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Ubiquitous Broadband Access

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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

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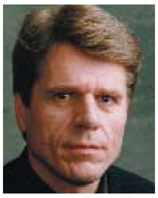

Terje Tjelta is Senior Research Scientist in Telenor R&I

Broadband access has shown a remarkable growth since its introduction some years ago. It follows the success of the mobile telephone system and may well take over to become the most important telecommunication wave we have seen.

There are several possible explanations for the broadband access growth; the technology was there on time, the service is affordable, and people trust electronically based services over the Internet. Many have broadband access at home and we expect to find access points at a growing number of wireless zones covering business gatherings or public areas.

In spite of being widespread and commonly used, the broadband access term itself is only loosely defined. Some may say it is an access network that provides higher two-way capacity than ISDN and to which one can always be connected, i.e. where the tariff is not based on connection time. Others may specify that broadband access is a network that can support a real-time two-way high-quality video service. In published statistics, very many access network solutions are considered to be broadband and many of these deserve the name by today's standard, but not all. In the future the networks have to develop towards significantly higher two-way capacity to still be considered as true broadband. For example, an ADSL solution is the most common broadband access today, but the future will require considerably higher capacities.

Broadband access is still in a fast development phase. One trend is higher capacity in the future. The cost will most likely become lower, if changed. A second trend is that more and more of the populated areas will be covered by broadband access networks. But it is a major challenge to provide everyone with broadband access wherever wanted and needed. A third trend is that service convergence takes places for broadband. Broadband, broadcast, and mobile access networks are getting better at what they are already doing and at the same time, they also try to deliver what the other two do.

In a global perspective telecommunication availability varies dramatically from those with a broadband network access to others that have to walk many kilometres to reach the nearest telephone. To bridge the digital divide is a major challenge for the involved parties. However, the information communication technology is among the most important elements for the developing countries to reach an improved quality of life.

This thematic issue of *Telektronikk* addresses ubiquitous broadband access. To a large degree it is based on results from the EU project BROADWAN. The articles provide a future perspective on markets including selected business case analyses. The broadband access for full coverage is treated using a multitude of technologies in a hybrid network architecture approach including automated software tool for cost-optimised network planning. Also the future broadband access needs for good solutions for interoperable seamless user access is addressed. The technology development for broadband fixed and mobile networks are covered, and radiowave propagation information is provided.

The broadband access market is growing quickly and the penetration has passed 50 % in several countries. Many other countries are quickly following the steep exponential growth rate. The dominating technology is ADSL. The remaining technologies such as fixed wireless solutions currently share a smaller part. The future will demand higher capacity and ADSL2+ or VDSL will take over from ADSL but with increasingly more fibre to the home. Also high speed wireless networks will become commonplace as an integrated part of the access, as a wireless home network, and as access to the home as well. As the users expect to bring the services with them also when moving around broadband mobile has to be dramatically upgraded.

Business case analyses show interesting opportunities for wireless solutions. These may include rural areas where it is difficult to provide satisfactory broadband networks. For example WiMAX networks in the licence bands at 3.5 GHz may be economically feasible for several realistic cases, but will not perform satisfactory in others. The same is the case for high frequency networks operating at frequencies above 20 GHz.

In order to deliver broadband services wherever wanted hybrid network technology has to be deployed with both wireline and wireless solutions

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including satellite systems. Future wireless technology can offer very high access bitrates, in the order of several hundred Mb/s. At high frequencies there will be satisfactorily large frequency bands for such a capacity, whilst at lower frequencies advanced signal processing is necessary and will help to some degree where there are limited bandwidths.

The high expectations to broadband access are there for good reasons. The broadband network will become increasingly more important to any society as electronic means and computer and electronic device networks are becoming more and more wide-spread.

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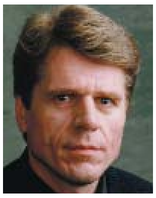
Ubiquitous broadband access

TERJE TJELTA



Terje Tjelta is Senior Research Scientist in Telenor R&I

Access to broadband services has become very important and is a business area that has shown a remarkable increase over the recent years. There are several reasons for this; in particular, the technology is pushing for faster two-way networks and society is increasingly becoming aware of the potential a true broadband network is. Broadband access for everyone can only be achieved using a plurality of access methods tailored to the actual constraints given by population density, geography, and other telecommunications infrastructure. It becomes important to provide services at an affordable cost, which means low cost in the end if a global perspective is taken. The development in the area is very fast, probably the fastest wave seen within telecommunications.

The EU project BROADWAN [1] addressed a number of key areas in business development, network architecture, next generation wireless access, network design guidance and tools, and demonstration of broadband services to rural users. The basic goal was to provide broadband access for everyone at an affordable cost. This paper, along with a number of companion papers in the special issue of *Telektronikk*, provides results within all the key areas.

1 Introduction

Over there recent years, broadband communication has received a lot of attention all over the world. Broadband access has become available at an affordable cost for many citizens and the number of broadband customers is increasing quickly. Also within telecommunication research there is a continued and strong focus on broadband access. It has for example been a key area in EU's sixth framework programme (FP6) [2] under the information society technologies (IST) priority where one of the projects was BROADWAN.

It is easy to understand why broadband access is considered so important. Europe is turning to electronically based knowledge industry and the European Council in 2000 issued the very ambitious goal to, within a decade "become the most competitive and dynamic knowledge-based economy in the world" [3]. The phrase has often been cited since then, but all parties realise that after formulating the ambitious goal a lot of other activities have to come. Research is certainly one of the most important ones.

This paper is based on results and discussions within BROADWAN. It is divided into three main sections between introduction and conclusion; broadband access trends, the right solution at the right place, and future developments.

2 The broadband access wave

Broadband access has developed to mean a network where the users are always connected and have a higher two-way capacity than provided by the integrated service digital networks (ISDN). However, broadband access means different things to different people. The definitions range from a certain two-way capacity to a certain set of services. If, for example, broadband means a couple of television channels provided along with high speed internet of a few Mb/s speed and a telephony service included, very few have broadband today provided by a single access technology. On the contrary, considering heterogeneous networks a large number of people enjoy broadband access in this sense.

The reference country is a developed society using advanced telecommunication technology and broadcasting networks. Taking a global perspective into account very many people have no access to simple telephony services, not to mention broadband. But it is on the political agenda to really address the digital divide and reduce or remove it as much as possible.

The statistics of actual broadband access customers in Europe by the end of 2004 are given in Figure 1, which shows the market penetration for some European countries. The data also include the actual technology used; digital subscriber line (DSL), cable modem, fibre to the home (FTTH), wireless local loop (WLL), power line communication (PLC), and satellite systems. The numbers are significantly higher today, by four times in Norway. But the general picture and variability remain much the same, see the paper by Montagne [4]. Penetration varies significantly across Europe and the DSL access technology dominates. Broadband fixed wireless access (BFWA) has a small market. However, there is business using BFWA technology in Europe as well as in the rest of the world [5].

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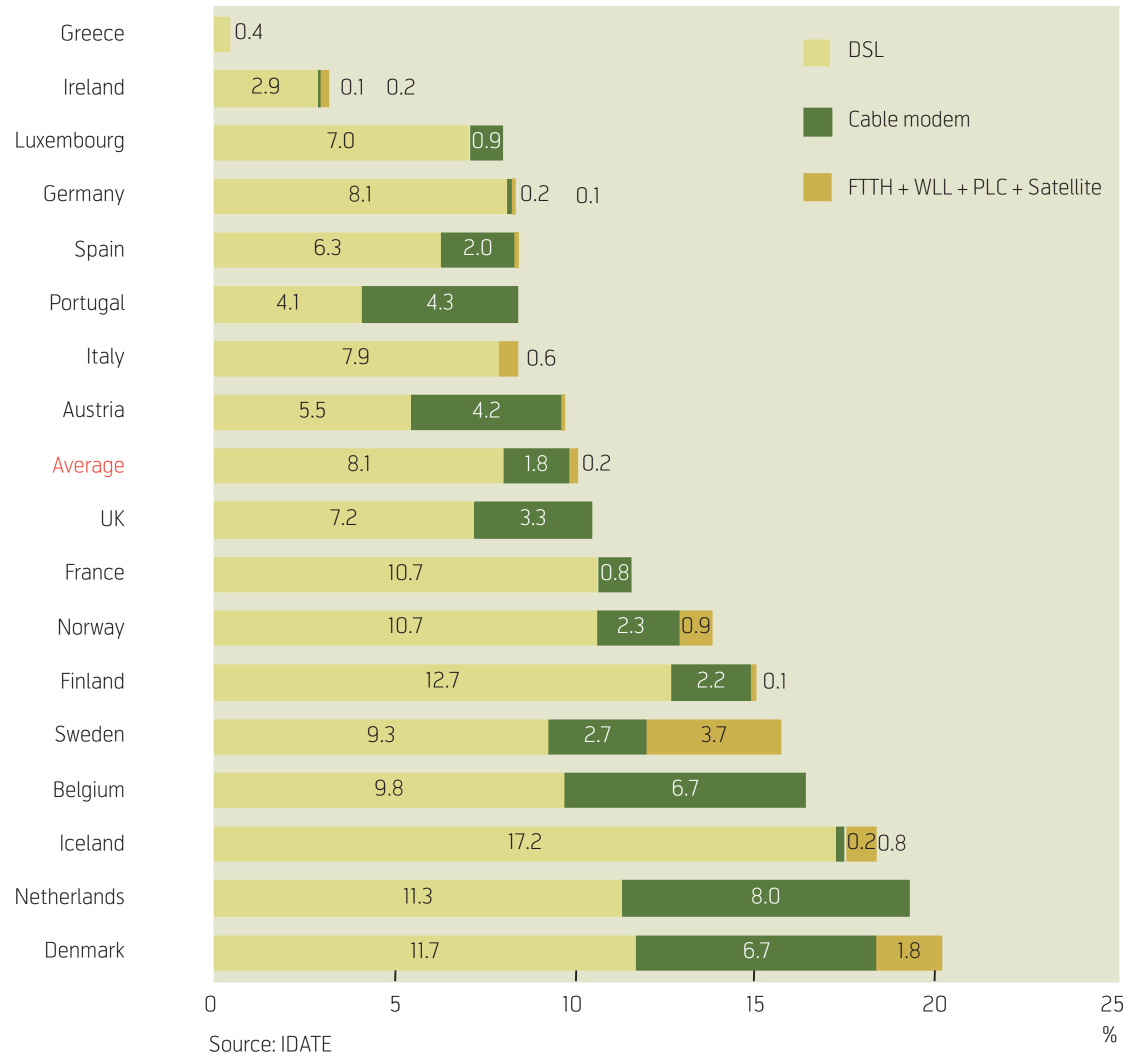

Figure 1 Broadband access penetration in Europe per December 2004, from [6] (Source IDATE)

The recently published data for Norway by Norwegian Post and Telecommunications Authority are given in Figure 2 [7]. The growth since 2001 demonstrates a very fast rate now passing 50 % of private households, estimated as 90 % of the subscribers in Figure 2 and with the total number of households taken from Statistics Norway [8].

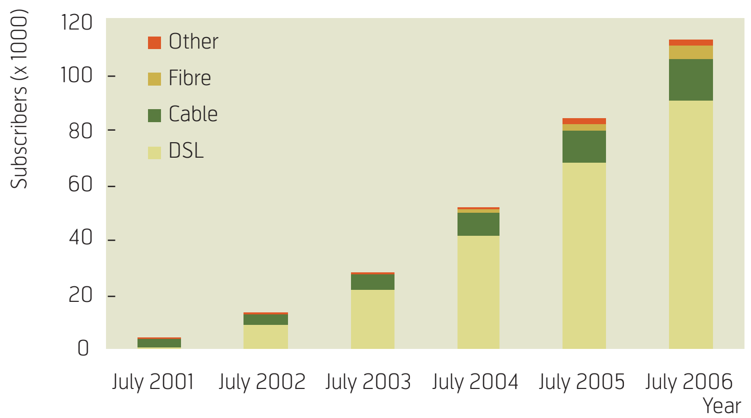

Figure 2 Broadband access in Norway, now 50 % penetration (source Norwegian Post and Telecommunications Authority)

In Norway the most common way of accessing a broadband network from the home is to use a Wi-Fi access point (AP), according to TNS Gallup polls announced by digi.no [9]. The amount of homes with Wi-Fi in November 2005 was 42 %, reaching 51 % in the 2006 second quarter polls [10]. Taking the statistics from above, most of them are connected to an asynchronous DSL (ADSL). Figure 3 illustrates that the typical broadband access is an ADSL line with Wi-Fi 802.11b/g wireless home network offering the freedom to freely connect from any room or outside the house.

In the sense of one access solution and another home network the picture will most likely remain like this in the future. But upgrades are necessary of both the home network to more capacity, and the AP fed by a higher capacity than ADSL of today. The development is driven by technology, seamless access to advanced and converged services, more peer-to-peer applications, and access as fixed, nomadic and mobile users. One of the critical issues is to provide a sufficient capacity from the access technology to the house,

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and another issue is the home network itself. The latter; connecting computers, television sets, telephones etc. will carry a lot more traffic than the actual connection to the outside world. The next sections deal with the development of broadband access trends.

3 Broadband access development trends

Broadband access has several drivers from a strong political motivation to technology push towards higher capacity, converged services, and better coverage.

3.1 Technology push

The information technology (IT) has developed quickly along with the electronic industry in general. Computers are becoming faster, data storage capacity is increasing, and the cost is going down. The same trend has happened to typical access network capacity. In terms of Internet connection bit rate the access capacity has increased steadily with a typical doubling rate every 1.9 years according to Eldering et al. [11].

As this prediction was made in 1999 based on typical data until then, see Figure 4, it is straightforward to establish that 1 Mb/s now typically available is very close to the prediction, noting that the solid line position and extrapolation in Figure 4 was not drawn in [11]. Future networks may grow to even faster access if the predicted mobile broadband access by the ITU-R Study Group 8 holds [12]. Here 1 Gb/s access is anticipated for the user in the low mobility (stationary) mode commonly used in 2015. Anyway, judged by available broadband in developed countries today it is fair to say that the prediction made by Eldering et al. is not overestimating and typical home access will be more than 10 Mb/s within a few years. However, the technology improvements in term of capacity may slow down taking a very long-term view. There are physical limits in the current electronic technology used in the hardware, and these will be reached within a ten year time frame. But for the next 8–10 years there seems to be good reason for the broadband access capacity trend to continue.

3.2 Triple play services

Of course, it would be impossible to reach anywhere with a slow communication network either based on analogue or ISDN. The DSL technology was introduced over the existing telecommunication hardware to quickly reach a significantly higher capacity broadband access network. Interestingly, the philosophy of ISDN remains a powerful way of thinking: integrated services, but now broadband services and perhaps called triple play, integrating data and video with voice over the Internet protocol (IP) network.

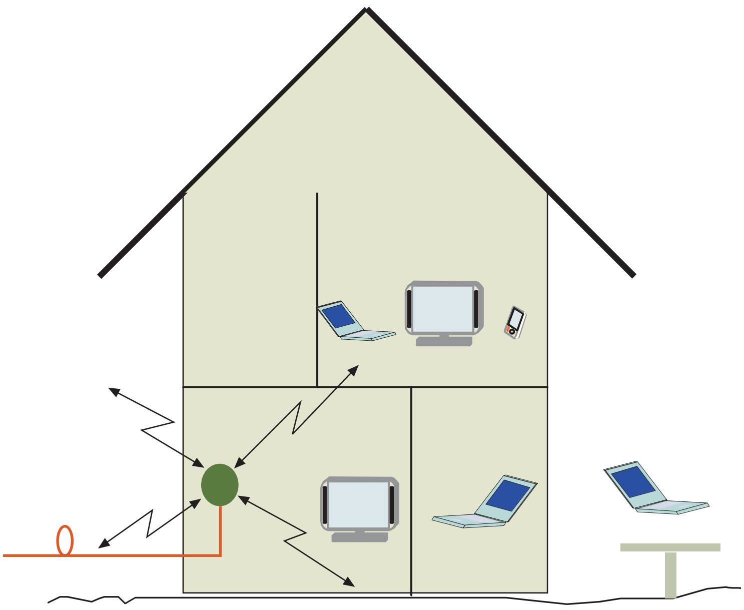

Figure 3 Broadband access is normally first meters wireless to an access point (AP) connected by wireline to a digital exchange

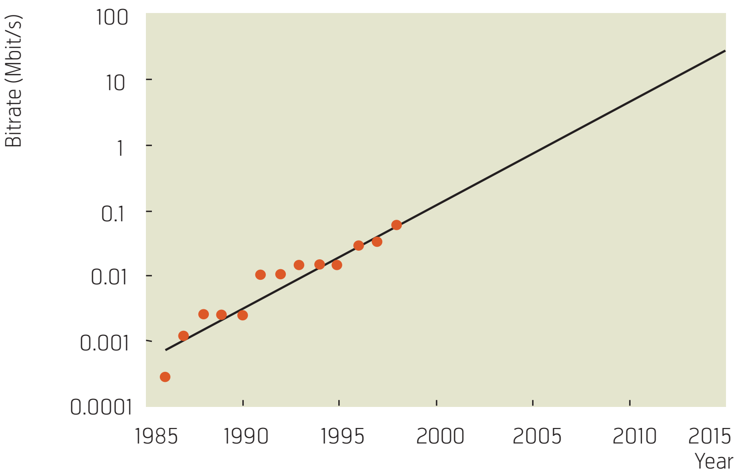

Figure 4 Capacity of residential access network (red dots) and predicted future trend. (The red dots are data reproduced from Figure 2 in Eldering et al. [11])

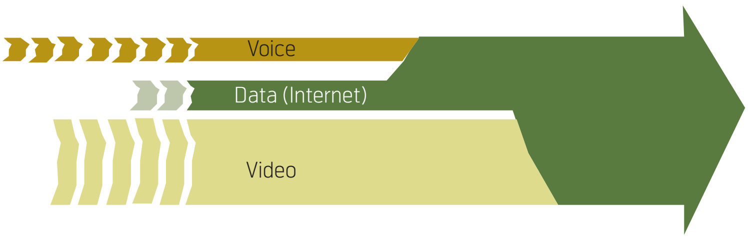

Figure 5 Integrated services of voice and video with data over the Internet

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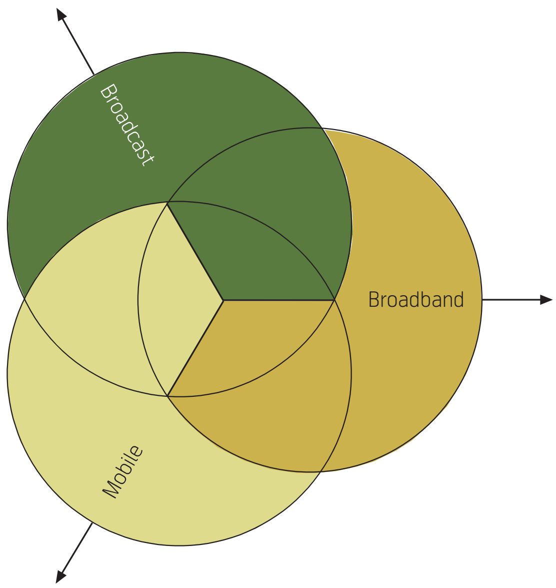

Figure 6 Broadband, mobile and broadcast networks strengthen their own characteristics at the same time as striving for delivery of the same types of services

With sufficiently high capacity the users will have the full triplet over the same network and this is exactly what is more and more taking place. Figure 5 illustrates this point and indicates that Internet is the convergence layer. If this happens, the traditional telephone operators are strongly challenged. But some see the threat and there are now more and more offers of high quality TV and voice over IP (VoIP) telephony, using the broadband Internet network. The triple becomes broadband Internet, broadband telephony, and broadband TV or IPTV.

3.3 Convergence

Convergence means that different broadband access solutions approach each other and eventually one day they become the same in terms of technology, capacity, and services offered. From a user point of view the service and capacity issues count most given that cost is comparable. On one hand there has been an interest in convergence over a long period, basically to provide better services at lower cost. On the other hand the established methods of service provision and technology solutions change slowly, and there is even signs of protection.

Seen from a fairly general view Figure 6 illustrates that the three network types broadband, mobile, and broadcast are also striving to get better at what they are already doing and at the same time pursue what the other two are doing. These are very clear trends today: new broadband solutions for mobile users, broadcast with return solutions for two-way communications, and new generation mobile systems offering increased bitrates as well as mobile TV. It seems that the three category network types will not disappear and convergence will basically take place in delivering the same sort of services.

4 The right solution at the right place

To provide broadband access to users wherever they may be is very challenging, even when restricted to where users live. Not a single technology can do this; there will be a combination of solutions. A simplified view for fixed access is wireline solutions for areas with high population density and wireless solutions where the population density is low. But the picture is more complicated with more axes than population density. Considering line lengths for DSL delivery these vary in both urban and rural areas, and may even show similar distributions. This means that if long line lengths is the problem there will be spots of non-covered areas in urban regions as well.

The ambition is nevertheless to offer broadband connection to a very large number of people. When considering the expected impact on and importance for the society, everyone should be reached and only a small fraction of a country left with more limited means. See Bråten [13] for a more detailed discussion of broadband access requirements and architecture, and Allen et al. [14] for automated cost-optimised hybrid network panning.

4.1 Hybrid networks

In many countries broadband access is completely dominated by the DSL technology in all the statistics provided. Typically figures above 90 % are claimed possible, but such statements are conditioned the capacity offered and the willingness to invest in DSL access multiplexers (DSLAMs) with their feeder network being close to the user's premises. If triple-play services are considered with two high definition television (HDTV) channels and broadband data and voice services over the Internet, the needed capacity will be in the order of 15–25 Mb/s. The DSL technology is restricted in a first approximation by the line length. Illustrated in Figure 7 using data from the DSL forum [14][16], the capacity envisaged can be provided if users have shorter line lengths than about one kilometre.

Taking the ambition of offering broadband access everywhere literally means to use wireless technologies. However, there may be little or no meaning in aiming at broadband everywhere in this sense. It is better to formulate the goals in terms conveying more meaningful messages such as where users are or want to be. It quickly becomes impractical to offer wireline connections wherever wanted, and the trend today is clearly that from the user's point of view the first metre of any broadband connection is wireless. Per date it is only the TV set that is connected to the cable; the computer and the phone is normally connected to a wireless access point. For the computer it is a Wi-Fi ABP, and the telephone is traditional cordless telephone or mobile if not overtaken by VoIP (wireless) solutions.

The question becomes; where will the AP be located? The current situation indicates that the AP is somewhere in the house and the wireless distance becomes up to say 10–20 m. This allows flexible solutions at home and it is presumably just a question of time before all broadband and broadcast equipment is wirelessly connected through a home network to the AP. The ultimate solution may be fibre to the home (FTTH) feeding the AP.

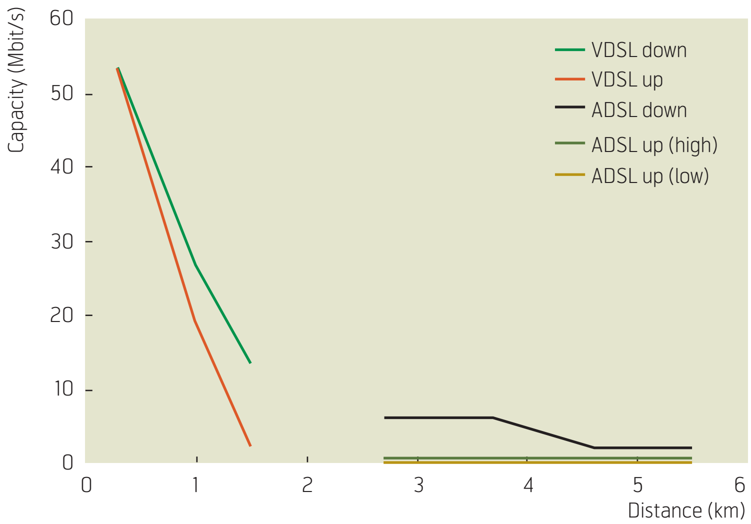

Figure 7 VDSL and ADSL capacity (Mb/s) versus distance (km)

Figure 8 points to the possibility that an AP may serve more than one home where each of the homes or flats will have their own home network. A common solution to connect the AP is the DSL technology over standard telephone lines. In the future the distance to the DSLAM has to be fairly short to accommodate the expected two-way traffic, or using fibre will become necessary. An alternative is to connect the AP to another aggregation point in the network using high capacity wireless technology.

However, neither the intermediate solution of DSL fed AP nor the ultimate solution of fibre fed AP solve the issue of services on the move satisfactorily. This may be any kind of move such as nomadic, portable, or mobile.

One of the most important and critical issues is the interworking and interoperability of several networks, see paper by Settembre and Tardy [17]. The users shall be offered seamless access without having to connect with different methods depending on technological access solutions.

4.2 Rural versus urban

From a technical point of view there is generally no problem providing broadband access in densely populated areas. There may often be coaxial cable networks beside the copper line DSL solutions, and at an increasing rate, optical fibre. It should be noted that there are also long telephone lines even in big cities preventing access to the highest capacity services offered by DSL technology. But with many customers it may not be seen so economically challenging to introduce DSLAMs closer to the users.

