different types of areas, such as urban, suburban and rural.
Cross-correlation		A correlation measure between two time-series.

Cross-sectional data		Statistics of a number of different units for a single time period. The cross-sectional data can be used to estimate relationships for a forecasting model. Cross-sectional data from e.g. different regions or countries could be utilised to improve a forecasting model.
CSV	Cross Sectionally Varying	
CWDM	Coarse Wavelength Division Multiplexing	A relatively low-cost WDM technology that uses wide spacing (about 10 nm) between wavelengths and un-cooled optics.
DAB	Digital Audio Broadcasting	Terrestrial digital radio system, also called T-DAB developed by the EUREKA 147 Project in the period 1986 – 1993. It offers near CD-quality sound, more stations and additional radio and data services. Standardized by ETSI and recognized by the ITU in 1994. Regular broadcast in several European countries. Operates in the frequency bands 47–68 MHz, 87.5–108 MHz, 174–240 MHz and 1452–1479.5 MHz. First transmissions from 1995. Is intended to replace conventional FM broadcast. http://www.worlddab.org, http://www.eurekadab.org.
Delphi technique		The Delphi method is based on extracting independent forecasts from an expert panel over two or more rounds. The forecasting results and supplementary summaries and perhaps arguments are provided and distributed after each round. The main point of the method is that the views of experts through the process should iterate towards a common opinion.
Diffusion		Evolution of services or innovations through a population. The evolution (aggregated demand) follows a sort of S-curve. The logistic model is one of the relevant models, where the demand is proportional to the number of users who have got the service and proportional to the number of users who have not got the service. The number of new users per year increases rapidly, then after stabilising, decreases as unsatisfied demand for service dies away. Mead and Islam (2001) examine the use of diffusion models for time-series extrapolation.
Diffusion models		Class of forecasting models for diffusion demand.
DSL	Digital Subscriber Line	A family of technologies that provide a digital connection over the copper wires of the local telephone network. Its origin dates back to 1988, when an engineer at Bell Research Lab devised a way to carry a digital signal over the unused frequency spectrum. This allows an ordinary phone line to provide digital communication without blocking access to voice services. Bell's management were not enthusiastic about it, however, as it was not as profitable as renting out a second line for those consumers who preferred to still have access to the phone when dialling out. This changed in the late 1990s when cable companies started marketing broadband Internet access. Realising that most consumers would prefer broadband Internet to a second dial-out line, Bell companies rushed out the DSL technology that they had been sitting on for the past decade as an attempt to slow broadband Internet access uptake, to win market share against the cable companies. As of 2004, DSL provides the principal competition to cable modems for providing high speed Internet access to home consumers in Europe and North America. The reach-restraints (line length from Central Office to Subscriber) are reduced as data rates increase, with technologies like VDSL providing short-range links (typically "fibre to the curb" network scenarios). Example DSL technologies (sometimes called **xDSL**) include: ADSL (Asymmetric Digital Subscriber Line), HDSL (High Bit Rate Digital Subscriber Line), RADSL (Rate Adaptive Digital Subscriber Line), SDSL (Symmetric Digital Subscriber Line, a standardised version of HDSL), VDSL (Very high speed Digital Subscriber Line), G.SHDSL (ITU-T Standardised replacement for early proprietary SDSL).
DSLAM	Digital Subscriber Line Access Multiplexer	A DSLAM is a network device, usually at a telephone company central office, that receives signals from multiple customer Digital Subscriber Line (DSL) connections and puts the signals on a high-speed backbone line using multiplexing techniques. Depending on the product, DSLAM multiplexers connect DSL lines with some combination of asynchronous transfer mode (ATM), frame relay, or Internet Protocol networks.

DSM	Dynamic Spectrum Management	DSM allows adaptive allocation of spectrum to various users in a multi-user environment as a function of the physical-channel demographics, to meet certain performance metrics. By contrast, static spectrum management necessarily fires spectrum allocation based upon a worst-case analysis. Many communication systems, for example DSL (Digital Subscriber Line), use static spectrum management to ensure that mutual degradation between services sharing a physical medium is within acceptable levels. Necessarily, such worst-case spectrum management reduces achievable data rates and symmetries in DSL.
DTH	Direct To the Home satellite system	
DTT	Digital Terrestrial Television network	A network for transport of digital TV channels. The network can also be used for broadband communication.