In rural areas it has been difficult to offer the users a reasonable broadband access. Not that the telephone line length distribution is so much different from elsewhere, but there is no high capacity network available to feed a DSLAM. The challenge is in providing a trunk to the high capacity backbone as well as reaching out to remote communities.

When it comes to very sparsely populated areas it may be difficult to find an access technology that is feasible in terms of economy. Chouinard has analysed broadband access technologies with respect to population density of Canada [18]. Figure 9 illustrates in a simplified manner the technology with lowest cost and complexity to serve an area given the population density. When the number gets below about two persons per km^2 it is only satellite that seems feasible, and anyway it gives the lowest cost/ complexity solu-

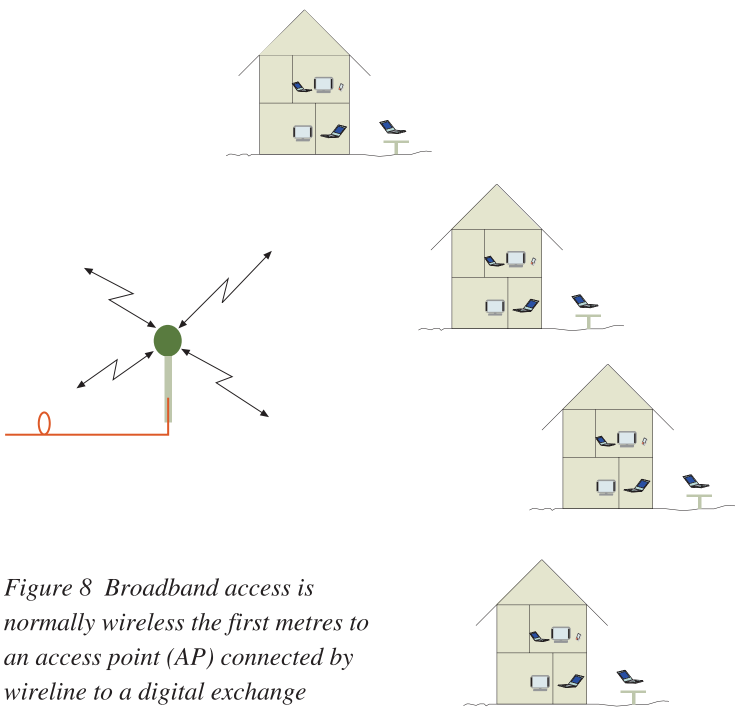

Figure 8 Broadband access is normally wireless the first metres to an access point (AP) connected by wireline to a digital exchange

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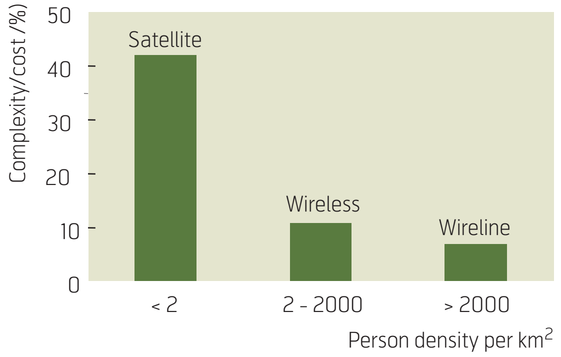

Figure 9 Broadband access technology lowest complexity and cost (data from Chouinard [18])

tion. Furthermore, satellite access does not vary much with person density and is therefore the natural solution for the remote areas. When the person density increases potential new wireless systems will be cost effective up to about 2000 persons per km^2, where it becomes slightly more costly and complex compared to wireline solutions. Beyond this density it is the wireline technologies, in particular ADSL, that are the lowest cost/complexity solutions. Chouinard indicates a value of about 60 persons per km^2 for ADSL to become competitive. Figure 1 in his paper [18] suggests about 2000, but it is seen that the numbers are somewhat comparable. As noted previously in this paper, such border lines also depend on what service is expected and the trend for the future is services that cannot be delivered by ADSL.

Person density is an interesting variable and examples like Figure 9 give some guidance in choosing the most cost effective solution. But it gives no information about how commercially viable the solutions are. See this issue of *Telektronikk*; Elnegaard [19] for technical economic analyses to derive possible viable business for wireless solutions with population densities up to 1000/km^2, and Seseña and Soro describe successful business using satellite systems [20].

It should also be noted that a true broadband network is generally more beneficial for a rural and remote area than for a big city. Many community services can be much easier accessible by electronic means such as health care, education, and other activities, without having to drive very long distances by car every time.

4.3 Developing versus developed countries

The status of actual telecommunication solutions varies dramatically between developing countries and developed countries. It is a question of those-that-have and those-that-have-not, really. But it cannot remain like this in the future. The telecom industry and operators will be the first to see the huge market potential in developing countries. The technical solutions have to be extremely low cost; not only providing the one-hundred-dollar PC [21], but the use of a broadband network as well.

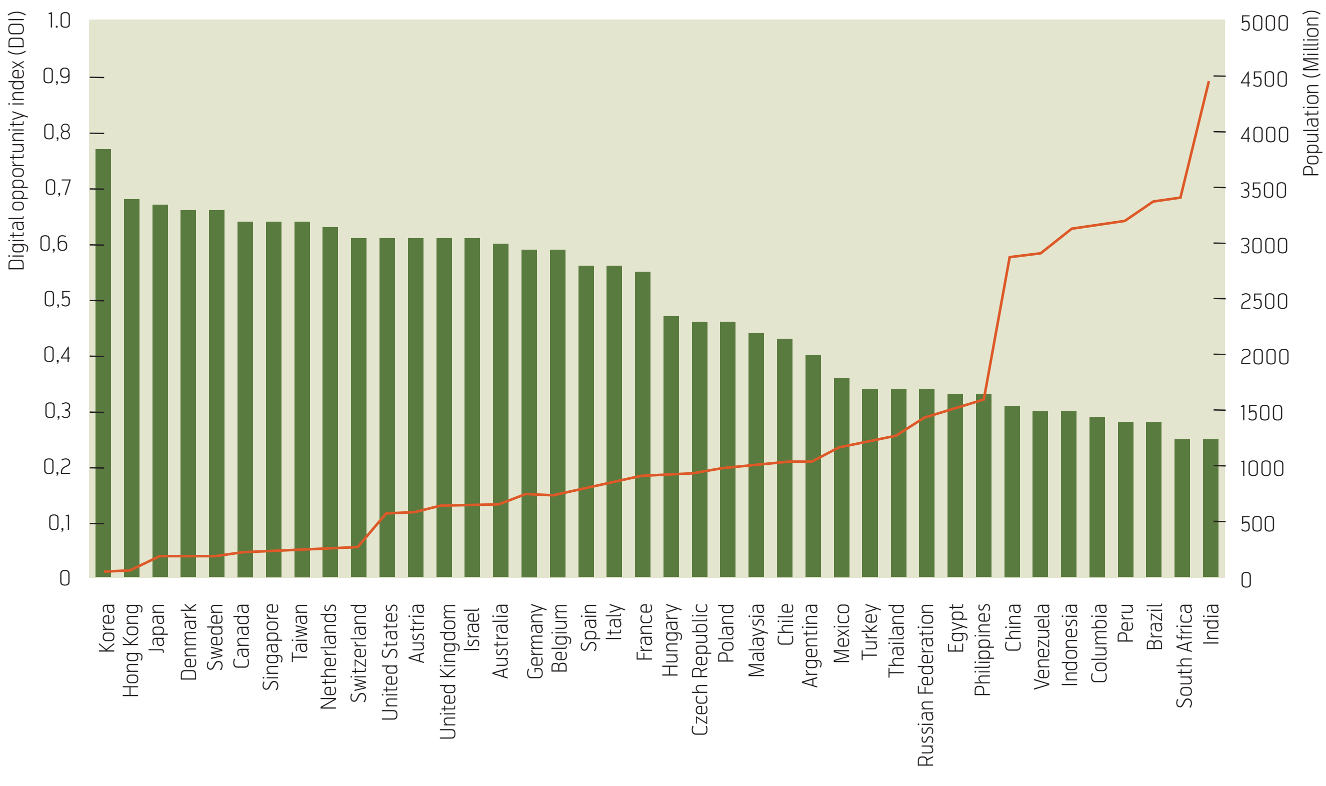

Figure 10 Digital opportunity index for 40 countries with three quarters of the world's population [22]

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The ITU has developed the digital opportunity index (DOI) to measure the digital divide around the world. It is based on the information and communication technology (ICT) network infrastructure in place, its utilisation and to what degree the population can take advantage of it [22]. Figure 10 shows the DOI for the 40 countries selected for this study. The high numbers belong to well developed countries with a remarkably strong focus on telecommunications infrastructure. The low values are for less developed countries with the majority of the world's population. The numbers in Figure 10 were obtained for ICT in general, of which broadband is a coming and increasingly important part. The figure illustrates also, to some degree, the gap between those that have broadband and those that have not. Looking at such numbers the telecommunication business can easily see that there are great opportunities, but at the same time they are being challenged by the very difficult task it is to provide broadband access to all.

Given that there is little or no telecom infrastructure, wireless solutions should have a very good potential. They are quickly deployable and can easily grow with required capacity and areas interested in service. The customer equipment may be battery powered if there is limited electricity available, and charging can be done using solar energy or other means such as a hand charger.

A telecommunication infrastructure is a very good investment for any country, developing as well as developed. It results in a better quality of life by making many basic services more easily accessible. See the President of India's address to the General Assembly of the International Union of Radio Science (URSI) held in 2005 [23].

5 Future developments

Networks providing residential broadband access have had a remarkable growth, probably greater than all earlier telecommunications and broadcasting systems introduced to the market. This trend will continue, as discussed in this section. See Howson [24] for a more detailed technology outlook for broadband and mobile networks.

5.1 First metres always wireless

It seems that the majority of broadband access users are connected through a wireless local area network (WLAN), more specifically a Wi-Fi AP to the broadband network. The future development at home will clearly be a home network of some kind, and a natural physical realisation of this will be Wi-Fi when these networks can offer the required capacities. Current solutions based on IEEE 802.11b/g may make it now, but not in the future when several tens of Mb/s will be needed. But the 802.11n-version will be available in 2007 and there might be alternative technologies such as ultra wide band (UWB) with a capability of more than 100 Mb/s.

5.2 Increased capacity and coverage and better spectrum utilisation

Both copper line and wireless are moving towards solutions with higher capacity and better spectrum utilisation. For the wireline technology it has a strong effect on the range; the higher capacity offered either by ADSL2+ or VDSL, the shorter becomes the line length. For the wireless technology the higher capacity and spectrum utilisation can be achieved without having shorter range if smart antenna and radio resource management are used. However, higher level adaptive coding and modulation will result in a shorter range for such systems.

Some years ago both ETSI and IEEE developed standards for broadband fixed wireless access to operate in the higher frequency bands, the IEEE 802.16 in the range 10–66 GHz for example. Within ETSI it was the HiperAccess project and solutions developed in the digital video broadcasting (DVB) with return channels. In fact, the worldwide interoperability for the microwave access (WiMAX) forum was first established to work out interoperability issues for this high frequency. But WiMAX now seems exclusively associated with the frequency bands below 11 GHz and increasing towards the mobile version of the standard IEEE 802.16 (2005).

BROADWAN has investigated next generation solutions aiming at very low cost end user equipment though radio architecture, medium access control (MAC), and equipment technology, see Grøndalen [23]. If commercialised, the analyses will result in low-cost solutions above 20 GHz that can offer very high capacity. There is already equipment available aiming at low cost that operates at 26 GHz, see the paper by Ohmoto [26]. The main advantage is capacities of several hundreds of Mb/s, but the links require line-of-sight (LOS). For an area it is possible to reach high coverage, say 90 % with sectors and a base station arrangement. See the CRABS project results achieved for 42 GHz multimedia systems for more detailed studies [27] [29] [30]. These show how base station arrangement and frequency planning can be done to achieve high coverage without using any more spectrum.

For links at these very high frequencies propagation impairments may reduce the applicability subject to the climate of the regions where they are deployed. Given line of sight (LOS) it is the precipitation that

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limits the maximum length, or coverage, for such a system. Assuming a system with 20 dB margin to protect itself against rain attenuation the maximum length of up to 99.99 % of an average year is depicted in Figure 11 for some cities. It is seen that the longer link lengths can be achieved at 26 GHz compared to 42 GHz, as expected, and the length will become shorter the more intense rainfall there is in a climate. See Willis [27] for radiowave propagation issues associated with wireless access systems. Under real system deployment it will most often be the traffic that limits the cell size, as in other cellular systems, and a 1 km range may well be more than appropriate.

There are several capacity increasing methods available for broadband access radio. The key is to take advantage of the local signal to interference ratio (C/I) using adaptive coding and modulation. A significant improvement is possible for individual traffic. But it should be noted that if the system carries broadcast traffic and the dimensioning is done according to that, a higher modulation level scheme with increased b/s/Hz does result in a lower gross capacity for interference limited cellular systems.

Coverage can be increased by increasing antenna directivity towards the users, a smart antenna solution that ensures signal power is only used where the users are. This remains possible even for interference limited systems, where the key is to maximise C/I for the users. By using a mesh network such that each node may serve a user and also relay other users' data, the coverage can be very high. Here it becomes crucial that the users let their equipment on even when it is not used by themselves. The actual throughput or gross capacity of such a system is under discussion. Some may say it has superior spectrum utilisation, but this does not seem commonly accepted.

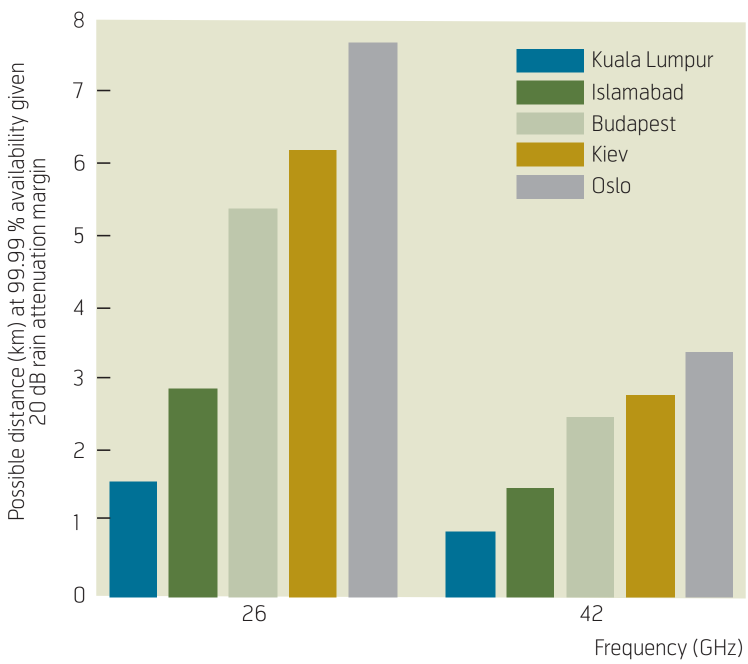

Figure 11 Possible service distance (km) at 99.99 % availability for a system operating at 26 GHz or 42 GHz (vertical polarisation) given 20 dB rain attenuation margin

5.3 New business for a mature mobile market

The mobile market is saturated in many developed countries concerning a mobile phone with traditional services. There may be new narrowband services to offer, but operators have good reason to look to broadband. To receive TV on the mobile is a very real service with great expectations. But also to become a contributor sending video and pictures from the user's mobile should have a reasonable growth potential. The technology is there to a certain degree, but the network will need upgrading.

Third generation (3G) mobile systems have now made their way to the market in many countries and networks are being upgraded and built at an increasing rate. The 3G mobile can offer higher capacity than the previous generation, for instance a 2 Mb/s downlink in certain cases. But for typical user scenarios the capacity is significantly lower. The technology is therefore developed further and several approaches have been taken to increase the capacity. For example, high speed packet access (HSPA) is seriously considered with about 14.4 Mb/s downlink and 5.8 Mb/s uplink. It is typical for many broadband systems that they are asymmetric in capacity with respect to downlink and uplink. As for VDSL the range from a base station becomes just a few hundred metres to get such capacities, which means a tremendous challenge of building a backbone network. A mesh network may increase the coverage, but will make the transport issue even more challenging.

For the fixed broadband access at frequencies below 11 GHz both the ETSI project Broadband Radio Access Network (BRAN) and the IEEE contributed to what is now known as WiMAX for fixed services, the standard IEEE 802.16 – 2004 [31]. Certified equipment is available and networks can be set up. The mobile part of WiMAX [32] has been approved as well, but equipment has still to come. Interestingly, the IEEE 802 LAN/MAN standards committee has another working group, 802.20 – Mobile Broadband Wireless Access (MBWA) [33]. It started earlier than mobile WiMAX, but seems now to be behind. The mobile interest organisation 3GPP points to HSPA, whilst ETSI also supports the mobile WiMAX as the solution for mobile broadband, see ITU-R WP 8A, input documents [34] and [35], respectively.

For mobile systems the capacity is dependent on the degree of mobility. For the long term mobile developments the user in the fixed mode will, according to the ITU-R have 1 Gb/s capacity, whilst for full mobility a 100 Mb/s [12] to be developed by 2010 for wide adoption in 2015. Other predictions may reduce the figures, but the perspective remains challenging for a system that is set to deliver services under full mobility.

The triple play services are there already for mobile systems now offering telephony, internet browsing and streaming service. The triple play services have to scale better to the network capability and the user's terminal, as illustrated in Figure 12, allowing people to be connected without interruption.

5.4 Broadcast digital switchover and mobile TV

The broadcast alternative is the digital terrestrial television (DTT) now being prepared for introduction in the terrestrial network. The standard is DVB-T originated for the digital video broadcast project. Similarly, the same project has made solutions known as DVB-S for satellite and DVB-C for cable systems. It is clear that both satellite and cable have used digital solutions for a long time already, whilst the terrestrial part will be taken into use in Europe from about 2010 onwards.

DVB-T is looked at with great interest from several points of view. The change from analogue to digital transmission means that the same number of standard definition TV (SDTV) channels can be sent with significantly less frequency resources. One analogue TV program is sent in a radio channel of 7 or 8 MHz in the VHF/UHF bands; with a DVB-T up to six programs can be sent. However, HDTV will soon be introduced and this format requires significantly more bandwidth than SDTV, but not as much as previous analogue methods. Some have therefore suggested that the remaining bandwidth, called digital dividend should be used for communication as well as broadcasting purposes. The broadcaster communities have pointed to other types of broadcasting such as various camera angles for the same channel, and seem therefore to conclude there is no real dividend that can be used for other purposes. Nevertheless, the issue of using a possible dividend feeds an ongoing discussion. It received some support from many countries participating at the Regional Radio Conference held this year (RRC-06), see Declaration 42 in [36].

With the mobile terminal in mind the Digital Video Broadcast (DVB) project developed the DVB-H solution for handheld devices. But there are alternatives, in particular the Digital Media Broadcasting (DMB)

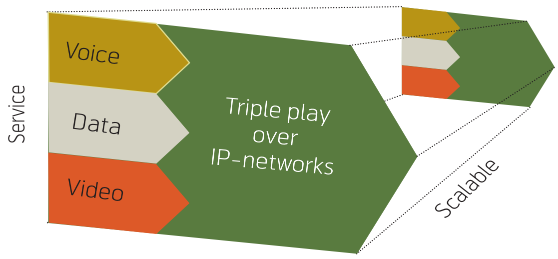

Figure 12 Future triplet services must scale to networks and user's equipment

based on Digital Audio Broadcasting (DAB). The DVB has been one of the biggest successes for European standardisation activities, but has been challenged by DMB. Interestingly, DMB is available both over satellite S-DMB and as a terrestrial system T-DMB. Based on 3G the Mobile Broadcast and Multicast Service (MBMS) has been developed. See Howson [24] for a more detailed presentation of mobile TV, and Laine et al. [37] for an overview of technologies also including hybrid terrestrial and satellite solutions.

5.5 Bridge the digital divide

From a social point of view it seems important to connect the whole population in a country with broadband. Only with a large part of the country in the network does it become possible to take more advantage of the broadband access network.

The geographical constraint is one clear challenge when providing broadband to the whole nation or area. As noted wireline technology can reach out, but with capacity problems. There is an interest to use power line communication (PLC) to reach rural areas. Whilst PLC might work within a house for communication between devices it quickly becomes a source for interference when signals are sent over electrical lines in the open air. The possible interference issue has caused considerable concern, particularly within the radio amateur community.

Satellite systems with return channels, such as DVB-RCS, can reach very far. Although there are shadows for any satellite system, whether it is a geostationary system or has another orbiting pattern, it is clear that very high coverage is possible. The challenging part is the cost of the equipment. Solutions for sharing a terminal can bring the cost down, as shown in the BROADWAN demonstrations [19]. New research and new systems will eventually bring down the cost of the equipment, and more importantly, the cost of satellite traffic such that the satellite system can become more competitive. An initiative has been taken by the IEEE, and the project group 802.22 is working towards wireless regional access networks (WRAN) just aiming at rural and remote areas [38].

Technically, it is possible to reach out and bridge the digital divide. The feasible solutions will have to be based on wireless radio solutions.

6 Conclusions

Broadband access has shown a remarkable growth. It is now commonplace in developed countries. This is true if broadband is considered to be an always-on network with a capacity larger than what ISDN can offer. By contrast, very few have broadband access if it means two or more HDTV television channels, and several Mb/s capacity for Internet and IP telephone over the same physical network. The latter may not be important, unless it gives the most cost-effective solution.

This paper has illustrated the technology trends moving towards higher capacity, scalable triple play services and a wireless access seen from the user connecting to broadband. The convergence of services and of physical networks may well happen, but perhaps services will only be available in a seamless fashion to a user who does not want to be concerned about which physical network is used.

It is possible to provide any community with a reasonable broadband access network using the right technology at the right place. No single solution can do this alone.

There are several major challenges ahead, technical as well as political. Regarding the network technology some of the main ones are interoperability when different technological solutions are present, secure and seamless access to the services, cost-effective network planning and roll-out, and not least a backbone able to connect base stations or nodes serving users with broadband.

Acknowledgements

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7 References

1 *BROADWAN web site*. Sep 2006. www.broadwan.org

2 European Union. *Sixth Framework Programme*. Sep 2006. URL: http://ec.europa.eu/research/fp6/index_en.cfm

3 European Council. Presidency conclusions. Lisbon, 22–23 March 2000. http://ec.europa.eu/growthandjobs/councils_en.htm. URL: http://consilium.europa.eu/ueDocs/ cms_Data/docs/pressData/en/ec/00100-r1.en0.htm

4 Montagne, R, Le Floch L. European broadband overview. *Telektronikk*, 102 (2), 14–21, 2006. (This issue)

5 Ramahandry, T (ed). *Business opportunities for broadband wireless solutions*. 11 May 2006. (BROADWAN Deliverable D34) (www.broadwan.org)

6 Montagne, R. *Business opportunities for wireless networks*. BROADWAN Workshop. Brussels, 24 May 2005. (www.broadwan.org)

7 *Norwegian Post and Telecommunications Authority*, 2006. (www.npt.no)

8 *Statistics Norway*. October 2006 – URL: http://www.ssb.no

9 Ryvarden, E. Very many households have wireless networks. *Digi.no*, 21 Nov 2005 (Published in Norwegian: Veldig mange hus har trådløst nett. URL: http://www.digi.no/php/art.php?id=280975)

10 Andersen, D. *TNS Gallup*, private communication, 18 October 2006.

11 Eldering, C A, Sylla, M L, Eisenach, J A. Is there a Moore's law for bandwidth? *IEEE Communications Magazine*, 37 (10), 1999. 117–121.

12 ITU. *Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000*. Geneva, International Telecommunication Union, 2003. (ITU-R Recommendation M.1645)

13 Bråten, L E. Requirements to and architecture of hybrid broadband access networks. *Telektronikk*, 102 (2), 22–38, 2006. (This issue)

14 Allen S M, Hurley S, Ryan D M, Taplin R K. Automated hybrid cost-optimised network design. *Telektronikk*, 102 (2), 58–70, 2006. (This issue)

15 DSL Forum. *VDSL Tutorial*. October 2006. (URL: http://www.dslforum.org/aboutdsl/vdsl_tutorial.html)

16 DSL Forum. *ADSL Tutorial*. October 2006. (URL: http://www.dslforum.org/aboutdsl/adsl_tutorial.html)

17 Settembre, M, Tardy, I. Interoperability issues for hybrid access and backhaul networks. *Telektronikk*, 102 (2), 39–47, 2006. (This issue)

18 Chouinard, G. Bringing broadband access to rural and remote areas. The Canadian experience. *ITU News*, no 3, April 2006, 24–28.

19 Elnegaard, N K. The prospects of wireless broadband solutions. *Telektronikk*, 102 (2), 48–57, 2006. (This issue)

20 Seseña, J, Soro, D. Hybrid satellite and terrestrial wireless access for rural deployment in Spain. *Telektronikk*, 102 (2), 89–94, 2006. (This issue)

21 *OLPC forum*, 2006. (URL: http://www.laptop.org)

22 Measuring the gap. Lessons from the new Digital Opportunity Index. *ITU News*, No. 7, September 2005, 3–9.

23 Kamal, A. *Electronic connectivity of a billion people*. Opening address at URSI General Assembly, 25 October 2005. (URL: http://presidentofindia.nic.in/scripts/sllatest1.jsp?id=628)

24 Howson, C. Technology outlook for broadband and mobile networks. *Telektronikk*, 102 (2), 71–76, 2006. (This issue)

25 Grøndalen, O. Next generation broadband fixed wireless access systems. *Telektronikk*, 102 (2), 77–88, 2006. (This issue)

26 Ohmoto, R. Experience of low-cost 26 GHz fixed wireless access system in Japan – WIPAS. *Telektronikk*, 102 (2), 95–100, 2006. (This issue)

27 Willis, M J. Radiowave propagation models for improved performance and use of spectrum. *Telektronikk*, 102 (2), 101–112, 2006. (This issue)

28 Craig, K H, Tjelta, T. Cellular radio access for broadband services: propagation results at 42 GHz. *Telektronikk*, 96 (1), 36–44, 2000.

29 Loktu, H (ed). *Specification of next-generation of LMDS architecture*. 2 February 1999. (CRABS Deliverable D2P1B) (URL: http://www.telenor.no/fou/prosjekter/crabs/d2p1b.pdf)

30 Tjelta, T, Nordbotten, A, Loktu, H. Broadband radio access for multimedia services. *Telektronikk*, 96 (1), 2000.

31 I*EEE Standard for Local and metropolitan area networks. Part 16: Air Interface for Fixed Broadband Wireless Access Systems*. IEEE standards association, 2004. (IEEE Std 802.16 – 2004) (URL: http://standards.ieee.org/)

32 *IEEE Standard for Local and metropolitan area networks. Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems. Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands and Corrigendum 1*. IEEE standards association, 2006. (IEEE Std 802.16e – 2005 and IEEE Std 802.16™-2004/Cor1-2005) (URL: http://standards.ieee.org/)

33 *IEEE 802.20*. October 2006. (URL: http://grouper.ieee.org/groups/802/20)

34 ITU. *Broadband wireless access standards in the mobile service*. Geneva, International Telecommunication Union, 15 March 2006. (ITU-R Document 8A/362)

35 ITU. *Working document towards preliminary draft new recommendation ITU-R M. [8A/NBWA]. Broadband wireless metropolitan area network radio interface standards for nomadic access systems in the mobile service operating below 6 GHz*. Geneva, International Telecommunications Union, 21 February 2006. (ITU-R Document 8A/310)

36 *Regional Radiocommunication Conference (RRC-06) Document 174 Rev. 1*. Geneva, International Telecommunication Union, 15 June 2006.

37 Laine, F, Urie, A, Kelly, P, Nussli, C. *Unlimited mobile TV for the mass market*. Alcatel White paper. 10 February 2006 (URL: http://www.alcatel.com/mobileTV/doc/mobileTV_whitepaper_E.pdf)

38 *IEEE 802.22*. October 2006. (URL: http://grouper.ieee.org/groups/802/22)

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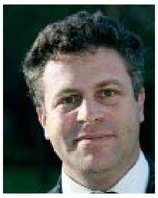
European Broadband Overview

ROLAND MONTAGNE, LOIC LE FLOCH



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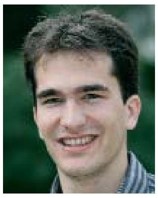

Loic Le Floch is Senior Consultant at IDATE

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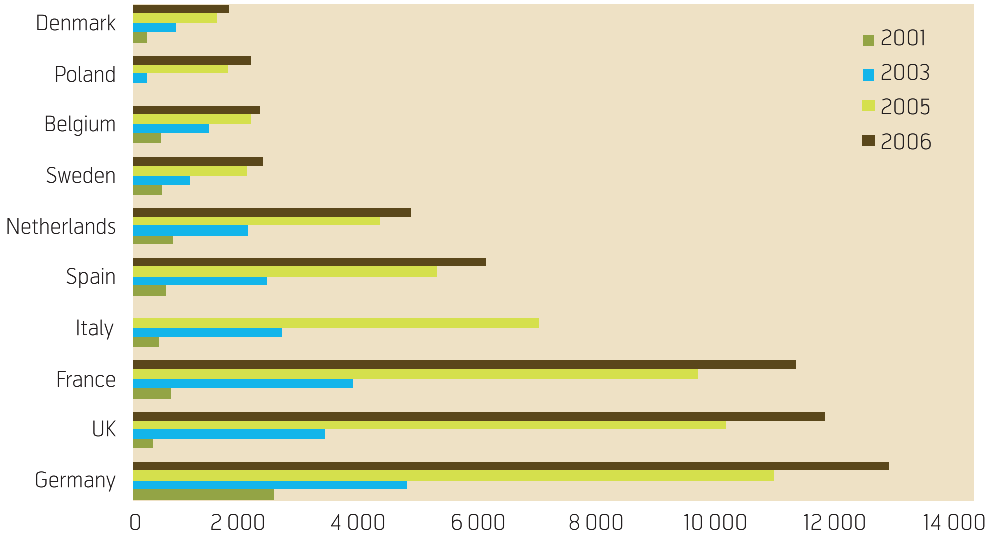

Figure 1 Growth of the broadband user base since 2001 in the countries being examined. Source: IDATE

1 Broadband take-up

In 2005, the broadband user base continues to grow at a phenomenal pace: results from Germany (+ 4 million), the UK (+ 3.8 million), Spain (+ 1.6 million) indicate more new broadband subscribers in 2005 than in 2004. In 2006, the number of new subscribers is predicted to slightly slow down except in Spain and Poland. Italy too is slowing down, despite an average penetration rate which would indicate still sizeable growth potential for the short-medium term.

In absolute terms, Germany has the largest broadband user base in Europe, ahead of both the UK and France. See Figure 1 and Tables 1, 2 and 3.

2 Broadband penetration

In June 2006, Denmark is the European benchmark leader for broadband penetration. The Netherlands and Sweden are reporting a penetration rate only slightly below. We expect all these countries (including Denmark) to gradually enter into a saturation phase. Ger-

	2001	2002	2003	2004	2005	2Q06
Belgium	230	520	786	1,056	1,295	1,389
Denmark	151	303	473	633	817	948
France	430	1,412	3,263	6,294	8,882	10,446
Germany	2,263	3,275	4,445	6,770	10,390	12,275
Italy	390	902	2,280	4,445	6,474	7,216
Netherlands	172	360	978	1,843	2,505	2,861
Poland	2	17	143	681	1,235	1,529
Spain	376	960	1,676	2,604	3,877	4,583
Sweden	288	427	570	883	1,230	1,407
UK	144	592	1,841	4,211	7,270	8,651

Table 1 Number of DSL lines. Source: IDATE

	2001	2002	2003	2004	2005	2Q06
Belgium	230	349	482	565	690	741
Denmark	88	155	243	334	431	490
France	187	283	394	454	560	630
Germany	30	45	75	145	240	288
Italy	0	0	0	0	0	0
Netherlands	480	761	940	1,297	1,573	1,710
Poland	7	34	74	180	343	449
Spain	162	345	551	836	1,180	1,293
Sweden	112	156	205	243	348	411
UK	203	769	1,364	2,027	2,630	2,902

Table 2 Number of cable modem lines. Source: IDATE

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	2001	2002	2003	2004	2005	2Q06
Belgium	0	0	0	0	0	0
Denmark	0	1	2	80	142	160
France	1	1	1	3	7	7
Germany	45	50	53	51	67	67
Italy	51	122	214	274	317	346
Netherlands	1	1	1	51	55	55
Poland	0	0	1	1	1	7
Spain	4	5	6	7	9	9
Sweden	89	130	169	240	315	345
UK	0	0	0	0	0	12

Table 3 Number of other broadband lines (Ethernet LAN/FTTx, Satellite, WLL). Source: IDATE

Population coverage	DSL	Cable modem
Belgium	100 %	84 %
Netherlands	100 %	82 %
Denmark	100 %	60 %
UK	99 %	50 %
France	95 %	26 %
Sweden	93 %	47 %
Germany	92 %	15 %
Spain	89 %	42 %
Italy	87 %	0 %
Poland	12 %	3 %

Table 4 Population coverage by access technologies (end 2005). Source: IDATE

many, Spain and Italy's rates are below the average for the larger European countries. See Figure 2.

3 Broadband coverage

DSL technologies are now largely available in Europe. Coverage of DSL is always higher than cable modem coverage but there are wide disparities in studied countries for cable modem coverage (from 0% in Italy to more than 80% in Belgium and the Netherlands). See Table 4.

4 Broadband competition snapshot

In Table 5 we have tried to describe country by country what is the stage of competition at mid 2006.

5 Close-up on broadband market players

2005 saw a stabilisation of the different broadband players' share on the retail market. In the intermediate market, unbundling is now a central part of alternative operators' strategies for migrating existing subscribers currently served via wholesale offerings, and for attracting new subscribers with triple play offers. What follows is a brief round-up of broadband market players' situation in early 2006.

Incumbent carriers

Competition

In 2005, Europe's incumbent telcos managed to contain their losses in broadband retail markets. Germany is the country where the impact of compe-

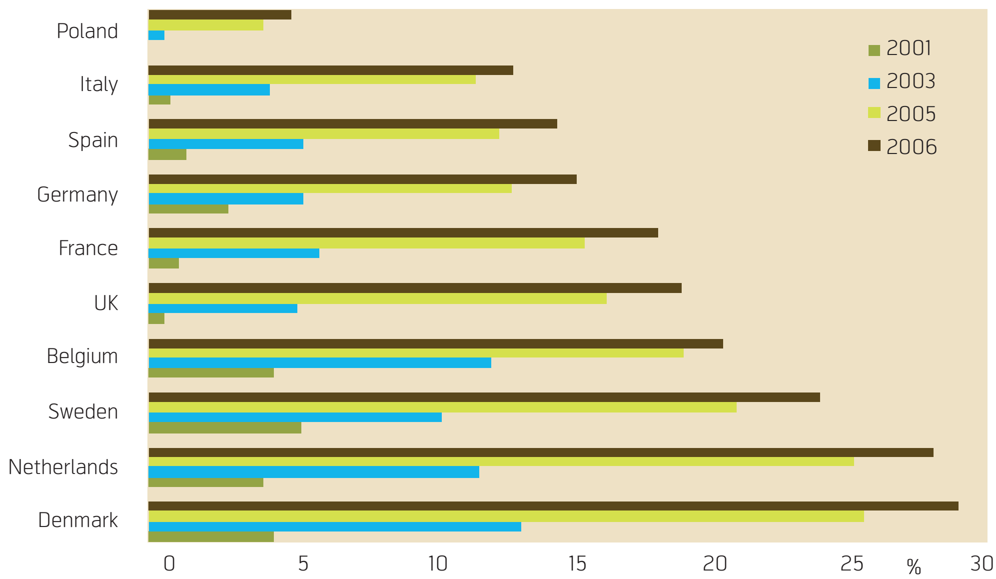

Figure 2 Broadband penetration. Source: IDATE

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Country	Infrastructure competition	DSL competition	Competition structure
Belgium	DSL competition by cable is tough and bound to intensify (bi-directional upgrade in the southern part). Around 95 % of Belgian households access cable TV.	Low take-up of unbundling in Belgium. Low prices and high level of customisation in resale discouraging investments in LLU.	Cable competition: high. DSL competition: low and based on wholesale.
Denmark	Denmark has a very tough infrastructure competition by end 2005: DSL coverage of close to 100 % population. Cable modem coverage of 60 % of households and enterprises. FWA and FTTx/ETTx coverage is increasing quickly.	OLO are under pressure from both incumbent and cablecos. The number of wholesale DSL is still increasing but LLU has shown the most significant increase. Denmark full unbundling price is among the lowest but shared access is expensive and gap is low with full LLU.	Cable competition: moderate. DSL competition: low and based on wholesale (except Cybercity). Other competition: FTTx led by Danish utilities.
France	Broadband cable remains marginal in France (6 % of the country's broadband base), despite the reorganisation that took place in late 2004 and 2005.	France is home to Europe's largest base of unbundled DSL. Virtually all of the country's ISPs have chosen to invest in their infrastructures to migrate to unbundling. Recent trend shows massive adoption of full LLU.	Cable competition: low. DSL competition: high and based on LLU.
Germany	Germany's cable network is very dense but rather outdated, and broadband cable is very marginal.	Unbundling for offering DSL services stepped up in 2005. The vast majority of LLU is full access. The resale offer, which was introduced in late 2004 by incumbent is now enjoying considerable success, accounting now for close to 2.5 million lines (mid 2006). Incumbent was obliged recently to grant competitors with an IP Bitstream offer.	Cable competition: low but potential. DSL competition: strong and based on LLU.
Italy	Cable modem is non-existent in Italy but FastWeb has developed a very high-speed offer through its infrastructures, although geographic coverage is still limited.	DSL unbundling is on the rise, but there is still little competition at the infrastructure level. Unbundling tariffs (particularly for full unbundling) are among the lowest in Europe, and could help increase retail market competition.	Cable competition: null. DSL competition: low and based on LLU. Other competition: FTTx.
Netherlands	The Netherlands has a very competitive market: DSL coverage of close to 100 % of the population. Cable modem coverage of 82 % of the population; cable accounts for 38 % of the country's broadband access base.	There is no regulation on consumer bitstream access offer in the Netherlands. It had been ordered by the regulator, OPTA, but the courts overruled the request. Naked DSL offers are available, however. In addition, after France, the Netherlands has one of Europe's largest bases of unbundled lines.	Cable competition: high. DSL competition: high and based on LLU.
Poland	Cable modem could represent a potential threat but needs important upgrades.	DSL competition at an early stage still relying on owned infrastructure.	Cable competition : low but potential. DSL competition: low and based on CLEC owned infrastructure.
Spain	With more than 1.3 million broadband cable subscribers, cablecos are proving viable competitors for DSL operators. ONO's takeover of Auna TLC (the country's two main cable operators) in Q3 2005 gives birth to Telefónica's leading rival in the broadband market.	The top DSL ISPs, which have long been using Telefónica's wholesale offers, are migrating to unbundling. T-Online's recent takeover of Albura's infrastructures and Tele2's acquisition of Comunitel are proof of this trend. Recent trend shows massive adoption of full LLU.	Cable competition: moderate. DSL competition: moderate but increasingly based on LLU.
Sweden	The Swedish market is characterised by healthy competition between three access technologies: DSL (65 % of the base, mid 2006), cable modem (19 %) and FTTx/ETTx (16 % of the broadband base).	Unbundling is fairly well developed in Sweden. Wholesale DSL is unregulated as it was suspended by appeal courts.	DSL competition: resale. DSL competition: moderate and based on LLU. Other competition: FTTx.
United Kingdom	Cable operators NTL and Telewest (which recently merged) control 25 % of the country's broadband base (by mid 2006): more than BT's retail operations.	Concerned with the poor development of unbundling, OFCOM recently intervened to force down reference offer tariffs. The national regulator has set the target of 1 million unbundled lines by mid 2006. The mainstay of competition in the UK has been built around BT's bitstream access offers (AOL, Orange). Unbundling will come to severely undermine BT's broadband revenues.	Cable competition: high. DSL competition: high and based on resale but LLU take off has begun.

Table 5 Competition structure in Europe (end 2005). Source: IDATE

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tition is being felt the most, due to the combined development of unbundling and bitstream offers.

Threats/opportunities

Incumbents are still having to contend to a degree with potential losses in the intermediate market, due to the detrimental effect that increasing use of unbundling is having on wholesale DSL offers, particularly in the UK. Naked DSL too may well prove a threat in non-unbundled zones.

Some telcos could elect to invest in very high speed to beef up their market positions but, for now, regulatory uncertainties continue.

Highlights

Telecom Italia has strengthened its position in Italy's broadband market. Cable's absence from the scene, along with FastWeb's only limited footprint, has allowed the incumbent to gain control of over 70 % of the country's broadband subscribers.

BT, in the meantime, is suffering the reverse, with only 23 % share of its domestic subscriber base at the end of 2005, trailing behind cableco NTL/Telewest.

Outlook

The incumbent broadband market share is patchy but will remain significant and the decline will be slow.

The presence of incumbents in each other's markets is a threat given their knowledge and resources. This would put pressure on voice pricing and bundled offers. (Source: IDATE)

	2001	2003	2004	2005	2Q06
Belgium	39 %	53 %	51 %	49 %	50 %
Denmark[1)]	51 %	68 %	63 %	60 %	60 %
France	67 %	50 %	44 %	47 %	47 %
Germany	94 %	87 %	80 %	59 %	51 %
Italy	74 %	60 %	72 %	71 %	69 %
Netherlands	19 %	24 %	27 %	31 %	32 %
Poland	20 %	61 %	73 %	72 %	72 %
Spain	55 %	48 %	47 %	54 %	55 %
Sweden	40 %	42 %	39 %	38 %	38 %
UK	24 %	25 %	24 %	23 %	24 %

Table 6 Evolution of incumbent telcos' ISPs' share of the broadband retail market. Source: IDATE

ISPs/alternative operators

Competition

With the exception of Germany, market shares appear to be stabilising. Alternative operators will pursue their subscriber acquisition strategies by relying increasingly on unbundling. The drop in the number of connections based on incumbent telco's DSL offers is proof of the trend. But resale of incumbents' DSL offers could enjoy a revival in countries where unbundling is already well under way.

Threats/opportunities

As market consolidation is expected to continue, some alternative operators could find themselves the choice targets of foreign telcos seeking to compensate for losses in their home markets (e.g. Telenor and its takeover of B2 and Cybercity), of mobile operators looking to get in on the ground floor of the fixed-mobile convergence, or even of rival alternatives working to achieve critical mass (neuf telecom/ Cegetel).

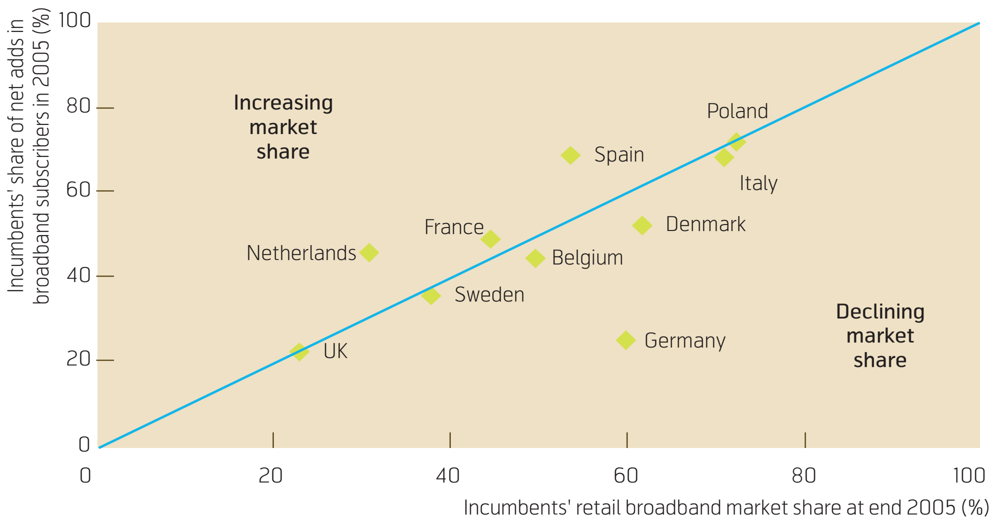

Figure 3 Incumbents' retail broadband market share at end 2005. Source: IDATE

1) *Including TDC's cable operation*

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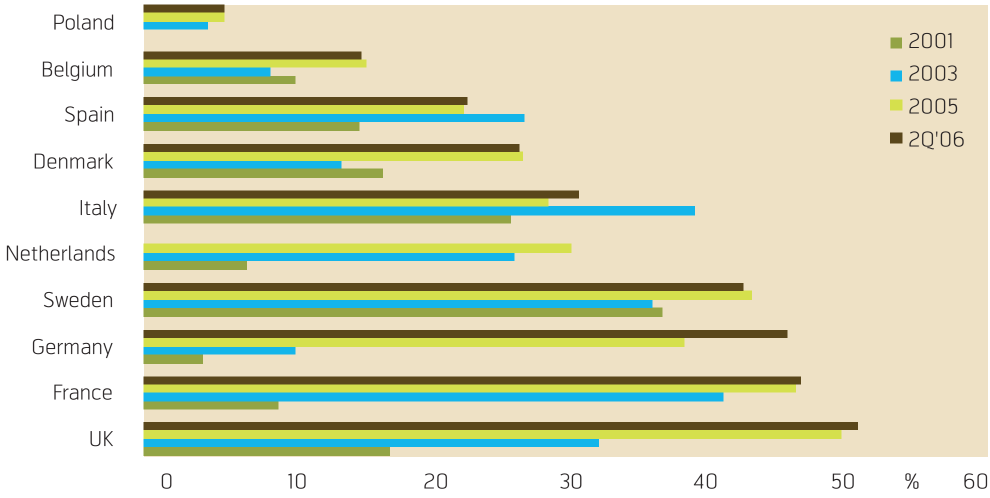

Figure 4 OLOs' broadband market share (Source: IDATE)

Highlights
ISPs and alternative operators in France and the UK have managed to grab around half of the broadband retail market, although the two national situations differ in many respects. In the UK, ISPs'/operators' services are based primarily on the resale of BT's DSL offer, although unbundling is expected to develop swiftly in 2006. In France, on the other hand, ISPs' and alternative operators' offers are already based largely on unbundling. France is at least a year or two ahead of the UK on the ADSL2+ front, and so enabling broader development of the triple play. (Source: IDATE)

Cablecos

Competition
With the exception of the Netherlands, Belgium, the UK and Spain, broadband cable is still only a marginal solution, particularly in Italy (absence), in France and in Germany.

Threats/opportunities
In some countries, cable has managed to hold its own in the broadband market. The combination of restructurings (NTL/Telewest), refinancing (Telenet IPO in Belgium, possibly IPO in Germany) and the launch of triple play bundles have all allowed cablecos to maintain their positions.

Beyond internet access, VoIP could also represent an excellent opportunity to conquer new subscribers. Cablecos in the Netherlands are in the process of testing a free VoIP calling system between their respective subscribers

Highlights
Cableco NTL/Telewest is number one in the UK's broadband market, with a 28 % share of subscribers.

Outlook
Cable competition is more capital constrained (upgrade to broadband is more expensive than DSL)

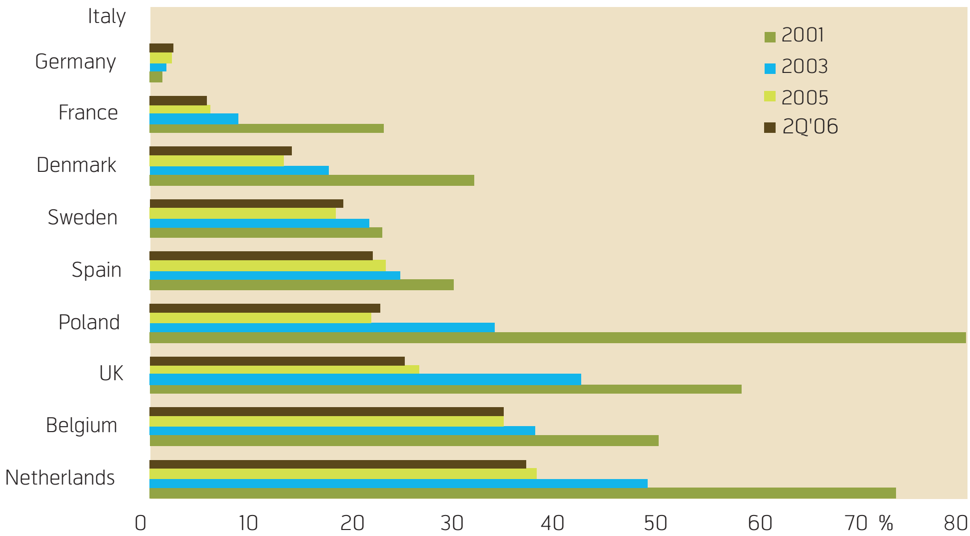

Figure 5 Cablecos' broadband market share. Source:IDATE

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and many cable operators have been financially constrained.

With the exceptions of Spain and Germany we estimate that DSL will gain market shares over the next years.

6 Roll-out of fibre outlook

While Japanese, South Korean and, more recently, US telcos have been rolling out large-scale, very high-speed deployment plans (FFTH or FTTN + VDSL), Europe is still lagging behind. Up until now, only a handful of specialised operators (the best-known being FastWeb in Italy, and B2 in Sweden – recently taken over by Telenor) have instigated developments in this direction. As of mid-2005, there were 650,000 very high-speed (VHS) subscribers in Western Europe, out of a total 2.5 million eligible, compared to a base of 45.2 million broadband subscribers in the region. Worth noting too is that 97 % of VHS subscribers are concentrated in five countries: Sweden, Italy, Denmark, the Netherlands and Norway.

But debates are heating up. Local authorities are investing more and more in these networks, with examples that include the city of Amsterdam (40,000 households passed in 2006) and the project deployed by the autonomous community of the Asturias in Spain (30,000 households covered in 2006). More significant still were the first signs of interest displayed by several heavyweight telcos in Western Europe in the second half of 2005.