DVB-H	Digital Video Broadcasting – Handheld	
DWDM	Dense Wavelength Division Multiplexing	A carrier class WDM technology that uses expensive, cooled optics and tight spacing between wavelengths of less than a nanometre based on specifications of the International Telecommunication Union (ITU). http://www.itu.int
DXX	Digital Cross Connect	Higher order cross-connects are generally used to route bulk traffic in blocks of nominally 155 Mb/s for network provisioning or restoration (including disaster recovery). They are designated as DXC 4/4. The first "4" refers to 155 Mb/s transmission ports on the cross-connect, and the second "4" indicates that the whole payload within the 155 Mb/s is switched as an entity. Lower order cross-connects (DXC 4/1 or 1/1, the "1" denoting primary rate at 1.5 or 2 Mb/s) are used for time switching leased lines, consolidation, and service restoration.
EDGE	Enhanced Data for GSM Evolution	A modulation method for GSM and IS-136 TDMA networks, standardized by ETSI, that allows for wireless data transfer up to 384 kb/s. http://www.etsi.org, http://www.3gpp.org.
Elasticity		Elasticity measures the percentage change in one variable caused by one percentage change in another variable. For example, the price elasticity of demand expresses the percentage change in demand if the price increases by one percent.
EMS	Enhanced Message Service	
Estimation		To fit appropriate parameter values based on a given statistical criterion.
Ethernet		International standard networking technology for wired implementations. Basic traditional networks offer a bandwidth of about 10 Mb/s, while Fast Ethernet offers 100 Mb/s and Gigabit Ethernet 1000 Mb/s.
ETSI	European Telecommunication Standards Institute	A non-profit membership organization founded in 1988. The aim is to produce telecommunications standards to be used throughout Europe. The efforts are coordinated with the ITU. Membership is open to any European organization proving an interest in promoting European standards. It was e.g. responsible for the making of the GSM standard. The headquarters are situated in Sophia Antipolis, France. http://www.etsi.org.
Extended learning curve model	Forecasting model for product and component costs	The model is an extension of the Learning curve model with the ability to make forecast for product costs.

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FCC	Federal Communication Commission (USA)	An independent United States government agency, directly responsible to US Congress. The FCC was established by the Communications Act of 1934 and is charged with regulating interstate and international communications by radio, television, wire, satellite and cable. The FCC's jurisdiction covers the 50 states, the District of Columbia, and US possessions. The FCC is directed by five Commissioners appointed by the President and confirmed by the Senate for 5-year terms, except when filling an unexpired term. The President designates one of the Commissioners to serve as Chairperson. Only three Commissioners may be members of the same political party. None of them can have a financial interest in any Commission-related business. As the chief executive officer of the Commission, the Chairman delegates management and administrative responsibility to the Managing Director. The Commissioners supervise all FCC activities, delegating responsibilities to staff units and Bureaus. The Commission staff is organized by function. There are six operating Bureaus and ten Staff Offices. The Bureaus' responsibilities include: processing applications for licenses and other filings; analyzing complaints; conducting investigations; developing and implementing regulatory programs; and taking part in hearings. http://www.fcc.gov.
FDD	Frequency Division Duplex	A method of separating the directions of a two-way communication link by using different frequencies in the two directions.
FDMA	Frequency Division Multiple Access	The oldest and most important of the three main ways for multiple radio transmitters to share the radio spectrum. In FDMA, each transmitter is assigned a distinct frequency channel so that receivers can discriminate among them by tuning to the desired channel.
First-degree price discrimination		Perfect price discrimination; the provider is able to have one price for each consumer type and price such that the entire willingness to pay is extracted from all types.
Fisher-Pry model	A forecasting model in the class of diffusion models	The model is the same as the Logistic model. See Logistic model.
FR	Frame Relay	An efficient data transmission technique used to send digital information quickly and cheaply to one or many destinations from one point. It can be used for voice, data, local area network (LAN), and wide area network (WAN) traffic. Each frame relay end-user gets a private line to a frame relay node. The frame relay network handles the transmission to its other end-users over a path which is always changing and is invisible to the end-users. Frame relay is a packet switched telecommunications network, commonly used at the data link layer (layer 2) of the Open Systems Interconnection reference model. Generally the concept of permanent virtual circuits (PVCs) is used to form logical end-to-end links mapped over a physical network. Switched virtual circuits (SVCs), analogous to circuit switching in the public switched telephone network, are also part of the Frame relay specification but are rarely applied in the real world. Frame relay was originally developed as a stripped-down version of the X.25 protocol.
FTTB	Fibre To The Building	This is in reference to fibre optic cable, carrying network data, connected all the way from an Internet service provider to a customer's physical building.
FTTC	Fibre To The Curb	Installation of optical fibre to within 1,000 feet of a home or enterprise. Typically, coaxial cable is used to establish the connection from curb to building.