The incumbent telcos indicated that, along with the technical and commercial results of these trials, the regulatory framework governing these new networks would affect any possible future deployments.

In this respect, European operators are reacting the same way as their American counterparts which awaited confirmation of lessened regulatory obligations before investing in VHS, or Australia's Telstra which recently put construction of its FTTN network on hold, after failing to secure a promise from the government that it would not be forced to open its network up to third-parties. Although Japan's NTT was a pioneer in the matter, it too counts on considerable support from the Ministry.

There are still a great many uncertainties over the timetable and scope of deployments in Europe, although 2005 marked a clear step forward after years of sitting on the sidelines. By 2010, the Old Continent could be home to over 10 million VHS subscribers, while still enjoying considerable potential given that, by that time, the broadband access base is expected to exceed 115 million users.

Country: Belgium

Player: Belgacom

Belgacom is investing EUR 300 millions to upgrade to VDSL over 2004–2006 via FTTC (street cabinet). Belgacom expects fibre to regulated wholesale and not LLU.

Player: Brutélé

Brutélé uses its fibre optics backbone, covering an important part of the Brussels-Capital Region and the agglomeration around Charleroi, Brutélé has progressively set up a high-speed transmissions network using DWDM, SDH and GBE technologies. The network is providing Fiber To The Office (FTTO).

Country: Denmark

Player: Danish utilities

Potential fibre by Danish utilities. Around 10 k subs end 2005. 9 % households coverage (see below) by end 2005. 500,000 homes passed planned by end 2007.

Country: France

Player: France Telecom

France Telecom has announced the launch of a pilot FTTH project by summer 2006, which will be carried out in six Parisian districts, and six nearby towns. The trials will be based on a GPON (Gigabit Passive Optical Network) delivering fibre optic connection to the home, and will involve several thousand households.

Player: Citéfibre

Created in 2004, Citéfibre initiated the project. Citéfibre is a French startup backed by Nicomvest, a private investment fund (whose capital contribution amount was 860 kEUR). In November 2005, Citéfibre launched its residential commercial triple play services in the 15th district of Paris. The basic service called "Access" includes Internet access (20 Mb/s symmetrical), VoIP, and television. The "Premium" service provides more TV channels and VOD. Citéfibre has deployed its own infrastructure in optical fiber, which is 140 km-long through the sewers and the subways of Paris. In 2007, Citéfibre plans to extend its network to the districts around the 15th district.

Country: Germany

Player: Deutsche Telekom

Deutsche Telekom in early autumn 2005 announced a roughly 3 billion EUR VDSL deployment programme, with the goal of equipping Germany's 50 largest cities by 2007, and an initial goal of covering the six sites hosting the next World Cup Football. But

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there were still regulatory issues that remained to be addressed at the start of 2006: before committing, the German incumbent wanted the reassurance that its fibre network would not be subject to unbundling obligations for the first few years, or at least that there would be no restrictions on the access fees charged to third parties.

Country: Italy
Player: FastWeb

In a market where there is no cable alternative, the main initiative was led by FastWeb with the help from utility companies during the first stages of deployment. FastWeb is currently focused on an unbundling model.

Country: Netherlands
Player: KPN and municipalities

The chief projects in the Netherlands have been instigated by the municipalities. Noteworthy are the projects launched by the cities of Amsterdam and Rotterdam. The largest FTTH project remains the one in Kenniswijk (Eindhoven, Helmond and Nuenen). 14,000 households are accessing an FTTH connection, out of the 15,000 homes passed. KPN is a stakeholder of this trial.

Country: Poland

MPEC Wroclaw is the Municipal Heating Energy Enterprise in Wroclaw. It is a public company. The network provides FTTH. Deployments are located in areas in Wroclaw. MPEC Wroclaw currently serves 4,200 households in Wroclaw with a wide range of telecommunications services through its fiber-optic network. MPEC Wroclaw's project would extend this network to the entire metropolitan area of Wroclaw and would introduce selected broadband services.

Country: Spain
Player: Government of Asturias

The Government of Asturias has recently launched (end of August 2004) an RFP for the project. Asturias is a small region in the north of Spain where the broadband telecommunication's infrastructure is poor. Only Telefonica, the incumbent operator is offering ADSL in the biggest cities. The regional Cable Operator has no plans to cover this area. The Government of Asturias has decided to build a Public and Open FTTH network that will reach >70 % of the homes and companies of this area. The Government will rent the FTTH network to the Operators at very competitive prices, being the project sustainable. The end user services will be supplied by these Operators. Services supported will be Analogue and Digital Broadcast TV, IP Video, Internet Access and IP Telephony.
Public financing and Open FTTH network.
Budget: 19 million EUR.
The deployment of the FTTH network will begin in 2006 and is expected to connect over 31,000 homes.

Country: Sweden
Player: Telenor B2

Public authorities supported the deployment of metropolitan optical infrastructures in a number of cities. There are now 200 of them across the country. These infrastructures are made available to operators and ISPs wanting to market broadband services. Noteworthy among the players involved is Stokab, the network in Stockholm. Alternative operator B2, one of Europe's leading ETTx/FTTx players and which took advantage of the municipalities' infrastructures to launch its FTTx offer. Other players are also offering FTTx services, including:

- Mälarenergi Stadsnät AB: a local electrical company owned by a municipality which took the initiative to deploy FTTx back in 2000.

- Svenska Bostäder's: a Stockholm-based real estate firm which is also active in the FTTx market. Svenska Bostäder's builds and owns the passive infrastructure, and relies on operators for their services.

Country: UK
Player: BT

The network mainly targets Homes (FTTH) and also FTTC (Fiber to the Cabinet). Up to 1,500 homes and businesses in Martlesham Heath in Suffolk, Milton Keynes and London's Docklands are to have fibre lines up and running in October 2004. In June 2004, BT announced the group is deploying fiber-to-the-home (FTTH) equipment from ECI Telecom to 1,500 trial customers. The trial will include 3,000 homes with active connections to 1,500 residential users and in excess of 100 business users. Since 18 November 2004, ECI Telecom's Fiber-to-the-Premises (FTTP) equipment has been carrying live traffic in BT's 21st Century Network (21CN) trials. Trials are still under way. However, BT is anxious to point out that this does not signify that it is planning a big FTTH deployment program any time soon. The trial is to collect "empirical data" to help BT work out what it should be doing, according to Bross, BT Group's CTO. BT has made it clear that even if successful, it is likely to install fibre only to new-build sites and developments. It has no plans to engage in the widespread replacement of existing copper cables.

7 Adapting regulation

In the deployment of very high-speed networks, a crucial aspect of investment strategy will be the status of optical fibre in regard to unbundling requirements. In regard to alternative operators, they will soon be faced with the question of unbundling the local sub-loop (included in the European Commission's recommendations) which technically is a highly complex operation.

These questions are among the main points addressed in the European Commission Review. At the end of 2005, the Commission launched the process for examining the European Regulatory Framework adopted in 2002, with a view to adapting the rules concerning market analysis. The unbundling requirements contained in European regulation, reappearing in the 2002 framework, currently apply to incumbent telcos for ensuring access to the copper loop or sub-loop. As such, they concern access to incumbents' infrastructure for the purpose of installing ADSL/SDSL equipment at the distribution frame or VDSL equipment (even if in this case the upstream section of the local loop has been replaced by optical fibre). It does not seem that these obligations have to be applied to infrastructure that is not based on the copper loop.

There are those who suggest that the deployment of FTTx infrastructure is not possible without a temporary period of monopoly, during which the new infrastructure would be exempt from ex ante regulation. This argument is based on the emerging market notion, recognised in European law. In this case, it would be necessary to distinguish between new services and high-speed Internet access services in defining the reference market. To be identified as a participating player in a distinct market, the operator must provide proof of the non "substitutability" of its high-speed offering for those of high-speed access operators, and logically of a significantly higher price. An SMP operator investing in an FTTH infrastructure would be exempted from access obligations when rolling out his services while continuing to ensure the maintenance of his copper loop to which unbundling obligations will still apply. On his own initiative he could provide third parties with access to his infrastructure, but at tariff rates fixed without the intervention of the regulator.

Then there are others who reject the emerging market notion for two reasons: on the one hand, they claim that the incumbents are already in possession of a network on which to base investments for offering new services, while on the other hand, they contest the idea of non "substitutability" between high-speed and very high-speed offers.

Roland Montagne joined IDATE in 1998 and is now Head of Broadband Practice at IDATE. Mr. Montagne played a leading role in previous IDATE International studies and is also Project Manager for the IDATE annual market report concerning World Broadband Access Market (DSL, cable, FTTH). He has carried out several studies dealing with European broadband roll-out. He is in charge of a survey on broadband access for the DGInfSo and also the IDATE representative in the FP6 Integrated Project BROADWAN. Since 2004 Roland Montagne has also been the project leader of the FTTH Council Europe European FTTx projects panorama. Recently, he achieved a major study for the French Government on scenarios for deploying Very High Broadband networks in France (cost model and Government options). In 2006 Roland Montagne carried out several strategic analyses focused on US and Asian developing FTTH markets. He is currently involved in an FTTH cost model analysis for the United Kingdom. Roland Montagne is a Telecommunications Engineer (ENST Paris, 1994) and received a Master on Electronics (University Paris 6, 1994). He also worked for AT&T Bell laboratories (USA) as Engineer on DWDM Optical Networks and ATM technologies. He started his career in France Telecom R&D labs working on optical communications.

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Loïc Le Floch, consultant at IDATE since 2002, has mainly been working on broadband access issues and on wholesale market topics (interconnection, wholesale DSL, LLU). He has also specialised in telecom industry development in countries of the Middle East and North Africa region, in particular on regulatory and technical issues. Prior to joining IDATE, Loïc Le Floch worked in the marketing direction of Neuf Telecom. Thanks to his position, he was involved in network roll-out plans and participated in the future choices of Neuf Telecom network architectures. Loïc Le Floch graduated as Engineer, holder of a diploma of the National Institute of Telecommunications (INT-2001).

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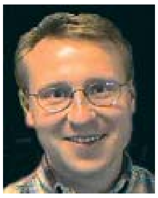
Requirements to and architecture of hybrid broadband access networks

LARS ERLING BRÅTEN



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Hybrid access networks are well suited to providing broadband access everywhere with enhanced performance in term of coverage, capacity and throughput compared to access networks based on a single technology. This paper addresses the design of an economically viable hybrid network architecture to provide full broadband coverage. The focus is on the efficient combination of wireless and wireline networks in areas ranging from urban to rural and remote areas. Both access and backhaul solutions are addressed.

Wireless broadband technologies have implicit advantages such as an ability to serve the customer everywhere and mitigate the digital divide, they are scalable in both capacity and coverage areas, an imperative as requested services evolve towards increasingly bandwidth hungry applications. Broadband Fixed Wireless Access (BFWA) systems, in licensed and license-exempt bands, are presented as attractive solutions for providing broadband services for both fixed, nomadic and mobile users. Interoperability of hybrid networks is a key design objective to drive solution costs down. Internet Protocol version 6 (IPv6) has been chosen as the convergence layer in the hybrid network. An IPv6 based protocol architecture is presented including features such as quality-of-service (QoS), security, mobility, multicast, auto configuration and intelligent agents for network management. Conclusions show that hybrid architectures, combining the advantages of the different wireless and wireline technologies, are central in delivering broadband services everywhere.

This paper is based on work in the project BROADWAN, partly funded under the Information Society Technologies (IST) priority of the European Commission Sixth Framework Programme.

I. Introduction

Development of the Information Society needs a cost effective, universal broadband access network that reaches everybody. This total network consists of several broadband access and backhaul technologies combined into a hybrid or heterogeneous network. Although specific technologies may dominate in certain regions, the full coverage requirement and the need for competition will create a situation where in most areas more than one technology will be deployed.

Broadband communication services are gradually being offered in Europe and elsewhere through interactive cable systems, digital subscriber line (DSL), digital video broadcasting – return channel via satellite (DVB-RCS), and BFWA systems operated in different frequency bands. Typical services currently include Internet browsing with rather asymmetric behaviour and solutions for business users operated to appear like a traditional leased line mode. However, only a small percentage of the total population has real access to broadband interactive services, including also broadband-TV as a transmission capacity driver.

Asymmetric DSL (ADSL) or interactive cable can provide 80 to 90 per cent coverage in European countries with a well developed copper line and cable network infrastructure. This is however valid only for some countries in the western part of Europe. A large fraction of the population in Europe will remain beyond the reach of the broadband coverage of these technologies. Optical fibre connections to the home are offered by a few operators in some countries, using separate wavelengths of light for TV, interactive services and telephony. An increasing demand for BFWA is arising, especially in Central and Eastern Europe owing to the lack of any suitable wireline infrastructure. BFWA in terms of WiMAX, following the IEEE 802.16 standard, will be developed in many areas to offer ADSL-like services for fixed, nomadic and mobile users. If higher transmission capacity is required, to provide for example triple-play or backhauling of Wi-Fi hotspots, BFWA operating above 20 GHz is currently investigated as a cost effective alternative to DSL and leased lines.

II. Service development trends

Restricted deployment of broadband access sets a limitation on the development of broadband interactions between individuals and groups of individuals. The starting situation of today is broadly represented by data delivery services from central nodes such as the web, and interactions within and between organisations. The main issue that gives the mobile domain strength is connecting people. The same effect will start developing for broadband access when popula-

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tion coverage, or more precisely, participation, becomes sufficiently high, anticipated to be in the range 50 to 70 per cent. We may then see a development where authorities at different levels can reach all citizens and communication between individuals and communities will develop as point-to-point, point-to-multipoint and multipoint-to-multipoint type of interactions.

The total number of fixed telephony lines has started to decline. The trend is now that young people have a broadband connection and a mobile phone. IP telephony, or broadband telephony, is gradually being offered as part of broadband subscriptions. With IP telephony there will be increased flexibility compared to traditional telephony. It will serve as both fixed and nomadic, and mobile services such as multimedia message service (MMS) can be adopted at a lower cost. Combining audio and video opens up for development of a broad range of IP based telephone services. With everybody having a separate IP address for the phone the location based identity assignment may be replaced by IP addresses. 3G and 4G mobile telephone services may be very similar for the mobile and for the IP-based broadband networks. In the same period there will be a strong technological push represented by

- Increased capacity and functionality of PC and storage systems in combination with efficient high capacity in-house networking;
- Capacity for advanced software packages for coding and decoding, editing and even language translation will give new possibilities;
- Digital devices like cameras, home cinemas, surveillance equipment are becoming more common and create traffic as well as making it possible to produce and deliver content from any location;
- New possibilities resulting from the use of IPv6 or other more advanced protocols.

With the new possibilities and the increased access network capacity users will have different sets of possibilities. It is no longer just to learn how to log on, send an email and find something on the web. There will be strong differences between users as a result of ability and interest. The problem of today of providing broadband connections is shifted towards the problem of educating the majority of a population to use the technology both for its own interest and in the building of an *e*Europe including the whole population.

Additional key elements required for a breakthrough for capacity demanding *e*-services are confidence and trust in *e*-based services by handling security issues seriously, overcoming the language barrier, standardised on-line payment methods and solving copyright issues.

A. Service capacity requirements

Broadband access is growing fast in countries that already have well developed fixed and mobile telecommunication networks. The term broadband is not clearly defined, and there seems to be little willingness to define it any closer than the common usage today. A good definition is "Broadband is a high capacity, two-way link between an end user and access network suppliers capable of supporting full-motion, interactive video applications" suggested by the Canadian Government National Broadband Task Force [1]. The access bit rate increases, but often the tariff remains the same or becomes lower. The steady increase in access capacity, as illustrated in Figure 1, has been like this for a long period of time [2]. The predicted future bit rates can certainly be debated, but from a technology point of view there is no reason to question that typical capacity soon will be in the range of several tens and even hundreds of Mbit/s.

The services and user experiences in the Norwegian trials reported in [3] showed that the always-on feature changes the usage of the services and leads to new ways of using broadband, such as increased use of music and movie download and exchange. For private users there was traffic all day and surprisingly high traffic loads from midnight until dawn, with

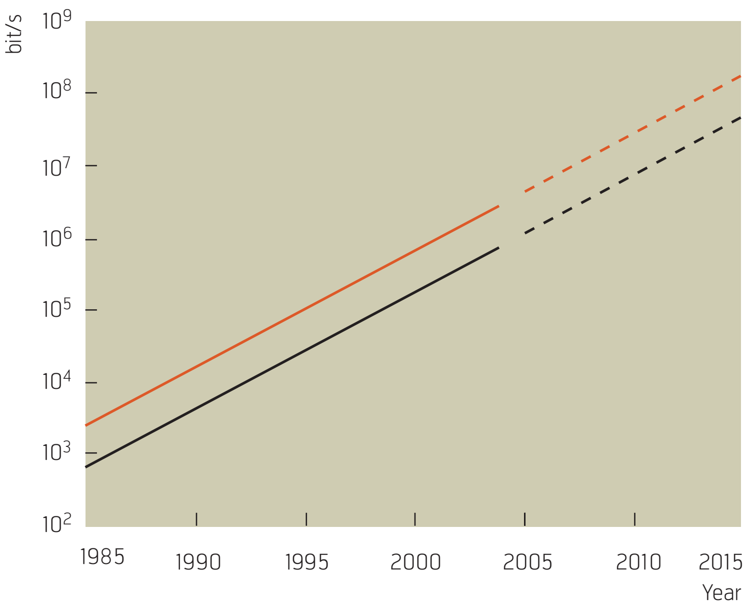

Figure 1 Development of peak access capacity for a typical and advanced residential user

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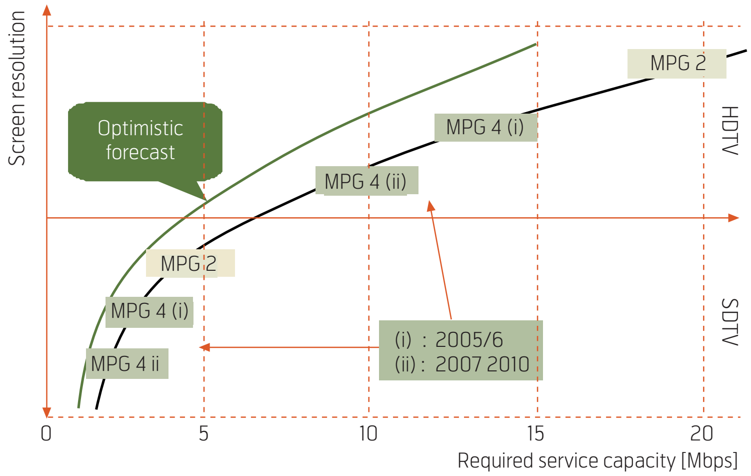

Figure 2 Evolution in video coding, screen size and required capacity

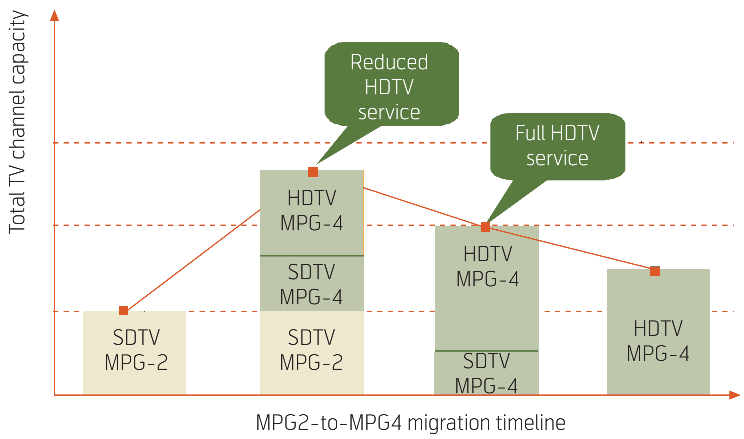

Figure 3 Capacity during migration from SDTV to HDTV

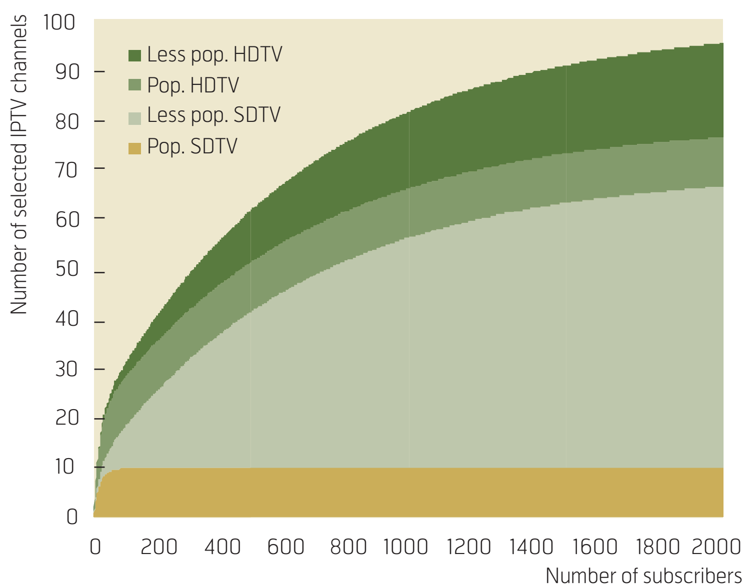

Figure 4 Number of selected IPTV channels per category

some reduction during working hours. Enterprises and schools had a short and intense user period in the daytime. A small fraction of the private users dominated the traffic volume, and for these users the traffic towards the network exceeded the incoming traffic volume. This type of usage is expected to be significant in the future. Thus, future broadband networks must have the capability to offer the individual user a capacity that can be asymmetric on demand in both directions as well as providing the quality of service required by the end users.

In addition to voice and data services, multicasting of video content will be the major dimensioning factor regarding capacity in both the access and backhaul networks.

B. Multicast of TV content

The introduction of triple-play is one of the most important drivers for increased access capacity. IP-TV with standard definition TV (SDTV, 576x720i) on MPEG-2 will be accelerated by terrestrial analogue shut-down throughout Europe.

The introduction of high definition TV (HDTV) is gaining momentum and HD-enabled Flat Panel TVs are becoming affordable. New generation game consoles support HD as well. High Definition DVD will be launched soon and Europe will probably introduce the 720x1280p-format. The anticipated evolution in video coding is shown in Figure 2 reproduced from [4].

More TVs move into peoples homes (bedroom, kitchen etc.), and TV-programs are becoming available on PDA and mobile devices requiring handling of multi-resolution. There is a number of issues to be handled during the migration from SDTV to HDTV only, including a period where both TV formats exist, resulting in a peak required backbone capacity during the transition, see Figure 3.

Open service provision will allow for multiple service providers, which will most likely increase the capacity demand further. To enable for example dimensioning of wireless base station capacity and the necessary backhaul capacity it is necessary to estimate the requested number of TV channels depending on the number of customers in the coverage area.

1. Multicast TV-traffic estimation

This section describes a framework for estimation of the real traffic demand in access networks employing multicast TV distribution in addition to unicast data and voice traffic.

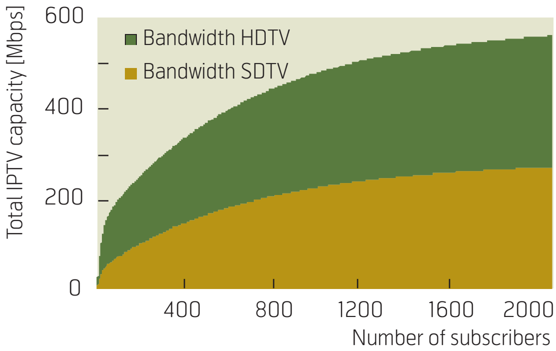

Figure 5 Required multicast bandwidth in a sector as a function of subscribers

Parameter	Value
Number of TV sets (active) per household	1.5
IPTV concurrency i.e. the percentage of subscribers being active simultaneously	0.8
Total number of IPTV channels	100
Number of popular SDTV channels	10
Number of less popular SDTV channels	60
Number of popular HDTV channels	10
Number of less popular HDTV channels	20
The probability of a selected channel being a popular channel	0.9
Capacity for a single SDTV channel	4 Mbit/s
Capacity for a single HDTV channel	10 Mbit/s

Table 1 Parameter values for IPTV multicast capacity requirements

In [4] the channels were divided into two groups; namely the "popular" channels and the "less popular" channels. In this case, each channel within a group has the same choice probability. If for instance there are 100 channels of which 10 channels are popular channels, each of these 10 channels are equally popular. In the same way, the remaining 90 channels are equally probable. The number of selected channels in the four categories is shown in Figure 4 as a function of the number of subscribers for the example parameter values given in Table 1.

During the migration phase from SDTV to HDTV it is then possible to derive the number of simultaneously requested TV-channels depending on the household density and cell size or coverage area. Similarly for DSL technology, the number of TV channels depends on the number of customers connected to a digital subscriber line access multiplexer (DSLAM). By assuming a given video coding technology and thereby an average bit rate, the aggregated backhaul capacity may be estimated as in Figure 5. In this example 4 Mbit/s and 10 Mbit/s are assumed for SDTV and HDTV respectively.

As seen in Figure 5, the number of TV channels, and thereby the required aggregated multicast capacity flattens out when the number of customers reaches a level of about 1500 to 2000 per base station (or DSLAM).

2. Multicast Architecture

As the number of channels required is normally smaller than the total number of channels offered in the package (in our case 100 channels) it may be useful to limit the number of channels transmitted from

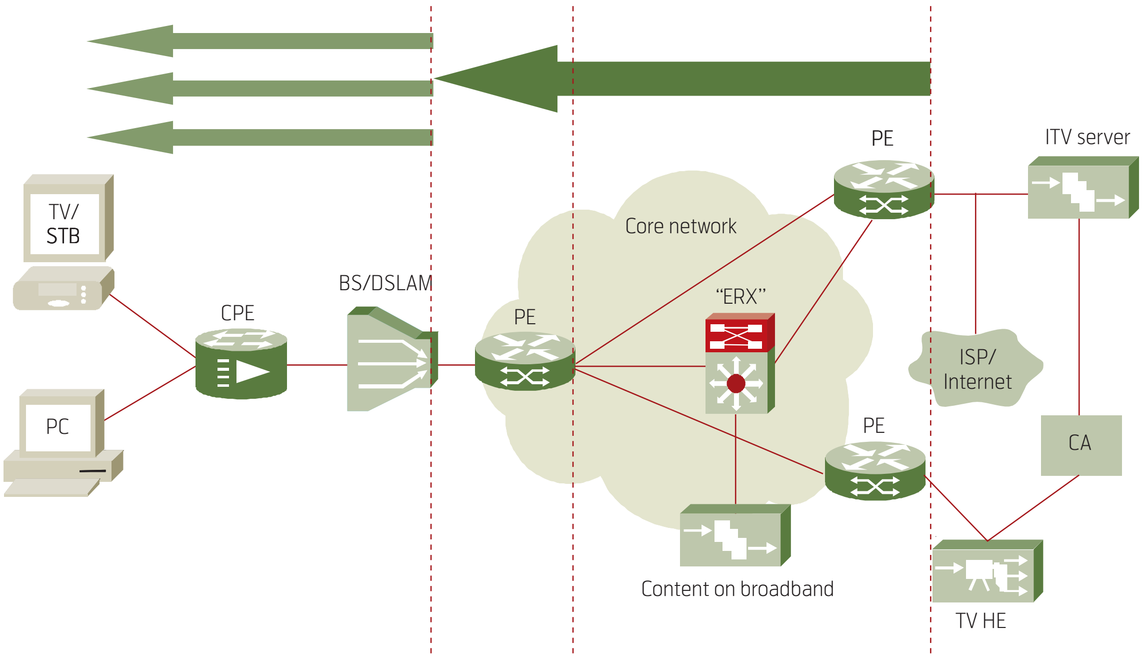

Figure 6 Static multicast from TV head-end to base station

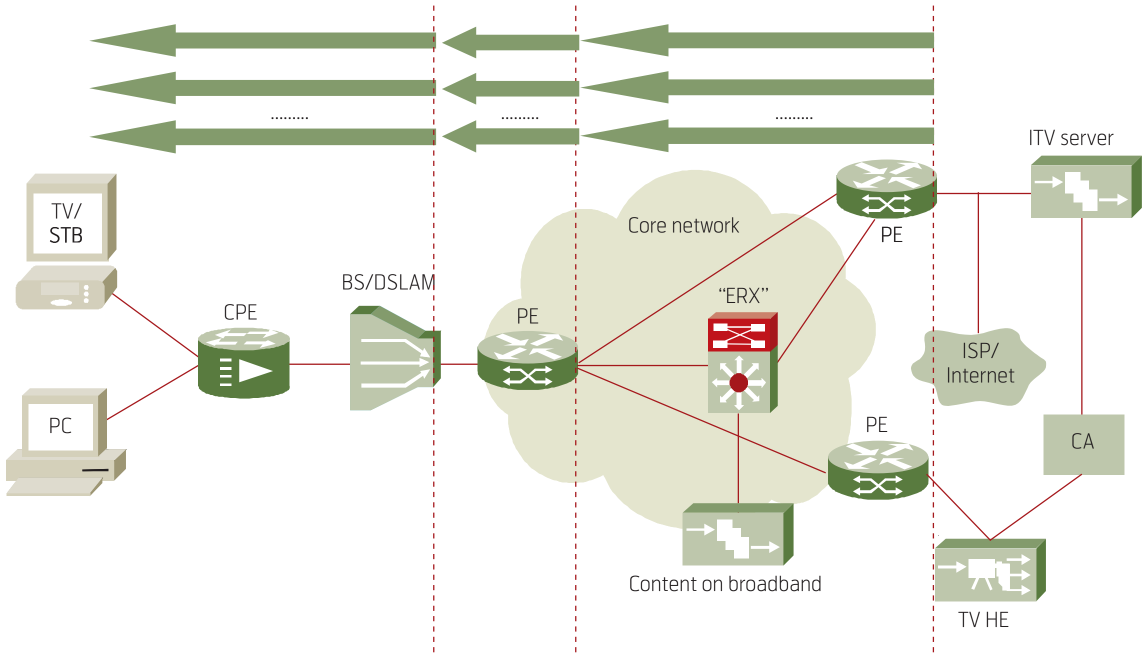

Figure 7 Dynamic multicast from TV head-end to base station

a central multicast server to a given base station / DSLAM to lessen the burden on the backhaul network. Both static and dynamic multicast may be applied for distributing broadband TV to the base stations, see Figures 6 and 7.

If utilising static multicast, all available TV channels are transmitted to the access node from the TV head-end. Dynamic multicast, on the other side, takes advantage of the fact that it is not necessary to transfer all of the channels simultaneously. For smaller local distribution areas this may imply a significant reduction on the multicast traffic in the backhaul network.

As seen in Figures 4 and 5, base stations or DSLAMs aggregating up to about 1500 – 2000 broadband TV customers should employ dynamic multicast to avoid unnecessary capacity allocation in the backbone network resulting from static multicasting.

In the future, methods could be sought to investigate the transitional behaviour for required capacity during commercial breaks in the programs, as these often coincide in time and result in frequent changes of channels during the breaks.

III. Hybrid Network architectures

In this section selected wireline and wireless broadband access technologies are described and some possible hybrid combinations discussed. Optical fibre already dominates the core network, supporting very high traffic volumes. An increasing share of the aggregation or distribution networks utilises fibres, especially in densely populated areas. For the access network, though, the technological options adopted will influence significantly both the technical capability to support broadband service delivery and the economic practicability of providing such services. In the access networks, xDSL on copper pairs, and co-axial cable, are the main dominating technologies for the final drop to the customer premises.

Wireless access provides an attractive alternative, offering considerable flexibility and speed of deployment and proving economical for the final sections of the access network. To date, radio systems have generally been considered on a stand-alone basis. However, with increased penetration of fibre in the access network toward the customer's premises it is appropriate to consider radio alongside the other final drop options, integrating radio with fibre in optical distribution networks to satisfy system-driven requirements. An overview picture is given in Figure 8.

The choice between these technological options depends on many factors including economic considerations, existing infrastructure and customer density, and on the type of service to be offered. In the following the main technologies relevant in the access network are discussed, highlighting their strengths and limitations.

A. Copper wire xDSL access technologies

Among the most common access technologies used so far in the residential and small office home office (SoHo) markets are digital subscriber lines. In most western European countries, good quality copper networks exist and cover almost every household. In

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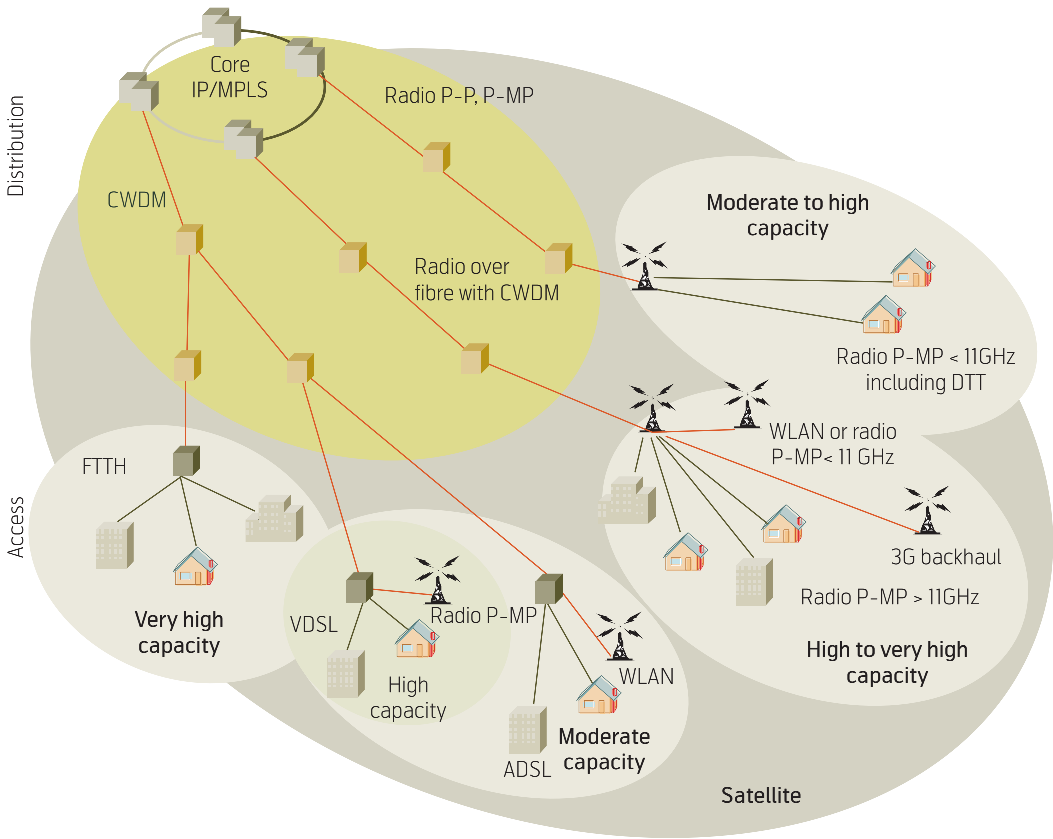

Figure 8 Hybrid network architecture. Dark lines represent access while red lines represent backhaul

these countries at least 80 to 90 per cent of the households will be covered by ADSL within the coming years.

Due to the short reach of VDSL, 1–1.5 km using conservative estimates, generally less than 50 per cent of the telephone lines in a central office area can be reached directly from the central office. ADSL2+, which has a longer reach, around 2 km, but also lower bit rate both downstream and upstream, will offer better coverage of triple play capability directly from the central office.

A large portion of telephone lines within a central office (at least in Europe) is between 1 and 2 km in length. Studies indicate that long copper lines exist in both urban, suburban and rural areas. However, a rather significant share of the lines will still be beyond reach if fibre is not stretched deeper in the access network and a large number of micro-DSLAM are placed in street cabinets. Deployment of fibre or wireless backbone capacity is necessary to obtain high capacity coverage. Using DSL technology to cover all households will then necessarily result in very high investment costs and alternative access solutions may have to be found [5].

B. Hybrid fibre cable networks

Hybrid fibre cable operators can provide DSL-like services over cable modem to residential customers. Often these services are bundled with TV packages and telephony into a triple-play service. In some countries such as the Netherlands and Belgium, the HFC coverage is as high as 80 per cent, whereas in Italy there is no cable TV coverage. Cable modem coverage is about 40 per cent in average in the OECD [5].

C. Wireless broadband technologies

As digital subscriber line and cable modem cannot always meet with broadband demand, most of the time due to distance limitations, there is a clear opportunity for broadband fixed wireless access. Broadband wireless access technology is establishing an efficient and integrated part of the global coverage of broadband fixed network, which provides converged multi-services for all. Radio based solutions offer:

- Flexible and scalable on-demand capacity;
- Coverage in areas not reached by wireline solutions;
- Stand alone solutions for full coverage;
- Competition with established broadband wireline technologies;
- Simple extension to nomadic and mobile users.

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Wireless solutions are expected to cost less than wireline systems in areas of medium to low population density. They also enable nomadic and mobile access and have economical advantages compared to wireline solutions when deploying broadband with capacities enabling triple-play including HDTV multicast.

The actual cost per subscriber depends largely on the cost of the customer premises equipment (CPE) and on how many subscribers can be serviced by the whole network and each of the base stations. The higher the number of subscribers, the lower the shared cost of common equipment at the base stations and network head end. Detailed investigations of the business cases for wireless broadband access are given, for example in [6], including cases where users share a BFWA terminal, for example by Wi-Fi to lower the investment costs.

Cell and channel planning is essential to increase the number of subscribers that can be accommodated in a given frequency bandwidth while reducing radio interference to maintain quality of service. Optimised hybrid network planning, taking network cost into account, is discussed in [7] and [8] based on a software network optimiser taking both economical and technological parameters into account. An overview of the architecture for some wireless access networks is given in Figure 9.

In this example three different wireless access networks are included:

- BFWA operating above 20 GHz providing high capacity triple-play services;
- BFWA operating below 20 GHz providing ADSL like nomadic services;
- BFWA operating below 2 GHz with long reach and cognitive radio concepts.

The base stations are connected to the aggregation/ distribution network and then to the core network. Backhauling issues, discussed later in this paper, refer to the aggregation/distribution network, which often represents a major cost for the operator.

The potential traffic density in a given area determines to a large extent the most appropriate frequency band. Although the lower frequency bands allow the deployment of base stations with longer ranges and indoor penetration, available bandwidth is generally limited. High traffic density requires a wide capacity per unit surface area. This fits well with the use of higher frequency bands, which simultaneously feature shorter ranges and offer more bandwidth.

Wireless meshed networks may be deployed as well. For operators targeting delivery of quality services with given QoS and target transmission capacity,

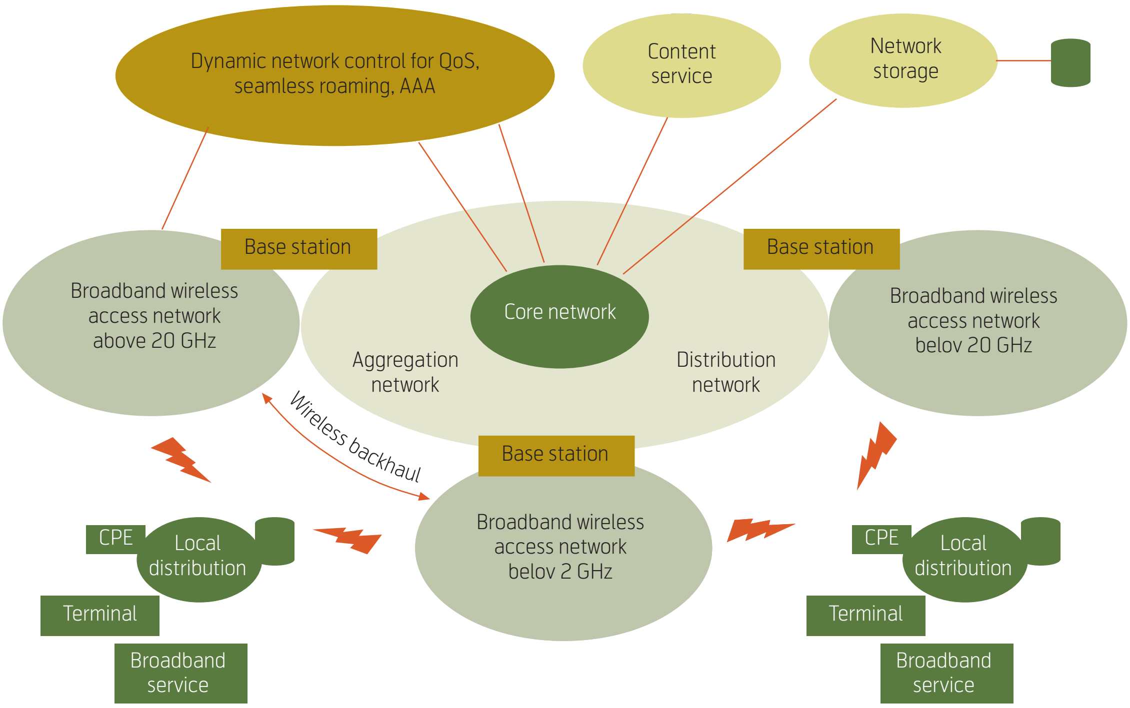

Figure 9 Wireless architecture

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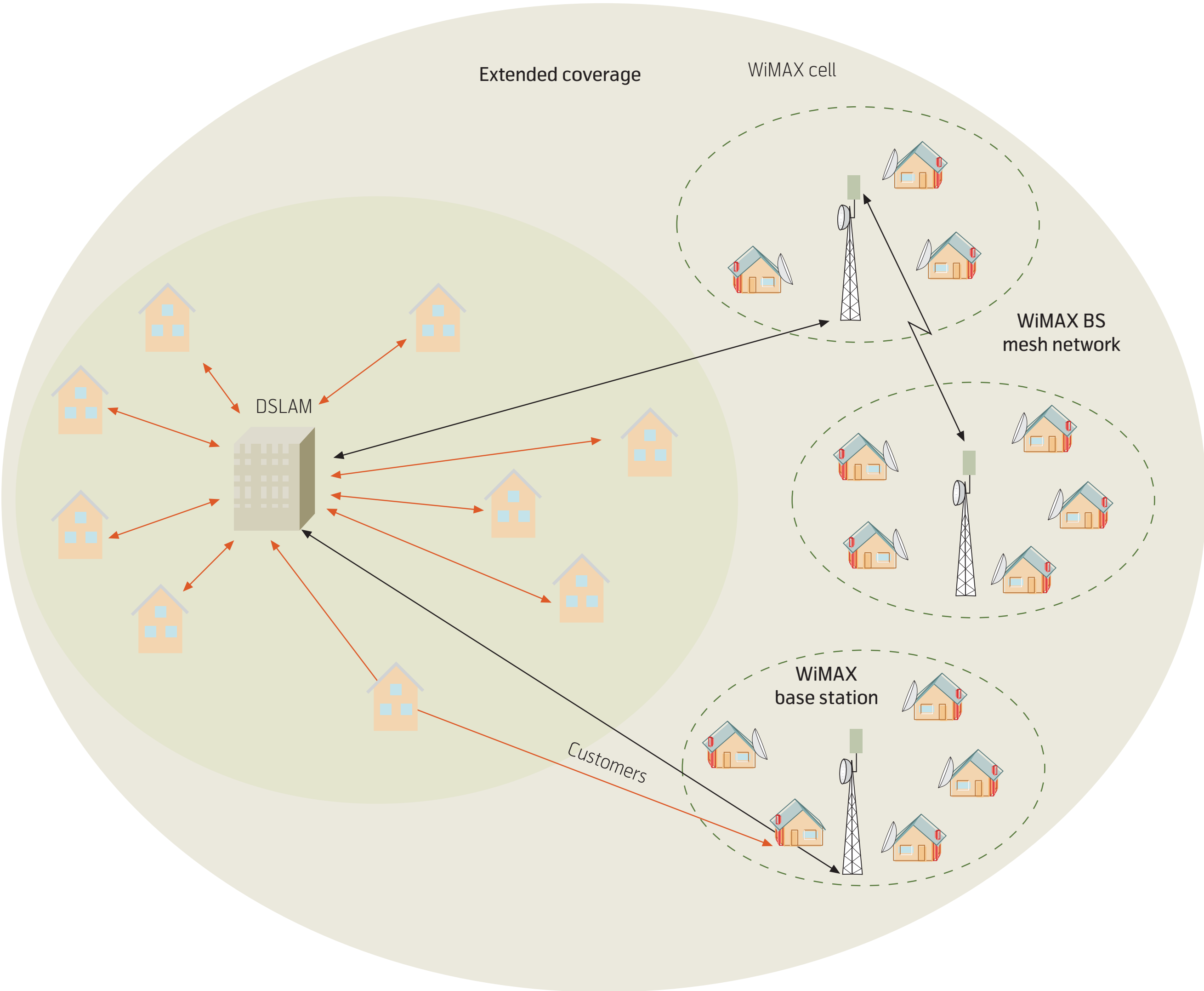

Figure 10 Extending ADSL coverage with WiMAX fill-ins

meshes may be most interesting in the boundary of the coverage area.

D. Hybrid networks

Hybrid architectures, combining the advantages of the different wireless and wireline technologies, are central in delivering broadband services in a cost-effective manner. A few relevant hybrid architectures are discussed in more detail below.

1. ADSL with WiMAX fill-in

In areas with copper based infrastructure, ADSL is usually the most cost efficient way of providing broadband to the public. However it is usually not possible to get full coverage using ADSL alone, as the copper line lengths to some of the customers will be too long. One way to provide broadband to the users who cannot be served by ADSL, is to overlay the ADSL network with a WiMAX network operating in a licensed frequency band, see Figure 10.

As WiMAX systems do not require line-of-sight, they will usually have good coverage in an area. Hence a number of users that cannot be provided with broadband by ADSL will be able to turn to WiMAX. The WiMAX network can also be used to offer the ADSL customers complementary services, for example nomadic access [8].

2. VDSL/ADSL2+ with BFWA above 20 GHz fill-in

In areas with good copper based infrastructure, VDSL or ADSL2+ will be the most cost efficient way of providing a triple-play service to the public. However, it is usually not possible to get full coverage using the wireline technologies Very high bit-rate DSL (VDSL) or ADSL2+ alone. A high capacity BFWA network operating above 20 GHz is able to complete the coverage. The deployment will look like that of ADSL-like services shown in Figure 10, replacing ADSL with VDSL and low frequencies with high frequencies. Technical-economical analy-

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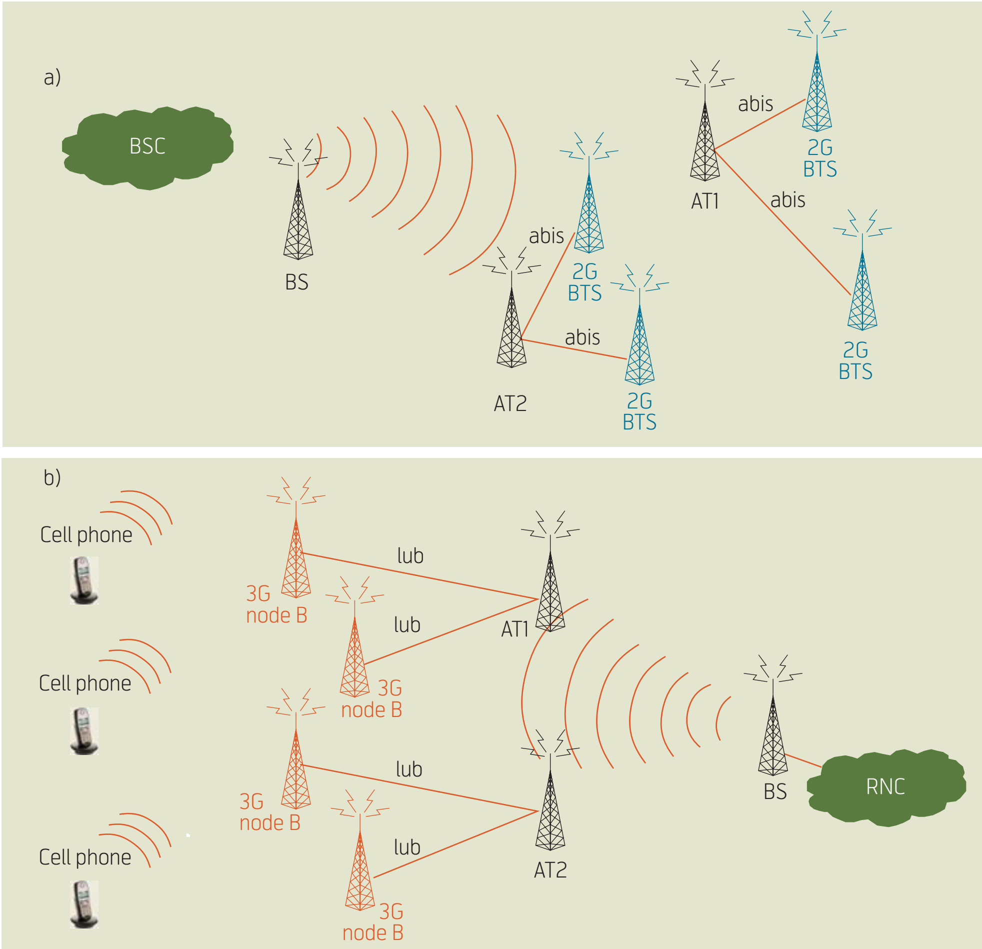

Figure 11 BFWA used for GSM/UMTS backhauling

ses and viable business models for these two cases are reported in [6].

3. BFWA above 20 GHz in a hybrid backhaul architecture

BFWA systems operating above 20 GHz are able to provide high transmission capacities to residential and business users and also simultaneously offer backhaul solutions to for example Wi-Fi hotspots, WiMAX and 2G/3G base stations, see Figures 11 and 12.