FTTH	Fibre To The Home	An all-fibre optic network design. Broadband or other telecom services are delivered to the customer premises by fibre optic cable. FTTH is also referred to as fibre-to-the-building (FTTB).
FTTx	Fiber to the (x = home, premise, building, curb)	
FWA	Fixed wireless	Fixed wireless access consists of a radio link to the home or the office from a cell site or base station. It replaces the traditional wireless local loop, either if the wire based infrastructure is sparse or to gain rapid expansion in denser urban or suburban areas.

GbE	Gigabit Ethernet	
GMPLS	Generalised Multi-Protocol Label Switching	GMPLS is also known as Multi-protocol Lambda Switching, a technology that provides enhancements to Multi-protocol Label Switching (MPLS) to support network switching for time, wavelength, and space switching as well as for packet switching. In particular, GMPLS will provide support for photonic networking, also known as optical communications.
GMRAE	Geometric Mean Relative Absolute Error	
Gompertz model	A forecasting model in the class of diffusion models	The accumulated demand Y_t is expressed by $\ln Y_t = \ln M + e^{-b(t-a)}$ where M is the saturation level and a and b are growth parameters.
GPRS	General Packet Radio Service	An enhancement of GSM mobile communication system that supports data packets. GPRS enables continuous flows of IP data packets over the system for such applications as web browsing and file transfer. Supports up to 160 kb/s gross transfer rate. Practical rates are from 12 – 48 kb/s. http://www.etsi.org, http://www.3gpp.org.
Growth period		The time elapsing from 10 % penetration to 90 % penetration of a product. Growth period is one of the parameters in the extended learning curve model used to forecast product costs.
GSA	Global mobile Suppliers Association	A forum and representative for the leading GSM/3G suppliers worldwide. It is an organization created to meet suppliers' needs and represents in 2005 over 80 % of the GSM/3G market share globally. Membership is open to all suppliers of GSM/3G systems, devices, services, applications and solutions from across the entire supply chain. http://www.gsacom.com
GSM	Global System for Mobile communications	A digital cellular phone technology system that is the predominant system in Europe but also used around the world. Development started in 1982 by CEPT and was transferred to the new organisation ETSI in 1988. Originally, the acronym was the group in charge, "Group Special Mobile" but later the group changed name to SMG. GSM was first deployed in seven countries in Europe in 1992. It operates in the 900 MHz and 1.8 GHz band in Europe and 1.9 GHz band in North America. http://www.etsi.org, http://www.3gpp.org.
HDSL	High Bit Rate Digital Subscriber Line	DSL technology providing symmetrical access with bit rates of 1.544 Mb/s in each direction on one copper pair.
HDTV	High Definition Television	Broadcast of television signals with a higher resolution than traditional formats (NTSC, SECAM, PAL) allow. Except for an early analog format in Japan, HDTV is broadcast digitally, and therefore its introduction sometimes coincides with the introduction of digital television (DTV). An HDTV-compatible TV usually uses a 16:9 aspect ratio. The high resolution images (1920 pixels × 1080 lines or 1280 pixels × 720 lines) allow much more detail to be shown compared to analog television or regular DVDs. MPEG-2 is currently used as the compression codec. Like NTSC and PAL, 1920 × 1080 broadcasts generally use interlacing to reduce bandwidth demands. Alternating scan lines are broadcast 50 or 60 times a second, similar to PAL's 50 Hz and NTSC's 60 Hz interlacing. This format is entitled 1080i, or *1080i60*. In areas traditionally using PAL 50 Hz *1080i50* is also used. Progressive scan formats are also used with frame rates up to 60 per second. The 1280 × 720 format is in practice always progressive scan (with the entire frame refreshed each time) and is thus termed 720p.
HFC	Hybrid Fibre Coax	Restructuring of CaTV networks to HFC networks to using fibre tree structures in the upper part and coax drop and cable modem at the customer premises.
Holt's exponential smoothing model		An exponential smoothing model for trends. The model has two smoothing parameters, one for the level and one for the trend.
Horizontal differentiation		Consumers disagree with respect to the most preferred variety or product design.

HSCSD	High Speed Circuit Switched Data	An addition to GSM for adding faster data transmission. While GSM originally supports 9.6 kb/s, HSCSD supports from 14.4 to 57.6 kb/s circuit switched data connections. http://www.etsi.org, http://www.3gpp.org.
HSDPA	High-Speed Downlink Packet Access	Enhancement of the 3G standard UMTS in order to provide higher bit rates on the downlink. http/www.3gpp.org.
ICT	Information and Communication Technology	The technology required for information processing. In particular the use of electronic computers and computer software to convert, store, protect, process, transmit, and retrieve information from anywhere, anytime.
ILEC	Incumbent Local Exchange Carrier	A telecommunications company that dominates a specific market area.
IM	Instant Messaging	An instant messaging service is reached by the use of an instant messenger client. Instant messaging differs from e-mail in that conversations happen in real-time. Also, most services convey an "online status" between users, such as if a contact is actively using the computer. Generally, both parties in the conversation see each line of text right after it is typed (line-by-line), thus making it more like a telephone conversation than exchanging letters. Instant messaging applications may also include the ability to post an away message, the equivalent of the message on a telephone answering machine. Popular instant messaging services on the public Internet include Jabber, AOL Instant Messenger, Yahoo! Messenger, .NET Messenger Service and ICQ. These services owe many ideas to an older (and still popular) online chat medium known as Internet Relay Chat (IRC).
Internet		From the commissioning of ARPANET by the US DoD in 1969 the packet switched Internet has gained acceptance and users all over the world. The release of WWW at the end of the 90s and the browsing possibilities (see WWW) increased the demand for Internet. The interconnection of heterogeneous subnetworks of different bandwidths, the best-effort service model and the global end-to-end logical addressing of the Internet Protocol (IP) has arranged for Internet to be the common information network multiplexing text, pictures, and video as well as packet switched telephony.
IP	Internet Protocol	A protocol for communications between computers, used as a standard for transmitting data over networks and as a basis for standard Internet protocols. http://www.ietf.org.
IP VPN	IP Virtual Private Network	A system that enables you to create networks using the Internet as the medium for transporting data. These systems use encryption and other security mechanisms to ensure that only authorized users can access the network and that the data cannot be intercepted.
IP WS	IP Wholesale	
IRR	Internal Rate of Return	
ISDN	Integrated Service Digital Network	A digital communication network that provides end-to-end digital connectivity to support a wide range of services, including voice and non-voice services, to which users have access by a limited set of standard multi-purpose user-network interfaces. The user is offered one or more 64 kb/s channels. http://www.itu.int.
IST	Information Society Technologies	Thematic Programmes of the 5th and 6th Framework Research Programmes funded by the European Union. The first IST programme runs from 2000 to 2004, the IST programme of the 6th Framework Research Programme started in 2003 and will run to 2006. http://www.cordis.lu/ist
IT	Information Technology	See ICT.
ITU	International Telecommunication Union	On May 17, 1865, the first International Telegraph Convention was signed in Paris by the 20 founding members, and the *International Telegraph Union* (ITU) was established to facilitate subsequent amendments to this initial agreement. It changed name to the International Telecommunications Union in 1934. From 1948 a UN body with approx. 200 member countries. It is the top forum for discussion and management of technical and administrative aspects of international telecommunications..http://www.itu.int

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Judgmental forecasting methods		Qualitative forecasting methods where subjective information is integrated to produce the forecasts.
L1/L2	Layer-1 /Layer-2	
LAN	Local Area Network	A network shared by communicating devices, usually in a small geographical area.
Learning curve co-efficient	Parameter in the Learning curve model	The Learning curve coefficient denotes the cost reduction when the production volume on a world-wide basis is doubled.
Learning curve model	Prediction model for product costs	Wright (1936) developed the forecasting model and applied it on component costs in aircraft production.
LL	Leased Lines	
LLU	Local Loop Unbundling	Option to rent only a local loop (e.g. copper access line to customer premises) by a non-incumbent operator.
LMDS	Local Multipoint Distribution System	System for wireless local loop applications that can replace cable based access to private and corporate customers. Typically operates in the millimetre wave band. Can provide bandwidth of several Mb/s to the end customer.
Logistic model		The logistic model expresses the demand as proportional to the number of users who have got the service and proportional to the number of users who have not got the service. Let Y_t and M be the saturation level, then the equation $Y_t = M/(1 + ae^{-b \cdot t})$ describes the accumulated growth of number of users of the service at time t, where a and b are constants controlling the rate of growth.
Logit model		Choice model in which the dependent variable is inherently discrete. Dependent variable may be binary (0/1), or multiple.
MAD	Mean Absolute Deviation	An alternative measure to the standard deviation of the error based on absolute deviations when ignoring the signs.
MAE	Mean Absolute Error	The average error when ignoring signs.
MAPE	Mean Absolute Percentage Error	The average of all the percentage errors ignoring signs.