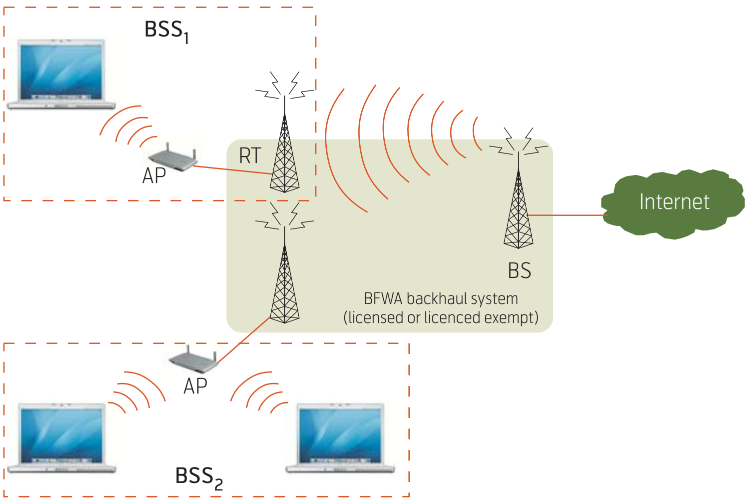

Figure 12 Example deployment with BFWA operating above 20 GHz and users connected through Wi-Fi

Hybrid solutions, as for example VDSL feeding of BFWA base stations as well as BFWA systems feeding street cabinets with xDSL modems, may be appropriate depending on the available backbone infrastructure and required backbone capacity.

Due to the high frequency, a line-of-sight between the user and the base station is required. In the CRABS project a frequency reuse plan for cellular deployment was developed, enabling 80 – 90 percent coverage even in urban areas [9].

The main bottleneck for these high frequency systems have until now been the rather high cost of user terminals (CPEs), however new manufacturing techniques have enabled a significant price reduction down to less than twice the price of a fixed WiMAX terminal. A high frequency CPE may be shared between several users by utilising for example in-house distribution (LAN/Wi-Fi/µDSLAM) due to the capacity provided, thus enabling cost sharing as well

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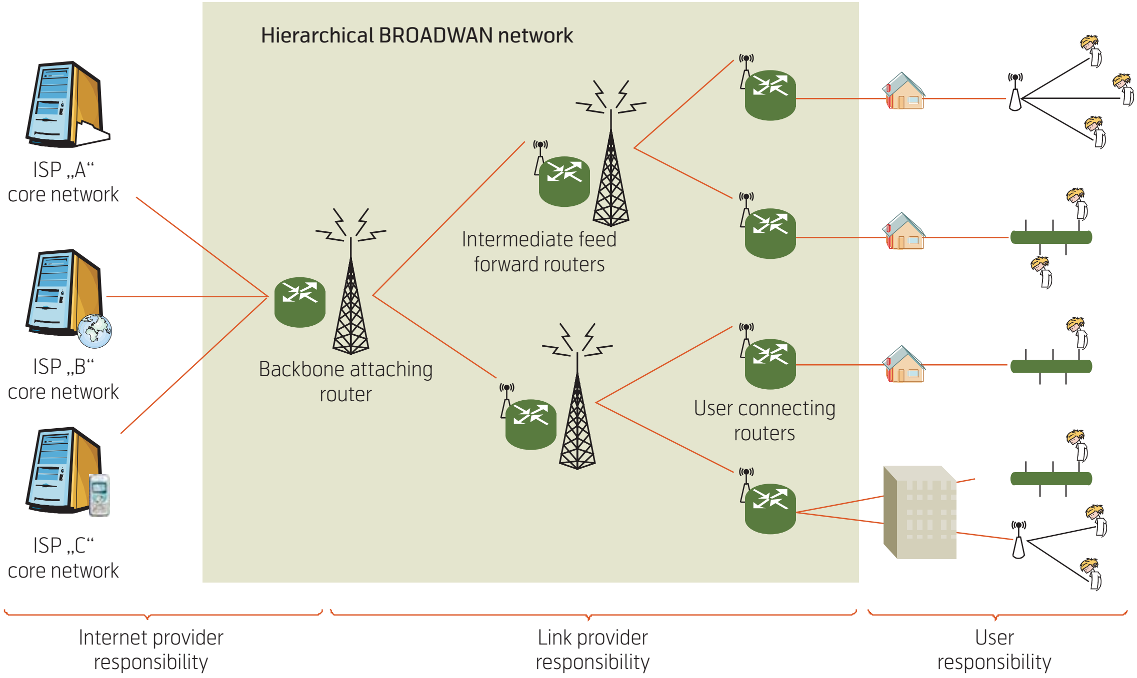

Figure 13 The Hierarchical IPv6 Network Model

as triple/quadruple play services to the users. Example business cases for such scenarios are presented in [6].

IV. Protocols and network management

The application of new communication technologies, new services and mobility requirements has led to developments in network architecture and protocols. There are several approaches to architectures for hybrid networks utilising IP as the convergence layer. ITU is working on next generation network (NGN), 3GPP is working on IP multimedia services (IMS) and also ETSI TISPAN is involved. The "Always best connected" perspective requires integration of both wireline and wireless IP networks. There is ongoing work on interworking of e.g. Wi-Fi (WLAN) and 3G mobile systems. The WiMAX forum is currently defining their end-to-end network systems architecture.

IPv6 is assumed here to be the convergence layer between hybrid networks and is expected to give a more manageable network, improve mobility of end-user devices and enhance the integration between mobile networks (e.g. UMTS), wireline networks and also broadband fixed wireless assess (e.g. Wi-Fi, WiMAX, BFWA). Seamless services, as well as authorisation and charging in wireless access networks require new developments as well as standardised architecture components and functionality.

A. Protocol architecture

The network architecture introduced in the BROADWAN project utilised a three-levelled approach. The overall architecture is separated into the backbone network, a hierarchical construct of wireline and wireless access networks, and the user local networks at the very far end of the hierarchy, see Figure 13.

It is then possible to build a scalable network that can even reach rural user communities with varying population densities and demands at low implementation costs. Satellite systems are particularly useful in remote areas lacking backbone infrastructure, either as a stand-alone solution or in combination with BFWA.

Another important benefit provided by the layered network architecture is the ability to separate the responsibility for link provisioning from the Internet connectivity supply. This is especially vital for the rather complex network architecture, as it breaks these considerations down into manageable entities.

In addition to the deployment costs, means to reduce the operational costs must be considered. Low-cost operation requires utilisation of auto-configuration mechanisms in as many places in the network and for as many maintenance tasks as possible. As the IPv6 networking protocol inherently supports a wide variety of auto- and self-configuration options and mechanisms, we propose to build the network architecture on an "All-IPv6" network. Furthermore, this is a future-proof solution that enables a converged archi-

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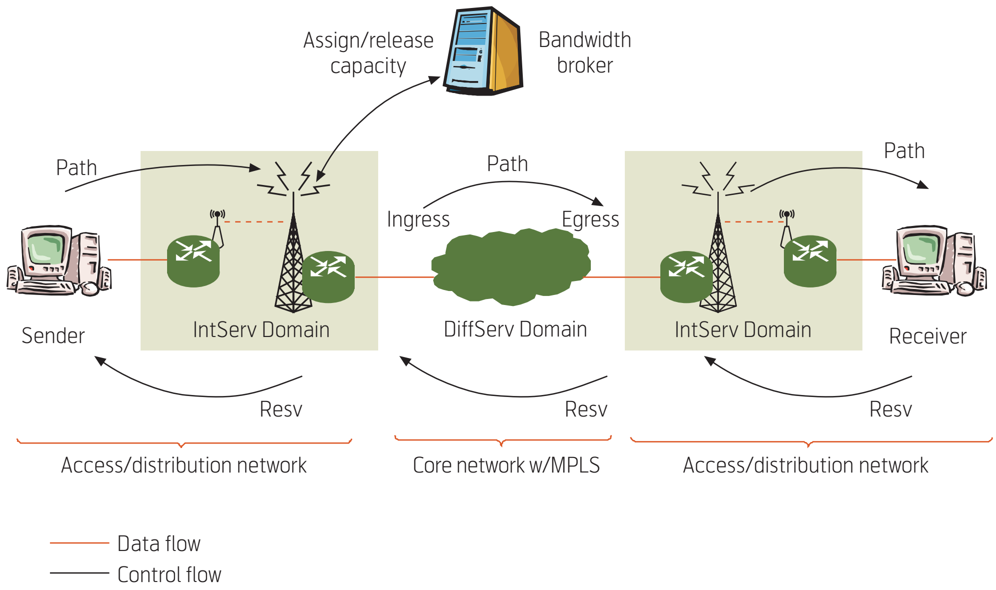

Figure 14 QoS mechanisms in the All-IPv6 network combining Integrated Services, Differentiated Services and Multi-Protocol Label Switching (MPLS)

tecture for broadband triple/quadruple-play services, allowing the transmission of voice, video and data over the same network links at the same time.

B. QoS architecture

Providing end-to-end QoS in hybrid IP networks may be realised by a combination of integrated services (IntServ, [10]) and differentiated services (DiffServ, [11]) at the IP layer. The IntServ architecture is able to provide end-to-end guarantees on a per-flow basis. For each user flow there is a path reserved through the network in accordance with a specified service type and a well-defined flow-profile. The reservation protocol (RSVP) [12] has emerged as the preferred protocol for resource reservations in IntServ environments [13]. With respect to constraints in both the IntServ and the DiffServ QoS architecture, the IntServ over DiffServ approach [14] has been proposed by the IETF. The idea is to replace the core of the IntServ network with a DiffServ cloud to address the scalability problem. User devices are connected to an IntServ domain and applications that support IntServ are able to request service guarantees via RSVP from the network. This allows scalability, due to the DiffServ aggregation, while keeping the advantages of end-to-end signalling by means of the RSVP protocol.

The utilisation of IntServ in the wireless or wireline access networks, RSVP signalling to communicate application requirements through the network, and

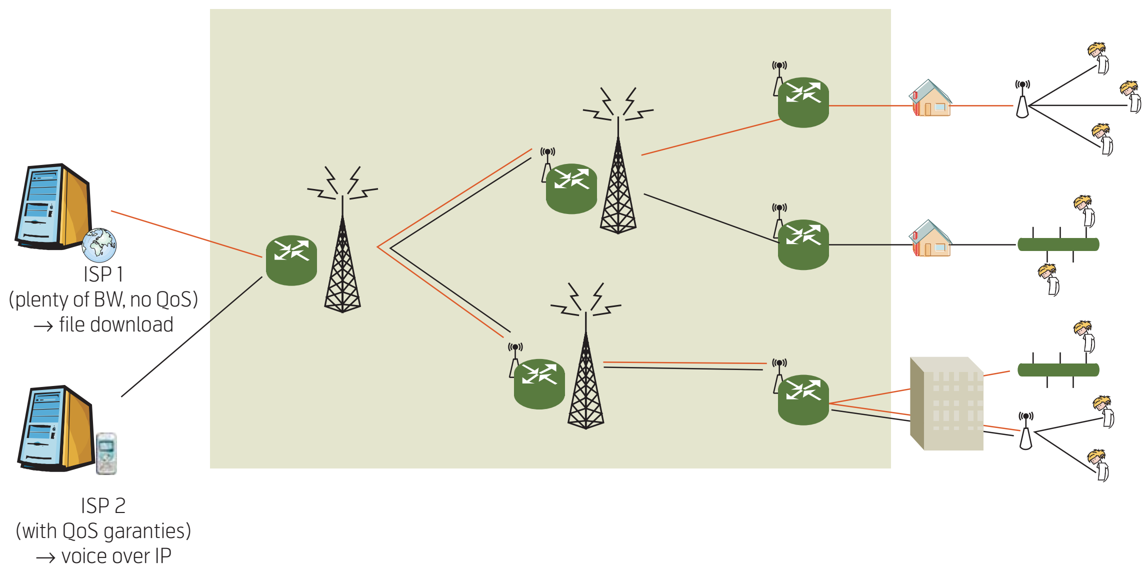

Figure 15 Multiple ISP Support

the DiffServ scheme to provide QoS in the core network are illustrated in Figure 14.

Service providers may offer varying degrees of QoS depending on their service portfolio, see Figure 15. It is then important, from a user perspective, to be able to select the service provider best suited regarding the tailoring of services with required QoS. For example a download can be directed to the ISP that offers lower fees while a VoIP session will go through the ISP that has QoS guarantees.

Some of the links in a hybrid network architecture are constrained by system inherent limitations such as physical propagation delays and/or limited link capacity. In order to circumvent these limitations and to increase the efficiency of the network it is essential to utilise advanced techniques such as performance enhancement proxies, multicast web caching solutions, compression, and improved transport or application protocols. For example, native multicast support in the wireless broadband access networks plays an important role in content delivery by increasing the capacity utilising spectrum efficient techniques. In addition, protocol header compression has been found to be important. Especially with new and bandwidth demanding services such as for example VoIP or IP over cellular links, compression of headers for better bandwidth usage is considered a reasonable alternative to simply increasing available bandwidth. Ultra-light encapsulation (ULE) is another mechanism that should be used to improve the link-layer efficiency for all those services that are based on MPEG-2. Other protocol issues, such as the interoperability between IPv4 and IPv6, and multicast security and multicast accounting related issues are also identified and briefly addressed in [15].

The QoS approach described above, utilising DiffServ, IntServ and multi protocol label switching (MPLS), will affect the lower layers in the protocol stack as well.

The provisioning of QoS in wireless networks, especially the IEEE 802.11 WLAN, which is the widely deployed wireless network by far, is challenging because of the mobility of the hosts and the unpredictable nature of the wireless link. Moreover, the number of different transmission services and the requirements of delay-constrained and mission critical applications such as video and multimedia streaming do complicate the provision of QoS in wireless networks. The layers below, particularly with wireless systems, are also affected as the network layer communicates with the system-specific control application programming interface (API) of the radio resource management (RRM) and/or physical layer.

As spectral efficiency is important in broadband radio networks, channel estimation and adaptation have to be performed to enable delivery of the required QoS during varying link conditions. Power control, adaptive modulation, forward error correction (FEC) schemes and advanced coding techniques are some commonly utilised techniques for increasing spectral efficiency and service availability.

C. Network management

Implementation of efficient network management systems, in particular the structure of a network management system tailored to the specific needs of the network architecture, is discussed in [15]. The management systems used by the wireless or wireline access network are integrated by the following tools: (1) a monitoring system that will supervise the links and access points of the wireless network; (2) a traffic management system that will consist of a management platform able to check the traffic of the users of the network; and (3) a bandwidth management system, an application aimed to control the bandwidth of all the connections existing in a given instant.

Many network management functions may be accomplished by intelligent agents which run on different network devices for different purposes. An intelligent agent is a software program that shows aspects of intelligence and can act independently on behalf of its users. The components of the proposed intelligent agent system for network management in the BROADWAN project include auto-configuration agents, proxy-interceptor agents, multicast address allocation agents, service discovery agents and QoS assurance agents. The intelligent agents' functions are different from each other. For example, the multicast address allocation agent is used to acquire a suitable multicast address for its hosting node, and a service discovery agent enables users and applications to find and/or access other services in the network.

D. Mobility and nomadic users

Mobile and nomadic computers and devices are currently becoming a significant population of the Internet, a trend that is likely to increase even more in the future. These nodes are likely to change their location and point of attachment to the network frequently. In order to retain existing connections on the transport layer and higher up, the nodes need to keep their IP address the same over these changes in connectivity.

IPv6 is the universal next-generation Internet protocol after IPv4, with many advantages over its predecessor. Mobility support for end-user devices is included in the protocol, which is becoming more and more important as portable devices acquire increasing popularity. This also allows for additional integration

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with the 3G/4G mobile world, and thus provides the basis for the development of a unified, "All-IP" communication standard.

Routing decisions are based on the subnet prefix of the packet destination IP address. When a mobile node is not attached to its home link, which is the link where the node's home IPv6 subnet prefix exists, packets destined for this node would continue to flow towards the home link and not reach the node at its foreign location. Without IPv6 mobility support, a mobile node would thus have to change its IP address every time the node moves to a new link and lose all existing connections, failing to provide a smooth transition to the new access network.

With support for mobile Internet protocol version 6 (MIPv6, [16]), a mobile node can move from one link to another without changing the mobile node's IP address. IPv6 mobility assigns an IP address to the mobile node within its home subnet prefix on its home link. This address is known as the node's home address. Packets that are routed to the mobile node's home address are forwarded and do reach their destination. The mobile node's current point of attachment to the Internet does not matter; the mobile node can continue to communicate with other nodes, whether stationary or mobile, after moving to a new link. Thus, IPv6 mobility solves the problem of transparently routing packets to and from mobile nodes while away from home. It allows users to keep the same Internet address all over the world, and applications using that address to maintain transport and upper-layer connections when the mobile node changes locations. It allows mobility across homogeneous and hybrid media, for example from an Ethernet segment to a wireless LAN cell, with the mobile node's IP address remaining unchanged.

In MIPV6 each mobile node is identified by two IP addresses: its home address and its "care-of" address. The home address is a permanent IP address that identifies the mobile node regardless of its location. The care-of address changes at each new point of attachment, and provides information about the mobile node's current location. When a mobile node arrives in a visited network, it must acquire a care-of address, which will be used during the time that the mobile node is under this location in the visited network. Any address allocation method can be used, such as IPv6 neighbourhood discovery, both stateless and stateful auto-configuration, or manual configuration [15].

MIPv6 does not solve all the problems related to the use of mobile computers or wireless networks. In particular, IPv6 mobility does not attempt to solve the following problems:

- The ability to handle links with partial reachability, which is the case for typical wireless networks. However, a movement detection procedure addresses some aspects;

- Access control on a link that is being visited by a mobile node.

1. Location of home agents

The main issue with MIPv6 support in the hybrid networks is the right location of the home agent within the network. Being a functionality module that might be implemented as part of an existing network infrastructure node, most likely a router, or on a dedicated machine serving just that very purpose, it has to be available on (sub-) networks that serve mobile nodes as home networks. Home network in this context is defined by the network prefix (netmask) of the respective segments and thus of the nodes requiring mobile access.

There must be at least one home agent configured on the home network, and the mobile node must be configured to know the IP address of its home agent. Location of the home agent is dependent on the actual global IPv6 address assigned to the mobile node, as it has to be on that network. This means there are two possible scenarios depending on who was responsible for the mobile node's global IPv6 address:

- The user connecting router (UCR) has to incorporate the home agent functionality;

- The backbone attaching router (BAR) or a node in the Internet provider's backbone network provides home agent functionality.

If the ISP's responsibility extends to the UCR, the first case would be the preferred solution. Otherwise, the mobility would have to be provided out of the backbone, the second solution. In this case it makes sense to include hierarchical mobile IPv6 (HMIPv6, [17]) as described below. Figure 16 illustrates these two potential home agent locations, including the hierarchical approach.

HMIPv6 is the proposed enhancement of MIPv6 that is designed to reduce the amount of signalling required and to improve hand-off speed for mobile connections. MIPv6 defines a means of managing global (inter-site) mobility, but does not address the issue of local (intra-site) mobility separately. Instead, it uses the same mechanisms in both cases, which is an inefficient use of resources in the case of local mobility. HMIPv6 adds another level built on MIPv6, separating local from global mobility. In HMIPv6,

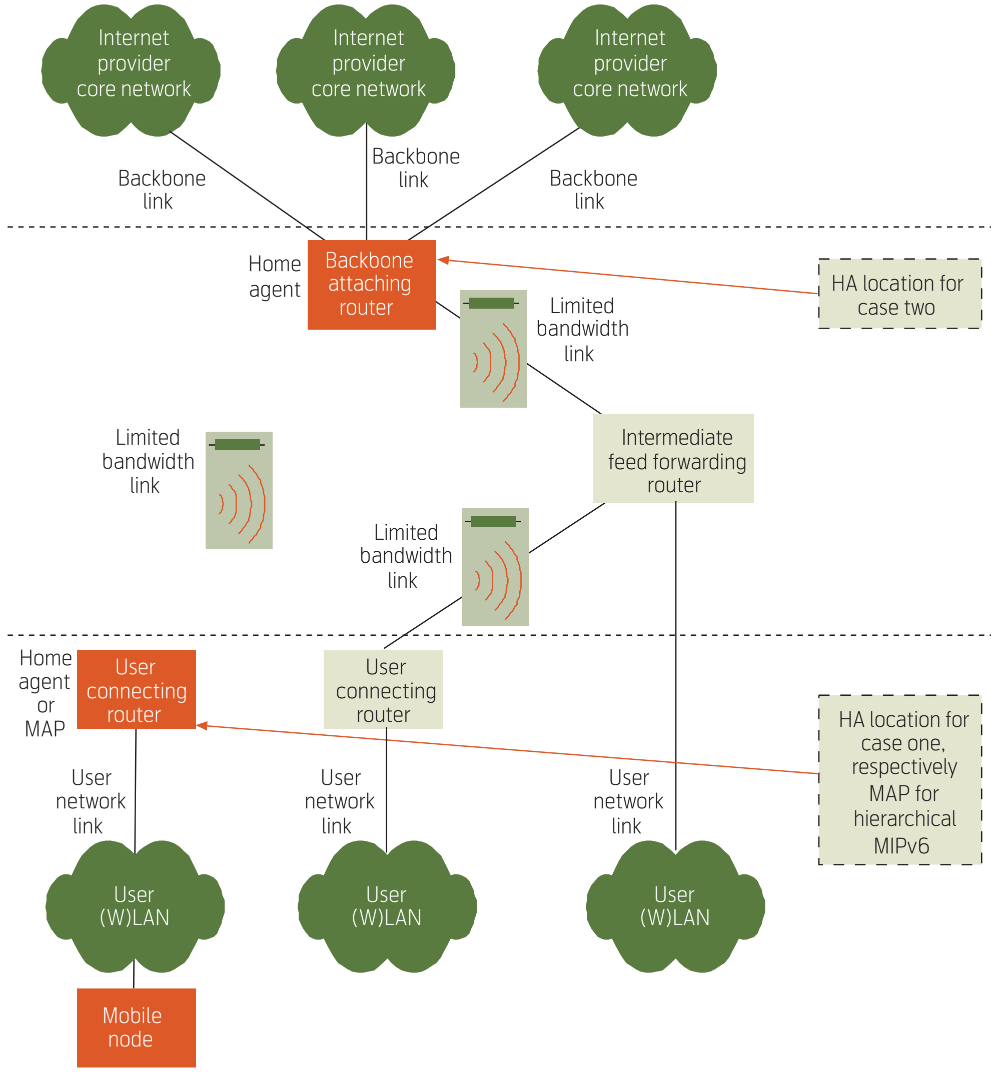

Figure 16 Potential home agent locations

global mobility is managed by the MIPv6 protocols, while local hand-offs are managed locally.

A new node in HMIPv6 – called the mobility anchor point (MAP) – serves as a local entity to aid in mobile hand-offs. The MAP can be located anywhere within a hierarchy of routers; there is no requirement for a MAP to reside on each subnet. The MAP helps to decrease hand-off-related latency because a local MAP can be updated more quickly than a remote home agent.

Using MIPv6, a mobile node sends location updates to any node it corresponds with each time it changes its location, and at intermittent intervals otherwise. This involves a lot of signalling and processing and requires a lot of resources. Furthermore, although it is not necessary for external hosts to be updated when a mobile node moves locally, these updates occur for both local and global moves. By separating global and local mobility, HMIPv6 makes it possible to deal with either situation appropriately.

E. Security

The users expect their privacy to be protected, including security mechanisms for authentication, integrity, access control, and confidentiality. The security issues are considered imperative to ensure take up of broadband services by the general public, as transfer of personal and confidential information is a prerequisite for a vast number of public and commercial services such as *e*Health and *e*Government.

Service and network provider has to make sure that their systems provide adequate protection against unauthorised access and in addition the protection of information when transmitting data and also the security of the electronic messages and files stored on central servers. Data transmitted on wireless networks instead of through wirelines is inherently easier to intercept. A wider area of security includes avoidance

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of identity theft, hackers, viruses, spam, and also protection of intellectual property rights. In the following subsections a discussion of network layer security provided by IPsec versus security provided by other layers are given.

1. IPsec network layer security versus encryption on other layers

It is important to trade off the simplicity of concentrating security on one layer against the advantages of a security scheme that spreads across layers. Candidates for responsibilities within the overall security scheme in addition to the network layer are the neighbouring layers; link layer and transport layer. Secure Internet protocol (IPsec, [18]) operates on the network layer, layer 3 according to the OSI reference model.

Link layer security is specific to a single link or single hop. Replacing a network layer security scheme such as IPsec with security on link layer would require every utilised link layer technology to provide the respective tools and mechanisms. Unfortunately this is not the case, particularly not if a strong security scheme based on session keys and authenticity is considered a requirement. As a conclusion, it is proposed that hybrid networks could apply link layer security wherever suitable mechanisms exist and wherever content is particularly exposed, such as on wireless links in general, but shall only be considered supportive to some higher layer security scheme.

It is widely assumed that security mechanisms provided within or as an extension of the transport layer (layer 4), as known from secure sockets layer (SSL) or transport layer security (TLS), should be the preferred solution. Even though this would guarantee end-to-end security at a level perfectly tailored to the particular service or application requiring it, it would also raise a number of issues that would need to be addressed. Every single user would need to become familiar with the issues of security, how to enable it, how to use it, and how to assess it. If the user is granted the freedom of choice, respective educational measures should certainly be considered. Applications and services would need to be adopted rather than the network infrastructure. Of course, it can be argued that services not requiring security today will not require it in the future. However, a network architecture consisting of a multitude of wireless links may jeopardise this point of view. Security schemes on layer 4 can be considered as valuable supplements to IPsec, but will as a single measure be unable to fulfil comprehensive security requirement.

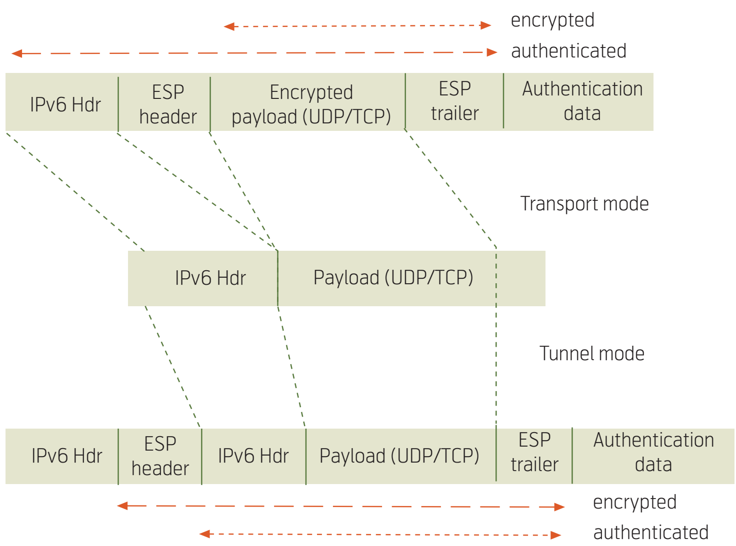

Figure 17 IPsec transport versus tunnel mode packet encapsulation (ESP)

2. Network layer security

IPsec is a well-defined security scheme for IPv6-based protocols that may be employed within the access networks. Infrastructural requirements to provide IP security, the trade-off of the advantages versus the problems introduced by IPsec, and also overhead considerations when mapping IPsec schemes to the network, are important issues that need to be considered by an operator [15].

While IPsec-based security would have to be retrofitted into the IPv4 protocol suite, it is an integral part of IPv6. The specification of IPv6 includes two types of security payloads, the *authentication header* (AH), providing a mechanism that enables the recipient to make sure the sender address is authentic and that the packet's content has not been modified during transmission, and the *encryption security payload* (ESP), ensuring that only the legitimate recipient is able to decrypt and read the packet. Both mechanisms are based on the concept of *security associations* (SA). A security association is the set of *security contexts*, each consisting of key (secret), algorithm, security lifetime, protocol mode, and other parameters related to the particular one-way security relationship between sender and recipient. It is essential that all network nodes that are required to handle IPsec support the ESP header. Even if authentication without payload encryption is sufficient, ESP can and shall be used as AH header support will generally be phased out in the future.

IPsec, regardless of the utilised security scheme – AH or ESP, can be operated in two modes: *transport mode* and *tunnel mode*, see Figure 17.

Transport mode requires the terminals involved in the secure communications, i.e. source and destination, to be IPsec-enabled. The IP packets are encrypted or signed at the originating host, without any modification to the secured payload at intermediate nodes, and decrypted or checked at the receiving terminal. The secure segment includes all links along the path of a packet (end-to-end security).

The tunnel mode, in contrast, implements the ingress and egress points into and from the secure segment of the path on some intermediate nodes. The terminals, emitting and receiving the packets are not required to be aware of IPsec. The primary purpose of the tunnel mode is to protect specifically exposed segments of the network, in particular wireless links or paths through public networks.

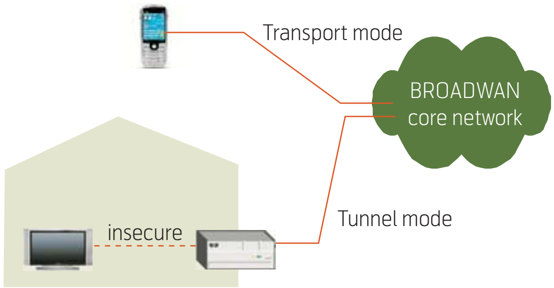

Figure 18 Secure network boundary for mobile and fixed devices

Whether particular segments or subnets of the hybrid network support transport or tunnel mode is mainly depending on the types of terminals and the environments in which they are operated. A mobile device running a service that requires secure transportation of data will need to support end-to-end security, i.e. transport mode, whereas a device which is part of a fixed home network may operate completely agnostic of secure data transport, relying on the edge device of the network, the user connecting router, to perform the necessary negotiations and packet encapsulation, see Figure 18.

V. Conclusion

Hybrid wireless and wireline access network technologies are well suited to providing broadband access everywhere with enhanced performance in term of coverage, capacity and throughput compared to access networks based on a single technology. This paper addresses the design of a hybrid network architecture to provide full broadband coverage. The focus is on the efficient combination of wireless and wireline networks in areas ranging from urban to rural and remote areas. Both access and backhaul solutions are addressed based on service requirements and the requested transmission capacity in the area.

Wireless broadband technologies have implicit advantages such as an ability to serve the customer everywhere and mitigate the digital divide, they are scalable in both capacity and coverage areas, an imperative as requested services evolve towards increasingly bandwidth hungry applications. Broadband fixed wireless access systems, in licensed and license-exempt bands, are presented as attractive solutions for providing broadband services for fixed and nomadic users. Interoperability of hybrid networks is a key design objective to drive solution costs down. Internet Protocol version 6 has been chosen as the convergence layer in the hybrid network. An IPv6 based protocol architecture including quality-of-service is presented, comprising features such as multicast, security, mobility, auto configuration and intelligent agents for network management. Conclusions show that hybrid architectures, combining the advantages of the different wireless and wireline technologies, are central in delivering broadband services everywhere.

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References

1 National Broadband Task Force. *The new national dream: Networking the nation for broadband access*. Canada Government, Industry Canada, 2001. (Available from broadband.gc.ca)

2 Tjelta, T, Bråten, L E, Howson, C, Montalant, T. Development and role of broadband wireless access networks for fixed and nomadic users. *Int. J. Mobile Network Design and Innovation*, 1 (1), 2005.

3 Bråten, L E, Tardy, I, Nordbotten, A, Elek, Z, Morozova, A. Future broadband access networks. Trends in user and service requirements. In: *Proceedings of Shaping the Broadband Society – users and services, SBS 2004*, Cetubal, 24–25 August 2004.

4 Ebert, J (ed), Frigyes, I, Kastner-Puschl, S, van Dijk, F, Gonzalez, C, Tardy, I, Bråten, L E, Elnegaard, N, Haslestad, T. *Enhanced Broadband Wireless Architectures*. BROADWAN Deliverable D33, May 2006. Available from www.broadwan.org.

5 Tardy, I (ed) et al. *Interconnected networks architecture*. BROADWAN Deliverable D14, Nov. 2004. Available from www.broadwan.org.

6 Ramahandry, T (ed), Montagne, R, Bråten, L E, Elnegaard, N, Seseña, J. *Business opportunities for broadband wireless solutions*. BROADWAN Deliverable D34, May 2006. Available from www.broadwan.org.

7 Allen, S M (ed), Taplin, R K, Ryan, D M, Hurley, S, Thomas, N J. *A demonstration of an automatic heterogeneous network planning tool*. BROADWAN Deliverable D18, May 2005. Available from www.broadwan.org.

8 Tardy, I (ed) et al. *Planning guidelines for broadband access networks with case studies*. BROADWAN Deliverable D21, May 2006. Available from www.broadwan.org.

9 Topman, M (ed) et al. *Coverage and Capacity provided by Wireless Access Networks*. BROADWAN Deliverable D22, Nov. 2005. Available from www.broadwan.org.

10 Braden, R, Clark, D, Shenker, S. *Integrated Services in the Internet Architecture: an overview*. IETF RFC 1633, June 1994.

11 Black, D, Blake, S, Carlson, M, Davies, E, Wang, Z, Weiss, W. *An Architecture for Differentiated Services*. IETF RFC 2475, Dec. 1998.

12 Braden, R et al. *Resource Reservation Protocol (RSVP) – Version 1 Functional Specification*. IETF, RFC 2205, Sep. 1997.

13 Wroclawski, J. *The Use of RSVP with IETF Integrated Services*. RFC 2210, Sep. 1997.

14 Bernet, Ford, P, Yavatkar, R, Baker, F, Zhang, L, Speer, M, Braden, R, Davie, B, Wroclawski, J, Felstaine, E. *A Framework for Integrated Services Operation over DiffServ Networks*. IETF RFC 2998, Nov. 2000.

15 Brauneis, W (ed) et al. *Interconnected networks, protocols and agents*. BROADWAN Deliverable D32, Dec. 2005. Available from www.broadwan.org.

16 Patel, A, Leung, K, Khalil, M, Akhtar, H, Chowdhury, K. *Mobile Node Identifier Option for Mobile IPv6 (MIPv6)*. IETF RFC 4283, Nov. 2005.

17 Soliman, Castelluccia, C, El Malki, K, Bellier, L. *Hierarchical Mobile IPv6 Mobility Management*. IETF RFC 4140, Aug. 2005.

18 Kent, S, Seo, K. *Security Architecture for the Internet Protocol*. IETF RFC 4301, Dec. 2005.

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Interoperability issues for hybrid access and backhaul networks

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The BROADWAN project aimed at developing cost-efficient, often hybrid, networks to obtain full coverage and high capacity for providing broadband services to all. This paper focuses on identifying key interoperability factors enabling successful communications between users across a variety of broadband wireless and wireline access and backhaul networks.

Given the complexity of the topic, the paper cannot be exhaustive, but rather points at the issues necessary to tackle interoperability in an anywhere-anyway scenario towards the cognitive interoperability concept. The main enablers and barriers for interoperability are considered and some specific and relevant interoperability case studies are analyzed.

This paper is based on work undertaken in the BROADWAN project, partly funded under the Information Society Technologies (IST) priority of the European Commission Sixth Framework Programme.

1 Trends towards converged services and networks

The telecom market is at a turning point. New players and partnerships are emerging and competition is ever increasing. Internet is challenging the traditional telecommunication infrastructure. In this environment operators are exploring different ways to increase revenue, reducing operating cost, providing solutions for reducing churn.

End user behavior is changing, emerging nomadic lifestyles increasing the ownership of personal and portable and multi-functions type devices (terminals are becoming a digital ”Swiss knife”), growing needs of anytime-anywhere connection – also when on the move – in the best possible way regardless of the connection. Segmentation, differentiation and customization have become a necessity to fulfill different consumer categories in an increasingly competitive market [1]. Moreover users expect reliability and guaranteed connection quality, independent of the access. From a security point of view, users expect no virus, no worms, no fraud, nobody listening in. Seamless services, as well as authorization, billing and charging in wireless access networks require developments as well as standardized architecture components and functionality. As compared with a decade ago the end user focus has gained increased importance [2].

Increased competition is visible also from a technology perspective. New wireless techniques like WiMAX, Flash OFDM, UMTS with the support of HSDPA, Mobile Broadband over WCDMA, with more or less ability to offer “3G-like” services are emerging. Moreover other important converged services are now available, such as triple play and WLAN plus 2G/3G bundled subscriptions. The development of wireless technologies has reached an important breakpoint where it is an enabler for true converged services, meaning that the same end user service can be reached via both fixed and mobile access and the same user interface [3].

While technology was a limiting factor a decade ago, it has today reached a level of maturity that enables convergent services, terminals and networks. The availability of open source and open standards facilitates the use of new technologies. The operators, service providers and vendors able to take advantage of the new technologies and combine them will be tomorrow’s winners.

2 Hybrid architecture and converging networks

In today’s competitive business environment, network architectures should evolve in order to provide efficiency scalability and flexibility for adjusting unpredictable workloads. The trend is toward a structured network with independent *functional* areas of connectivity, control and services. In this way, when the operator wants to introduce new services or equipment into one layer, fixed or mobile, it is not necessary to re-engineer the entire network, as depicted in Figure 1, or completely replace the hardware. This converged approach will give the operator much greater flexibility and the possibility to response to market demands even quicker [1].

The network architecture enables high quality services to traverse different segments of the network: the core network, the distribution/aggregation network, also called backhaul network, and the access networks. There are a number of different technologies, both wireless and wireline, available for the three main components of the network, as shown in Figure 2.

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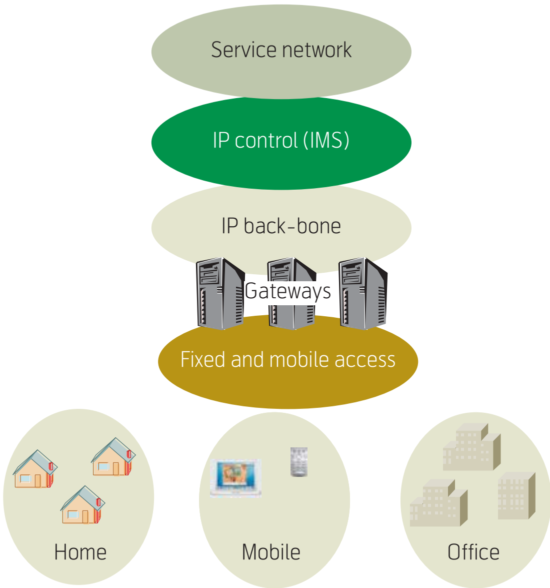

Figure 1 An example of multi-service multi-access layered network architecture

The various access, distribution and core network technologies include, but are not limited to:

- Wireless: Digital Terrestrial Television (DTT), Broadband Fixed Wireless Access (BFWA), Wireless Local Area Networks (WLAN), Free SpaceOptics (FSO), Satellite and Stratospheric platforms.
- Wireline: copper pair (for example xDSL), optical fibre, coaxial and power-line cable.

By suitably exploiting and combining the capabilities of all these different technologies, the resulting broadband network architecture should be able to provide high capacity for true broadband services (i.e. ADSL-like services with extension to nomadic users, full triple play delivering telephony, data and video on the same network and the ability for demanding return channel applications) and global coverage including also rural areas, at an affordable cost. In order to fulfill this goal the different technologies and systems, encompassing the depicted hybrid network scenario considered in the BROADWAN project, [4], have to properly inter-work with each other. Interoperability has therefore become of paramount importance for delivering broadband services to all.

Interoperability between backhaul and access network – vertical interoperability – as well as interoperability between different access networks – horizontal interoperability – have to be ensured. Examples of vertical interoperability include 40 GHz high capacity BFWA in the access part of the network that feed lower capacity base stations, including base stations in mobile networks (UMTS/GSM, 4G), 5 GHz WMAN base stations (such as WiMAX) in a dual layer access network architecture and WLAN zones. The (backhaul) fibre or radio over fibre must inter-

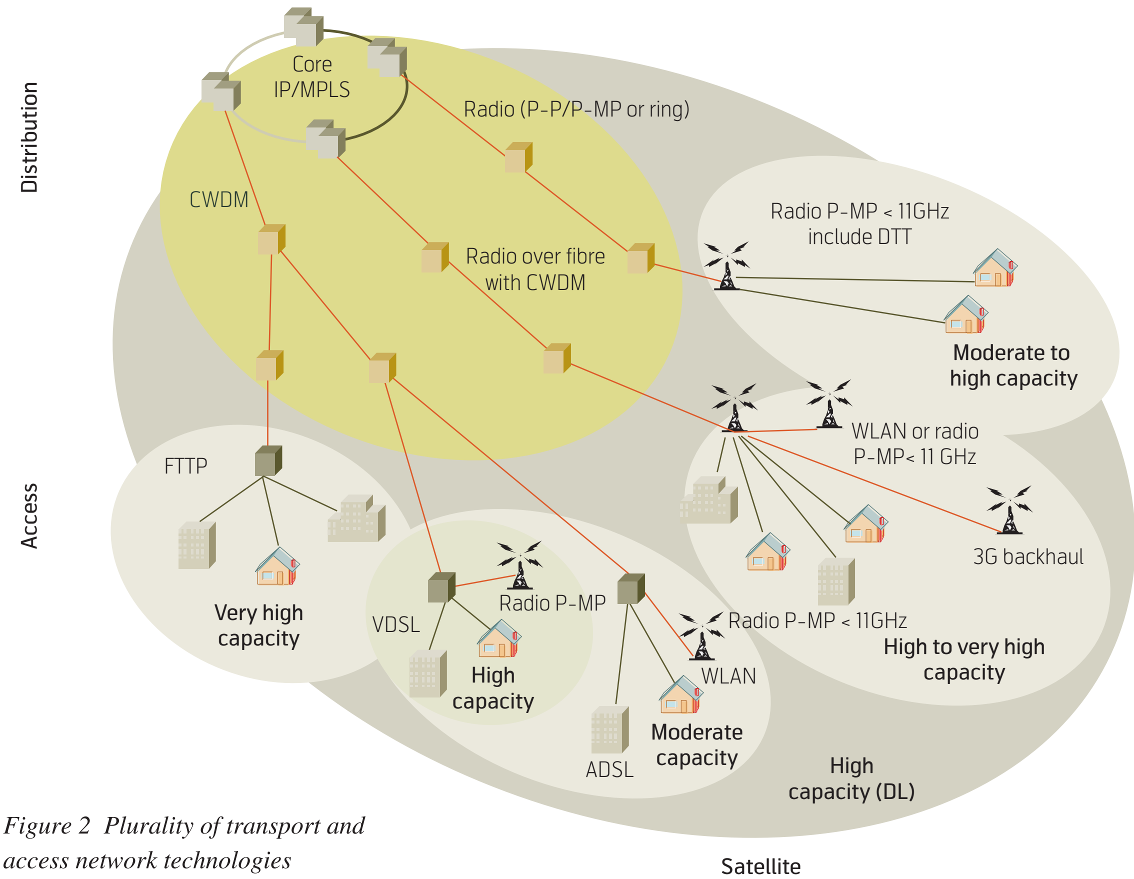

Figure 2 Plurality of transport and access network technologies

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operate with 40 GHz wireless networks, which in turn must interoperate with the lower frequency local area network. In-house distribution of a high-capacity wireless system can also be done by wired technologies, particularly in dwellings. An example of horizontal interoperability is customer premise equipment (CPE) that is compatible with 40 GHz access, 5 GHz access and WLAN. Nomadic usage of a (fixed) BFWA network is another example of horizontal interoperability where the available capacity of a WMAN network can be dedicated to the nomadic users, [5],[6],[7].

The interoperability of such diverse networks imposes a number of challenges regarding service provision and management (including Authentication, Authorization Accounting, AAA). Interoperability basically requires connection to the network everywhere and easily, unique authentication mechanisms and handover, which means end-to-end connectivity. Moreover users want security to be kept at the same level regardless of the number of technology or network crossed. The end-to-end quality of service (QoS) management implies that features such as service scalability between different networks have to be available. In (wireless) multicast situations this feature is also required between base stations and individual users to account for various transmission capabilities in the access network, [8].

Due to the complexity and wide scope of the interoperability concept, there is no silver bullet solution but it needs to be addressed on multiple fronts. The main barriers and enablers for interoperability are then analyzed and finally some relevant case studies are considered.

3 Enablers for interoperability

In this challenging context, there are some important key enablers for interoperability, most notably associated with the widespread diffusion of IPv6, Ethernet, IMS, open architectures and standardized interfaces, open source software.

3.1 All-IP architecture

It is widely recognized that the IP paradigm is used in almost all areas of communication. The interworking of IP protocols allowing a seamless, end-to-end connectivity between all types of endpoint and network devices is of paramount importance [9]. A common IP-based network enables a number of common functions and, therefore, reduces operating costs. The potential savings for operators are substantial and one of the most important drivers for network convergence. Ethernet is a key factor for interoperability since Ethernet has become the dominant transport and interconnection technology in metropolitan areas, wide areas and core networks due to its simplicity, cost effectiveness, scalability and familiarity to customers. Ethernet, being a packet-based technology, complements IP-based services and perfectly suits the “all IP scenario”, as that one envisaged in the BROADWAN project. On the other hand, although new Ethernet services (e.g. E-line, E-LAN) are now offered by a wide range of service providers, the challenge is to prove that Ethernet is really a carrier grade technology, offering scalable, trustable traffic segregation, resilience, multiservice and OAM capabilities also beyond the metropolitan and across wide area networks.

IPv6 is the convergence layer potentially enabling interoperability at the IP layer and above [10], [11]. In particular it facilitates the end-to-end quality control, roaming and nomadic access due to its features such as extending addressing modes and automatic configuration and multicast functionalities. However, IPv4 to IPv6 migration is still considered on open issue to be solved, particularly as far as IPv4/IPv6 multicast interoperability is concerned. Interoperability between IPv4 and IPv6 hosts and networks is usually easily feasible if a host is dual stack equipped. Most nodes will actually support both protocols and will be able to communicate via both IPv4 and IPv6 multicast. If all participants supply the same protocol then this raises no serious problems, except that tunnels through parts of the network may have to be established. However, problems arise when a node only supports IPv4 multicast and wants to participate in an IPv6 multicast group and vice versa. Translation between the two multicast protocols involved might be needed in some cases. A number of translation techniques have been defined for unicast (such as SIIT and NAT-PT [12],[13]), but there is still a lack of functional and scalable multicast translation techniques.

3.2 IMS

3GPP (Third Generation Partnership Project), in collaboration with IETF and OMA, has defined in its release 5 the IP Multimedia Subsystem (IMS) that is a standard based architecture both for circuit switched services, like VoIP, and multimedia services, enabling a secure migration towards all IP architecture. IMS was initially developed by the 3GPP and 3GPP2 organizations, as an IP core network architecture for cellular/wireless. Now it is being embraced also by other standard bodies including ETSI/TISPAN and supported by industry leaders for converged services from all types of services

– wireless, wireline cable and applications. The standard in fact supports multiple access types including GSM, WCDMA, CDMA2000, wireline and wireless broadband access and WLAN [14].

IMS provides session layer control functionalities that establish, modify and release sessions in IP networks. The protocols defined in IMS address the session, the media and the security, and authentication. IMS is not a vertically integrated communication system. The IMS defines an overlay control layer on top of IP-based fixed and mobile networks, which enables the seamless provision of multimedia services. IMS provides signalling to control real time multi-media services for the packet domain in UMTS networks and allows for smooth integration of new IP-based services (e.g. Voice over IP). The major signalling protocol used is IETF Session Initiation Protocol (SIP). The Session Initiation Protocol (SIP) establishes, modifies and terminates multimedia sessions. Real-Time Protocol (RTP) and Real-Time Control Protocol (RTCP) timestamp IP packets and synchronize them to a reference clock that is of particular interest for video delivery. Authentication functions are added as well.

IMS defines a set of components:

- Call Session Control Function (CSCF), which acts as Proxy CSCF (P-CSCF) in Visited network, Serving CSCF (S-CSCF) in Home network or Interrogating CSCF (I-CSCF) in Home network, to route and control the session establishment;

- Home Subscriber Server (HSS) with AAA functionality and unique service profile for each user;

- Media Gateway Control Function (MGCF) with Signalling Gateway, which controls Media Gateway and performs protocol conversion between ISUP and SIP;

- Media Gateway (MGW), which interacts with MGCF for resource control;

- Multimedia Resource Function (MRF), which controls media stream resources;

- Breakout Gateway Control Function (BGCF), which selects the network in which PSTN breakout is to occur;

- Application Servers (AS), which offer value added services.

The IMS architecture allows service interoperability and roaming and provides bearer control, charging and security. It is a cornerstone for interoperability in a converged networks and services scenario.

3.3 Standardizations

Operators are experiencing an increasing need for interoperable solutions in order to fulfil their requirements of flexibility in deployment of their infrastructures, possibly using equipment provided by different vendors, and integrating different technologies. At the other end users also claim their needs for interoperable solutions. Open standards are key to enabling interoperability and promote the widespread adoption of wireless technologies. Interoperable standards result in higher volumes and hence lower equipment costs.

Several standardisation bodies have defined tasks that focus on interoperability issues. These include IETF, IEEE 802.21 (analyzing handover and interoperability between heterogeneous network types including both 802 and non-802 networks), IEEE802.16 and IEEE 802.11 family standards for WiMAX and WLAN systems, respectively, ITU-T, ETSI HIPERACCESS, HIPERLAN, HIPERMAN, 3GPP and 3GPP2 [5].

Besides the organizations for the development of standards, there are also regulatory bodies, government bodies that may have an impact on frequency allocation, legal issues to promote competition and innovation, and rules for both private and public use of technologies. There is also a growing number of trade associations of vendors and manufacturers that associate in order to achieve interoperable products, promote and market the technology, collaborate with standards and regulatory bodies to facilitate deployment.

4 Barriers for interoperability

4.1 Proprietary solutions vs. standardization

Given the complexity of the scenario and the number of involved standardisation bodies, convergence towards a real common shared view is not a trivial task. In spite of efforts already dedicated to this subject by different standardisation bodies, it is a matter of fact that full and end-to-end interoperability is still far from reality. Many off-the-shelf proprietary solutions handling very limited interoperability hinder rapid development of seamless solutions.

An uneasy tension has always existed between innovation and standards or interoperability. This tension makes it difficult for everything to work well together, with entrenched interests often pledging support for interoperable standards while at the same time pushing their proprietary "enhancements", maneuvering that is totally rational from a business perspective.