MBMS	Multimedia Broad-cast Multicast Service	A broadcast / multicast service defined for UMTS.
MBWA	Mobile Broadband Wireless Access	Term used by the IEEE 802.20 Working Group. Specification of physical and medium access control layers of an air interface for interoperable mobile broadband wireless access systems, operating in licensed bands below 3.5 GHz, optimized for IP-data transport, with peak data rates per user in excess of 1 Mb/s. The aim is to support various vehicular mobility classes up to 250 km/h in a MAN environment and targets spectral efficiencies, sustained user data rates and numbers of active users that are all significantly higher than achieved by existing mobile systems. http://grouper.ieee.org/groups/802/20/index.html
MdAPE	Median Absolute Percentage Error	The median of all percentage errors ignoring signs.
MDF	Main Distribution Frame	
MdRAE	Median Relative Absolute Error	If outliers are expected, MdRAE should be applied instead of GMRAE, which is using the median instead of the geometric mean of the relative absolute errors. See RAE.
MIMO	Multiple Input – Multiple Output	MIMO is an antenna technology for wireless communications in which multiple antennas are used at both the source (transmitter) and the destination (receiver). The antennas at each end of the communications circuit are combined to minimize errors and optimize data speed. MIMO is one of several forms of smart antenna technology, the others being MISO (multiple input, single output) and SIMO (single input, multiple output). MIMO technology has aroused interest because of its possible applications in digital television (DTV), wireless local area networks (WLANs), metropolitan area networks (MANs), and mobile communications.

MMS	Multimedia Message Service	MMS – sometimes called Multimedia Messaging System – is a communications technology developed by 3GPP (Third Generation Partnership Project) that allows users to exchange multimedia communications between capable mobile phones and other devices. An extension to the Short Message Service (SMS) protocol, MMS defines a way to send and receive, almost instantaneously, wireless messages that include images, audio, and video clips in addition to text. http://www.3gpp.org
Monte Carlo simulation	A procedure for simulating real-world events	First, the problem is decomposed; then a distribution (rather than a point estimate) is obtained for each of the decomposed parts. A trial is created by drawing randomly from each of the distributions. The procedure is repeated for many trials to build up distribution of outcomes.
MP3	MPEG-1/2 Audio Layer-3	A standard technology and format for compressing a sound sequence into a very small file (about one-twelfth the size of the original file) while preserving the original level of sound quality when it is played. MP3 files (identified by the file name suffix of ".mp3") are available for downloading from a number of Web sites. MP3 files are usually download-and-play files rather than streaming sound files that you link-and-listen-to with RealPlayer and similar products. (However, streaming MP3 is possible.)
MPE	Mean Percentage Error	The average of all percentage errors.
MPLS	Multi Protocol Label Switching	An IETF standard intended for Internet application. MPLS has been developed to speed up the transmission of IP based communications over ATM networks. The system works by adding a much smaller "label" to a stream of IP datagrams allowing "MPLS" enabled ATM switches to examine and switch the packet much faster.
MSE	Mean Squared Error	The sum of the squared forecast errors for each of the observations divided by number of observations.
MVNO	Mobile Virtual Network Operator	An MVNO is a mobile service operator that does not have its own licensed spectrum and does not have the infrastructure to provide mobile service to its customers (i.e. it does not own the network on which its voice and data traffic is carried). Instead, MVNOs lease wireless capacity from pre-existing mobile service providers and establish their own brand names different from the providers.
Naïve models		A model assuming that the evolution will remain as it has been in the past.
NG-SDH	Next Generation SDH	NG-SDH enables the operator to smoothly introduce Ethernet-based services over the existing SDH network. See also SDH.
NMT	Nordic Mobile Telephone	Automatic mobile telephone system based on analogue transmission technology. NMT was developed by the Nordic public telephone administrations in the 1969 to 1980 period. The first version NMT 450 operated in the 450 MHz band (NMT-450) and was launched in 1981/82. Later, the system was enhanced to operate in the 900 MHz band – NMT 900 in 1986.The system offered voice telephony with international roaming. The technology used was narrowband frequency modulation (FM) with 25 kHz user channels. The NMT-900 service was discontinued in 2001 when the GSM coverage had reached a sufficiently high level, and to release the frequency resources. In Norway, the NMT-450 system will be discontinued at the end of 2004. (Cf. *Telektronikk*, 91 (4), 1995).
NPV	Net present value	
NxISDN	Multiple ISDN lines	The system offers more than one ISDN line to the customers. See SMAKS.
OA	Operator access	
OA&M	Operation, Administration and Maintenance	

OECD	Organisation for Economic Co-operation and Development	The OECD groups 30 member countries sharing a commitment to democratic government and the market economy. With active relationships with some 70 other countries, NGOs and civil society, it has a global reach. Best known for its publications and its statistics, its work covers economic and social issues from macroeconomics, to trade, education, development and science and innovation. The OECD produces internationally agreed instruments, decisions and recommendations to promote rules of the game in areas where multilateral agreement is necessary for individual countries to make progress in a globalised economy.
OIF	Optical Internet working Forum	Industry group whose mission it is to foster the development and deployment of interoperable products and services for data switching and routing using optical networking technologies. OIF's purpose is to accelerate the deployment of interoperable, cost-effective and robust optical internetworks and their associated technologies. Optical internetworks are data networks composed of routers and data switches interconnected by optical networking elements. http://www.oiforum.org/
OLS	Ordinary Least Squares	OLS is found by minimising the sum of squares of the deviations between actual and predicted values. Because of its statistical properties, it has become the predominant method for regression analysis.
OPEX	Operations Expenditure	
OSI	Open System Interconnection	Refers to the 7 layer reference model developed by the ISO. The reference model breaks communication functions down into one of seven layers, each layer providing clearly defined services to adjacent layers. They are often referred to as Layer 1 through 7: 1. Physical layer 2. Data Link layer 3. Network layer 4. Transport layer 5. Session layer 6. Presentation layer 7. Application layer
OTN	Optical Transport Network	
Outliers		Observations that differ significantly from the expected value given a model of the situation.
OXC	Optical Cross Connect	A space division switch that can switch an optical data stream from an input port. Such a switch may utilise optical-electrical conversion at the input port and electrical-optical conversion at the output port, or it may be all-optical. An OXC is assumed to have a control plane process that implements the signalling and routing protocols necessary for computing and instantiating optical channels connectivity in the optical domain.
P2P	Peer-To-Peer	A computer network that does not rely on dedicated servers for communication but instead mostly uses direct connections between clients (peers). A pure peer-to-peer network does not have the notion of clients or servers, but only equal *peer* nodes that simultaneously function as both "clients" and "servers" to the other nodes in the network.
PDA	Personal Digital Assistant	Handheld device that combines computing, telephone/fax, Internet and networking features. A typical PDA can function as a cellular phone, fax sender, Web browser and personal organizer.
Penetration		The percentage of units (e.g. persons, households, firms) who have subscribed for a service. Quite often service penetration is calculated for a country. Then the penetration is the number of units who have subscribed divided by the total number of units in the country.
PIM	Personal Information Manager	
PLC	Power Line Connection	A system for transmitting broadband signals through the power lines directly to the customer premises.

PON	Passive Optical Network	A passive optical network (PON) is a system that brings optical fibre cabling and signals all or most of the way to the end-user. Depending on where the PON terminates, the system can be described as fibre-to-the-curb (FTTC), fibre-to-the-building (FTTB), or fibre-to-the-home (FTTH). A PON consists of an Optical Line Termination (OLT) at the communication company's office and a number of Optical Network Units (ONUs) near end-users. Typically, up to 32 ONUs can be connected to an OLT. The passive simply describes the fact that optical transmission has no power requirements or active electronic parts once the signal is going through the network.
POTS	Plain Old Telephone Service	A very general term used to describe an ordinary voice telephone service. See also PSTN.
Price elasticity		Own price elasticity: Percent change in demand when the price increases by 1 %. Cross price elasticity: Percentage increase in the demand for good *j* when the price of good *I* increases by 1 %.
Price-quality discrimin-ation		A firm price-quality discriminates when it sells different quality versions of a product at different prices, where price differences do not reflect differences in costs.
Product damaging		Product damaging occurs when a firm reduces the quality or value of a product in order to sell it at a lower price.
Product life cycle		The accumulated sales of a product are assumed to follow an S-shaped curve, growing slowly in the early stages, achieving rapid and sustained growth in the middle stages, slowing up to the mature stage, and then declining. This should help in the selection of appropriate forecasting method.
Product growth period		See Growth period.
PSD	Power Spectral Density	The power spectral density is defined as the Discrete Time Fourier Transform of the autocorrelation function.
PSTN	Public Service Telephone Network	Common notation for the conventional analog telephone network.
PTT	Post and Telecom-munication operator /authority	Common notation for the postal and telecom regulatory authority in a country. Previously common term for the national postal and telecom operator.
PTT	Push To Talk	
QoS	Quality of Service	The *"degree of conformance of the service delivered to a user by a provider, with an agreement between them"*. The agreement is related to the provision/delivery of this service. Defined by EURESCOM project P806 in 1999 and adopted by ITU-T in recommendation E.860. http://www.itu.int, http://www.eurescom.de.
RACE	Research in Advanced Commu-nications in Europe	Name of the 2nd and 3rd Thematic Programmes in Information and Communication Technologies funded by the European Union. In the 1st Framework Research Programme (FP), the "Community Action" RACE 0 was the definition phase from 1985-1986 and formulated a reference model for Integrated Broadband Communications (IBC). The first RACE programme (RACE 1) ran from 1987-1992 as a "Community programme in the field of telecommunications technologies". The 2nd RACE programme (RACE 2) ran from 1990-1994. The 4th FP was followed by the ACTS Thematic Programme. http://www.cordis.lu
RAE	Relative Absolute Error	The absolute error of a proposed time-series forecasting model divided by the absolute error of the random walk (no change) model. The RAE is similar to Theil's U2.
READSL	Reach Extended Asymmetric Digital Subscriber Line	The system utilises new coding by improving the signal to noise proportion. See also DSL.
RMSE	Root Mean Squared Error	The squared root or mean squared error, see MSE.

Robust trend		A trend estimate based on medians or modified means instead of arithmetic means.
RSS	Remote Subscriber Stage	A remote part of a digital exchange.
RSU	Remote Subscriber Unit	A remote part of a digital exchange.
Saturation level		The maximum units or number of members of a population who may adopt a service. Experience shows that knowledge and market insight could be the best basis for estimating the saturation level.
SDH	Synchronous Digital Hierarchy	SDH (Synchronous Digital Hierarchy) is a standard technology for synchronous data transmission on optical media. It is the international equivalent of Synchronous Optical Network. Both technologies provide faster and less expensive network interconnection than traditional PDH (Plesiochronous Digital Hierarchy) equipment. SDH uses the following Synchronous Transport Modules (STM) and rates: STM-1 (155 Mb/s), STM-4 (622 Mb/s), STM-16 (2.5 Gb/s), and STM-64 (10 Gb/s).
SDSL	Symmetric Digital Subscriber Line	See DSL.
Second-degree price discrimination		Discrimination by self-selection, the provider offers a menu of price differentiated product varieties and consumers select their most preferred variety.
Self selection		Self selection occurs when different types of consumers voluntarily buy the package or product that is designed for them.
Sensitivity analysis		A methodology to examine the effect generated by different critical variables through a systematic variation.
SHDSL	Single pair High-speed Digital Subscriber Line	See DSL.
SIM	Subscriber Identity Module	A smartcard securely storing the key identifying a mobile subscriber. SIMs are most widely used in GSM systems, but a compatible module is also used for UMTS UEs (USIM) and IDEN phones. The card also contains storage space for text messages and a phone book.
SLA	Service Level Agreement	A contract between a provider and a customer that guarantees specific levels of performance and reliability at a certain cost.
SMAKS	SMalbånds AKSess (Norwegian) Narrow band access	A Norwegian broadband system offering up to 256 kb/s and flat rate to all customers in Norway with 100 % coverage. The system is based on NxISDN.
SME	Small and Medium Enterprises	Micro, small and medium-sized enterprises represent 99 % of all enterprises in the European Union. The European Commission published in 2003 a revised definition of SMEs. According to this definition, micro-sized enterprises have less than 10 employees and a turnover less than € 2 mill. A small enterprise has less than 50 employees and a turnover of less than € 10 mill. Medium-sized enterprises have less than 250 employees and a turnover of less than € 50 mill. http://europa.eu.int/comm/enterprise/enterprise_policy/sme_definition/ index_en.htm.
SMP	Significant Market Power	
SMS	Short Message Service	A means by which short messages can be sent to and from digital cellular phones, pagers and other handheld devices. Alphanumeric messages of up to 160 characters can be supported.
SNR	Signal-to-Noise Ratio	The power ratio between the useful signal level (C) and the thermal noise level (N). Often expressed in dB. SNR = C / N
SONET	Synchronous Optical Network	

Take rate	Proportion between demand and supply	Take rate in an area is the number of units (e.g. persons, households, firms) who have subscribed divided by the number of units who have got the offer. The penetration is always less or equal to the take rate. Take rate and adoption rate are identical concepts.
TDMA	Time Division Multiple Access	A method of separating the directions of a two-way communication link by using different time slots in the two directions.
Third-degree price discrimination		The provider can observe a signal correlated with consumers' willingness to pay, and price discriminate based on this signal.
TVoDSL	TV over DSL	
UMTS	Universal Mobile Telecommunication System	The European member of the IMT-2000 family of 3G wireless standards. UMTS supports data rates of 144 kb/s for vehicular traffic, 384 kb/s for pedestrian traffic and up to 2 Mb/s in support of in-building services. The standardisation work began in 1991 by ETSI but was transferred in 1998 to 3GPP as a corporation between Japanese, Chinese, Korean and American organisations. It is based on the use of the WCDMA technology and is currently deployed in many European countries. The first European service opened in 2003. In Japan NTT DoCoMo opened its "pre-UMTS" service FOMA (Freedom Of Mobile multimedia Access) in 2000. The system operates in the 2.1 GHz band and is capable of carrying multimedia traffic. http://www.3gpp.org/.
UNI	User Network Interface	A term used in ATM and Frame Relay networks, UNI is the interface between the ATM end-user and a private ATM switch. It can also represent the interface between a private ATM switch and the public carrier ATM network.
USIM	Universal Subscriber Identity Module	See SIM.
VC-x	Virtual Circuit-x	
VDSL	Very high speed Digital Subscriber Line	Very High Speed Digital Subscriber Line transmits data in the 13 Mb/s – 55 Mb/s range over short distances, usually between 1000 and 4500 feet (300 – 1500 metres) of twisted pair copper wire. The shorter the distance, the faster the connection rate. See DSL.
Vertical differentiation		Goods are vertically differentiated if consumers agree on the ranking of available product varieties. If goods are differentiated with respect to one quality parameter, then vertical differentiation implies that all consumers agree that more (less) is better with respect to this quality parameter.
VOD	Video On Demand	An umbrella term for a wide set of technologies and companies whose common goal is to enable individuals to select videos from a central server for viewing on a television or computer screen. VoD can be used for entertainment (ordering movies transmitted digitally), education (viewing training videos), and videoconferencing (enhancing presentations with video clips). Although VoD is being used somewhat in all these areas, it is not yet widely implemented.
VoIP	Voice over IP	Voice transmission using Internet Protocol
WAN	Wide Area Network	This is a generic term covering a multitude of technologies providing local area networking via a radio link. Examples of WLAN technologies include Wi-Fi (Wireless Fidelity), 802.11b and 802.11a, HiperLAN, Bluetooth and IrDA (Infrared Data Association).
WAP	Wireless Application Protocol	An open international standard for applications that use wireless communication, for example Internet access from a mobile phone. WAP was designed to provide services equivalent to a Web browser with some mobile-specific additions, being specifically designed to address the limitations of very small portable devices.

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WLAN	Wireless Local Area Network	This is a generic term covering a multitude of technologies providing local area networking via a radio link. Examples of WLAN technologies include Wi-Fi (Wireless Fidelity), 802.11b and 802.11a, HiperLAN, Bluetooth and IrDA (Infrared Data Association). A WLAN access point (AP) usually has a range of 20-300 m. A WLAN may consist of several APs and may or may not be connected to Internet.
Wi-Fi	Wireless Fidelity	A term for certain types of wireless local area network (WLAN) that use specifications in the 802.11 family. The term Wi-Fi was created by an organization called the Wi-Fi Alliance, which oversees tests that certify product interoperability. A product that passes the alliance tests is given the label "Wi-Fi certified" (a registered trademark). http://www.wifialliance.org.
WiMax/ WMAN	Wireless Metropolitan Area Network	Commonly referred to as WiMAX or less commonly as WirelessMAN™ or the Air Interface Standard IEEE 802.16. A specification for fixed broadband wireless metropolitan access networks (MANs) that use a point-to-multipoint architecture. Published on April 8, 2002, the standard defines the use of bandwidth between the licensed 10 GHz and 66 GHz and between the 2 GHz and 11 GHz (licensed and unlicensed) frequency ranges and defines a MAC layer that supports multiple physical layer specifications customized for the frequency band of use and their associated regulations. 802.16 supports very high bit rates in both uploading to and downloading from a base station up to a distance of 30 miles to handle such services as VoIP, IP connectivity and TDM voice and data. http://www.ieee802.org/16/, http://www.wimaxforum.org/
WWW	World Wide Web	An international, virtual network based information service composed of Internet host computers that provide on-line information. Created at CERN, Geneva in 1991. http://www.w3c.org/
xDSL	(Any) Digital Subscriber Line	Various configurations of digital subscriber line: X = ADSL – asymmetric, VDSL – very high speed, SHDSL – single pair high speed, SDSL – symmetric, HDSL – high speed. See DSL.

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