4.2 Spectrum regulations

The seeming abundance of spectrum poses some limitations to interoperability. As an example, in the case of WiMAX systems spectrum regulations represent one of the most important barriers to interoperability. Little common spectrum is available in all the countries and moreover a multiple spectrum choice (also in licensed and license exempt bands) has resulted in incompatibility or the need for multi band devices.

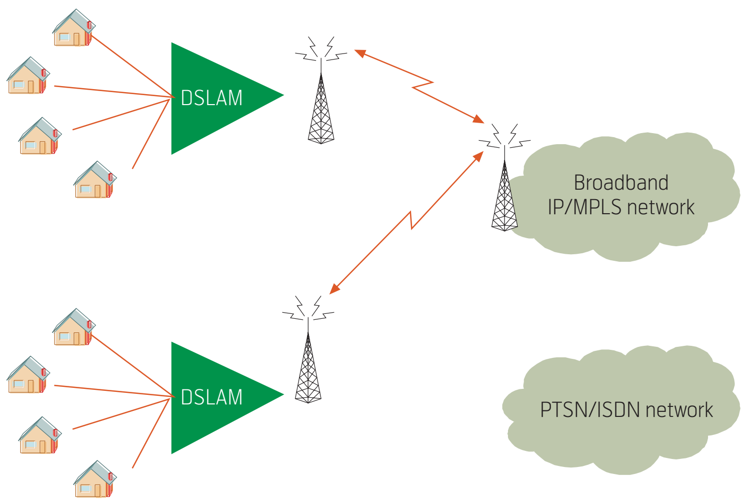

Figure 3 Hybrid DSLAM/BFWA scenario

5 From theory to practice: Interoperability scenarios

Two cases of significant and immediate interest are now presented and illustrate the complexity of vertical and horizontal interoperability. The first one is BFWA as an extension of ADSL, the second horizontal interoperability of BFWA, WLAN and mobile networks, [5].

5.1 BFWA to extend DSL coverage

It is a matter of fact that a significant number of European citizens are outside the possible coverage for current digital subscriber line and cable access technologies. Asymmetric Digital Subscriber Line broadband technology (ADSL) expansion is mainly confined to cities and high density populated areas for economic reasons, particularly ADSL2+. It is expensive to lay optic fibre to DSL nodes with a small number of subscribers in rural or less developed areas. However, a combined ADSL and BFWA scenario can provide a fast and economic alternative to provide full coverage and mitigate the digital divide [15].

The ADSL lines from the homes are gathered in an access node, called a DSL Access Multiplexor (DSLAM), which separates voice and conveys data from an Ethernet switch to the nearest broadband router or local switch. Typically, the second mile or backhaul is the problem, particularly in rural areas. BFWA can be used as high capacity backhaul networks for DSLAM, allowing operators to save both money and time and provide flexibility and scalability to easily move a link or add higher capacity when required, as depicted in Figure 3.

This is an especially attractive solution in combination with micro DSLAMs placed in street cabinets, where wired feeders may be more expensive. Moreover, alternative spared capacity in the DSL wired access may be used as feeder links for BFWA to extend the DSL coverage and enable nomadic usage. This is already in practical use where neighbors share an ADSL connection distributed locally by WLAN, or simply to fulfill the demand for higher available bandwidth.

To provide an efficient hybrid DSLAM/BFWA architecture major interoperability issues have to be considered, mainly dealing with end-to-end QoS and security, [5]. Figure 4 shows the path followed by a packet across a protocol stack.

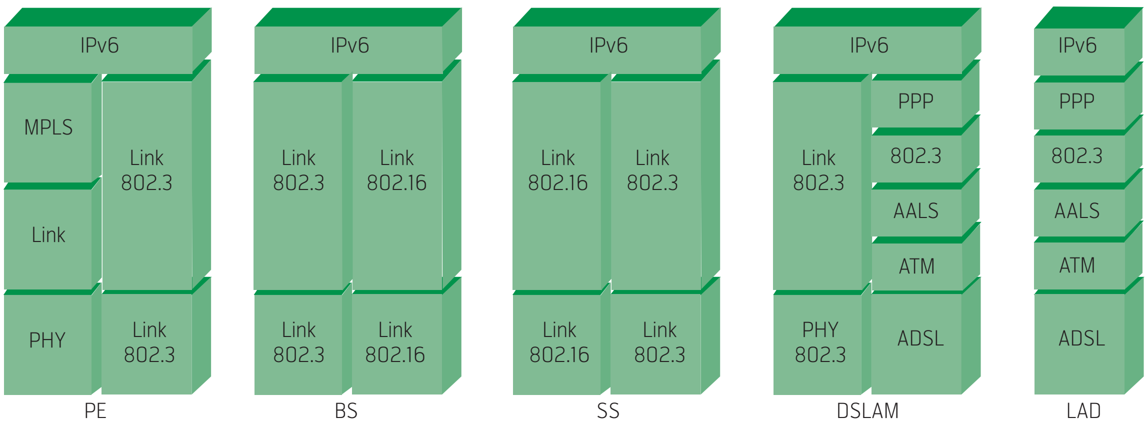

Figure 4 Protocols stack from a DSL client to the IP/MPLS core network

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As we assume the chosen convergence layer is IPv6 in this heterogeneous environment QoS mechanisms in both interconnections DSL/BFWA802.16)/ Core(IP/DiffServ/MPLS) systems will have to be mapped through the IPV6 layer, while the latency due to the transition across the hybrid system should be as low as possible (e.g. < 50 ms). So, routing and priority rules have to consider the IPv6 header fields and a mapping (wired-to-wireless side) between the priority classes of IPv6 packets and the QoS classes defined in MAC layer is required.

There will be

- Filtering rules to select the IPv6 packets based on “traffic class” field and eventually on “flow label” field;
- Priority-based queues for each QoS class defined in MAC layer;
- Scheduling policy able to handle these queues that ensures the required QoS for a certain flow.

On the other hand (wireless-to-wired) the MAC QoS classes have to be mapped with some values of the IPv6 , “traffic class” field and eventually “flow label” field, so that the IPv6 packets can be handled in the IP domain according to the required QoS.

In other words Layer 2 QoS mechanisms have to interoperate with DiffServ mechanisms in order to meet layer 3 demands, Classes of services based on DiffServ classification (e.g. Expedited forwarding (EF), Assured Forwarding 1 (AF1), Assured Forwarding 2 (AF2) and Best Effort (BE), should be mapped with Classes of Service defined in 802.16 standard (Unsolicited Grant Service (UGS), Real Time Polling Service (rtPS), Non Real Time Polling Service (nrtPS), and Best Effort (BE)) and with ATM based traffic classification (Constant Bit Rate (CBR), Real Time Variable Bit Rate, rt VBR, Unspecified Bit Rate, UBR+, UBR) and IPv4 and IPv6 interoperability issues should be considered.

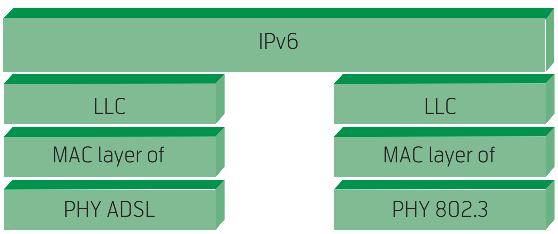

Figure 5 Protocol Stacks in an Ethernet ADSL2 + DSLAM

We are witnessing a growing interest for IP/Ethernet based DSLAMs allowing to maximise IP aggregation closer to the end user and minimising transport costs. As we assume that the DSLAM is an advanced ADSL2+, using Ethernet instead of ATM technology, the four layers indicated in Figure 3 (ATM, AAL5, 802.3 link and PPP) would be replaced simply by the link layer of Ethernet, typically installed at the customer’s site. Figure 5 shows the protocol stack in an Ethernet ADSL2+ DSLAM.

Concerning authentication today, ADSL still uses PPP tunnels, which produce overhead and lead to bandwidth wasting. The idea is to move to a unique secure port based authentication mechanism, like 802.1x, which would improve bandwidth efficiency and relies on the Ethernet layer.

End-to-end security can in principle be achieved with IPsec included in IPv6, independent of lower layer, but interoperability issues with IPv4 devices should be considered.

5.2 Interoperability of BFWA, WLAN and mobile networks

A second example of horizontal interoperability in a heterogeneous scenario encompassing fixed radio solutions like BFWA and WLAN and 2G/3G mobile radio systems is presented in this section. Each of these networks had been developed separately for specific purposes, but the idea of combining them to lower costs and extending services is gaining momentum [15].

In particular both cellular and WLAN operators are experiencing a need for increased backhaul capacity, as the number of new subscribers grows and new bandwidth consuming services become available. Today backhaul cost represents a significant percentage (up to 20–30 %) of the total network Operating Expenditure (OPEX). Traditional backhaul solutions are typically based on static dedicated and costly point-to-point leased lines or radio links. As a result, it is clear that both manufacturers and operators are investigating and developing new technologies in order to reduce operative cost and increase efficiency of backhaul solutions.

Point-to-multipoint BFWA systems have interesting features that favorably apply both for broadband access and for a backhaul network infrastructure. Their coverage area is in the range of a few kilometers depending on the adopted systems and environmental conditions, allowing the operators to flexibly locate the base stations anywhere within the coverage area. Moreover a point-to-multipoint architecture facilitates a scalable extension of the network in a cellular manner and reduces antenna visual pollution, especially in areas where the density of telecommunications equipment is high such as in urban zones.

In the framework of the BROADWAN project two different technological solutions for wireless backhaul based on point-to-multipoint (PMP) radio systems are considered:

- New generation high capacity PMP radio systems operating in the 40 GHz band;
- Below 20 GHz solutions (e.g. WiMAX systems) exploiting non line-of-sight or nearly non line-of-sight capabilities in both licensed and unlicensed spectrum.

BFWA systems operating in the licensed spectrum above 20 GHz have very high bandwidth and thereby high capacities, with QoS provisioning. The main limitation of such systems is the close to line-of-sight (LOS) requirement between the user antenna and the base station and the cost of the user equipment. For their features, it is likely that such systems are going to play a key role for 2G/3G traffic backhaul, particularly in urban scenarios. On the other hand, lower frequency systems, possibly licensed, will more favourably apply to suburban and rural scenarios and for backhauling WLAN hotspots or serving WMAN hot zones. In Figure 6 is shown a possible interoperability scenario of BFWA, WLAN and mobile networks.

There are many challenges to be overcome to assure interoperability between WLAN and BFWA and mobile networks. These challenges are most notably associated with radio spectrum (WLAN uses license exempt spectrum, BFWA both licensed and license exempt, and mobile networks licensed spectrum) and QoS handling (BFWA and mobile networks use connection oriented mechanisms, while WLAN has basically the Ethernet MAC, which is not connection oriented) interoperability between the different standards involved.

Moreover real time charging and payments as well as dynamic user and service management within service execution are extremely important. A very challenging task to facilitate an efficient interoperability is to enable better exploitation of the capabilities of Ethernet technology as a common transport technology with enhanced QoS performance to offer telecom grade quality.

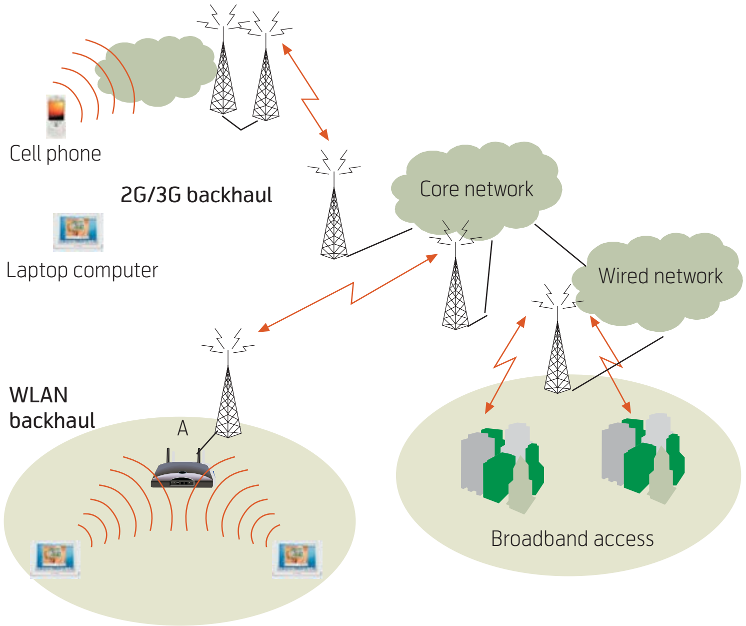

Figure 6 Interoperability scenario of BFWA, WLAN and mobile networks

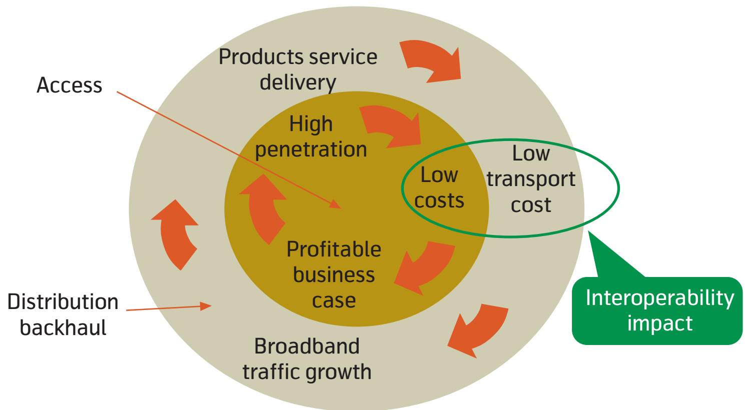

Figure 7 The interoperability challenge

6 Conclusions

The concept of interoperability in telecommunication networks is probably one of the main clues for delivering broadband services on convergent networks at reasonable prices for all kinds of users. A well-managed interoperability in the backhaul and access networks will contribute to more efficient, flexible and lower-cost systems, as shown in Figure 7. It basically relies more on an evolutionary path than a revolutionary one towards new generation networks, focusing on maximum reuse of existing infrastructure and technologies.

The concept of interoperability involves many different issues that have been identified and addressed in this paper. Both interoperability between backhaul

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and access networks (vertical), and among different access networks (horizontal) have been considered.

While interim solutions that can provide a limited communication interoperability capability exist today and examples of convergence and interoperable implementations are coming (bundling, triple play, seamless WLAN/2G/3G connection, multi access mobile devices), additional technology development and standardization efforts are necessary to deliver powerful adaptable systems capable of providing seamless on-demand interoperability. IMS is widely recognized as a technological cornerstone for enabling true convergence and interoperability.

7 References

1 Morganti, M. Convergence in communications – technology and business impacts. *Proceeding of Broadband Europe (bbeurope.org)*, Bordeaux, 13–15 December 2005. (http://bbeurope.org/)

2 Ericsson white paper. *Evolution towards converged services and networks*. April 2005. (http://www.ericsson.com/technology/whitepapers/convergence_b.pdf)

3 Ericsson white paper. *Key Business issues in the service layer*. December 2004. (http://www.ericsson.com/technology/whitepapers/service_wp_layer.pdf)

4 *BROADWAN*. 11 September 2006 [online] – URL: http://www.broadwan.org.

5 *Interoperability of broadband access networks*. BROADWAN (FP6-2002-IST-1), Deliverable 16, February 2005.

6 *Achieving broadband delivery in rural area*. BROADWAN (FP6-2002-IST-1), Deliverable 9, November 2004.

7 *Interconnected network architecture*. BROADWAN (FP6-2002-IST-1), Deliverable 14, November 2004.

8 *Interconnected networks; protocols and agents*. BROADWAN (FP6-2002-IST-1), Deliverable 32, December 2005.

9 Ericsson white paper. *Telecom Quality in all-IP networks*. March 2006. (http://www.ericsson.com/technology/whitepapers/3063_Telecom_Quality_all_IP_B.pdf)

10 Deering, S, Hinden, R. *Internet Protocol, Version 6 (IPv6) Specification*. December 1998. (IETF RFC 24609)

11 *Internet Protocol Version 6 (IPv6) Addressing Architecture*. 2003. (IETF RFC 3513)

12 *Stateless IP/ICMP Translation Algorithm (SIIT)*. 2000. (IETF RFC 2765)

13 *Network Address translation-Protocol Translation (NAP-PT)*. 2000. (IETF RFC 2766)

14 Ericsson white paper. *IMS-IP multimedia subsystem: the value of using IMS architecture*. October 2004. (http://www.ericsson.com/technology/whitepapers/ims_ip_multimedia_subsystem.pdf)

15 Tardy, I, Bråten, L E, Bichot, G, Settembre, M, Seseña, J. Hybrid architecture to achieve true broadband access in rural areas. *Proceeding of Broadband Europe (bbeurope.org)*, Bruges, 8–10 December 2004. (http://bbeurope.org/)

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The prospects of wireless broadband solutions

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Broadband coverage has now reached impressive levels in most OECD countries. However, in certain regions – mostly rural and remote areas – broadband coverage is still at a low level compared to competitive urban and suburban areas. Even though the price level of DSL line cards and modems has dropped to around 20 % (!) of the 1999 level, the cost of backhaul will in many cases be prohibitive for small and remote central offices. Therefore alternative solutions are required in order to fulfill the European vision of "Broadband to all citizens".

The term "residual market" is used in this paper for the households and businesses that are outside the planned coverage for existing wired access solutions for a given category of service offerings. The residual market for "ADSL-like" services is quite small in many OECD countries. However, the residual market for Triple Play services is in many areas over 50 % with today's infrastructure.

Due to the low percentage of copper loops that are too long for ADSL in urban areas, the residual broadband market is too small for WiMAX to be profitable unless the household density is sufficiently high and the coverage radius above 1.5 km. In rural towns and villages, profitability can only be obtained when WiMAX is a substitute to ADSL. Due to the small residual broadband market in suburban and urban areas, other services such as nomadic, hotspot and mobile applications will be required in order to make WiMAX profitable.

A significantly percentage of the copper loops is outside DSL reach with today's typical Triple Play requirements. Therefore the residual market within a central office area can be significant. Broadband Fixed Wireless Access (BFWA) in the 42 GHz band, if available on the market in due time, is a viable and cost-efficient alternative to high speed DSL in urban and suburban areas due to the possible cost sharing of receiver antennas on rooftops of buildings. In rural towns and villages, the high backhaul costs and the customer premises equipment (CPE) cost will in many cases make BFWA unprofitable although with lower costs compared to fibre-to-the-node (FTTN) using VDSL2 in the last drop to the customer.

The work presented in this paper has been carried out in the project BROADWAN [1] funded by the EU Commission.

1 Introduction

Wireless solutions are good candidates to cover the residual market. WiMAX has attracted considerable interest during the last few years. Especially the licensed frequency band around 3.5 GHz has been seen as alternative/complementary technology for "ADSL-like" services including mobility. In the higher frequency bands above 20 GHz, LMDS (local multipoint distribution system) has earlier been seen as a viable alternative to high-speed DSL, e.g. VDSL. Field trials with LMDS in the 40 GHz band focusing on the residential market has been carried out, e.g. by Telenor in 2000–2001. However, volume production has never taken off resulting in very high prices for customer premises equipment (CPE) – typically around 1,000 EUR.

LMDS in the 26 GHz band has been deployed merely for the business market for which the CPE cost is not that crucial.

The size of the residual market depends strongly on the service offering bitrate and coverage/reach of the technology. For all broadband technologies there is an inverse relation between capacity and reach although specifically pronounced for DSL, which uses the twisted pair telephone line as transmission medium. The choice of wireless technology in a specific area depends on the services to be delivered and whether the solution is complementary to an already established wireline solution in the area or a substitute.

In general, the coverage of a service with ~10 Mb/s downstream speed is in many cases fairly high in competitive urban regions, whereas the opposite is most often the case in exurban and rural areas. In the following, WiMAX in the 3.5 GHz licensed band and BFWA in the 42 GHz will be considered as complementary technologies or alternatives/substitutes to wireline broadband technologies in different types of areas: urban, suburban and rural town/village.

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	"Complementary"		"Alternative"	
Area type	Potential: Residential	Potential: Business	Potential: Residential	Potential: Business
Town/village	0 – 5 % **(2 %)**	0 – 5 % **(0 %)**	**100 %**	**100 %**
Surroundings	(70 % – 100 %) **100 %**	(70 % – 100 %) **100 %**	**100 %**	**100 %**
Suburban	0 – 5 % **(2 %)**	0 – 5 % **(0 %)**	–	–
Urban	0 – 5 % **(2 %)**	0 – 5 % **(0 %)**	–	–

Table 1 Broadband business potential of WiMAX in the 3.5 GHz band

	"Complementary"		"Alternative"	
Area type	Potential: Residential	Potential: Business	Potential: Residential	Potential: Business
Town/village	20 – 40 % **(40 %)**	20 – 40 % **(35 %)**	**100 %**	**100 %**
Surroundings	(90 % – 100 %) **100 %**	(90 % – 100 %) **100 %**	**100 %**	**100 %**
Suburban	20 – 40 % **(40 %)**	20 – 40 % **(35 %)**	–	–
Urban	20 – 40 % **(40 %)**	20 – 40 % **(35 %)**	–	–

Table 2 Broadband business potential of BFWA in the 42 GHz band

Table 1 and Table 2 show typical example values of the market potential for WiMAX as a fixed broadband access technology in the 3.5 GHz band and BFWA in the 42 GHz band, respectively, in terms of percentage of households and businesses in the different types of areas under study. The numbers highlighted in bold are used in the calculations.

Analysis of the copper loop length statistics in Norway indicates that business loops are generally shorter than residential lines.

2 WiMAX in the 3.5 GHz band

Medium and large towns are likely to get ADSL in the near term due to the reduction in ADSL equipment prices over the last years. In Norway, exchanges with down to ~200 phone lines are expected to be equipped with ADSL within the next two years. However, a certain percentage of the lines within an exchange will still not be within coverage. For a 1 Mb/s service, more than 90 % of the lines are in many cases within the required 5 km from the exchange, however for a 10 Mb/s service, typically less than 50 % are covered.

Using DSL technology to cover the remaining part of households requires installation of micro-DSLAMs (Digital Subscriber Loop Access Multiplexer) in street cabinet locations or closer to the subscriber. In small villages and towns, there are often very few households, 2–5, sharing such a node. Such an approach will result in prohibitive infrastructure costs. WiMAX therefore seems to be a good alternative to cover the "residual market".

Only the 3.5 GHz frequency is considered in this section, because most of the activity in the industry is on this frequency.

The broadband take rate assumptions are presented in Figure 1.

The main service assumptions are as follows:

Residential subscribers

Throughput first year:	0.5 Mb/s
Yearly traffic increase:	30 %, for five years and then remaining flat
Contention rate:	20:1
ARPU (monthly):	35 EUR

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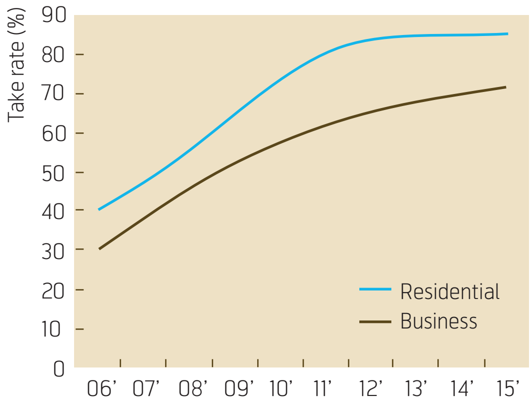

Figure 1 Broadband take rates

SME subscribers

Throughput first year:	0.7 Mb/s
Yearly traffic increase:	30 %, for five years and then remaining flat
Contention rate:	5:1
ARPU (monthly):	55 EUR

A sector capacity of 2 · 12 Mb/s = 24 Mb/s is assumed, meaning a channel capacity of 12 Mb/s.

Table 3 and Table 4 show the CAPEX and OPEX cost assumptions respectively.

CAPEX	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
WiMAX BS – three sectors	28 000	26 072	24 277	22 606	21 049	19 600	18 251	16 998	15 824	14 734
WiMAX BS – four sectors	35 000	32 590	30 346	28 257	26 312	24 500	22 813	21 242	19 780	18 418
WiMAX BS – additional sector	7 000	6 518	6 069	5 651	5 262	4 900	4 563	4 248	3 956	3 684
WiMAX BS – 1 sector omnidirectional	7 000	6 518	6 069	5 651	5 262	4 900	4 563	4 248	3 956	3 684
WiMAX outdoor CPE	350	291	243	202	168	140	117	97	81	67
WiMAX indoor CPE	250	208	173	144	120	100	83	69	58	48
WiMAX outdoor antenna installation	150	150	150	150	150	150	150	150	150	150
Radio link 34 Mb/s – incl. installation	17 000	17 000	17 000	17 000	17 000	17 000	17 000	17 000	17 000	17 000
Radio link 155 Mb/s – incl. installation	20 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000
Site installation – co-siting	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
Site installation – new site	60 000	60 000	60 000	60 000	60 000	60 000	60 000	60 000	60 000	60 000
Installation of new sector	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
Base station – basic equipment	10 000	9 311	8 670	8 073	7 518	7 000	6 518	6 069	5 651	5 262
Base station installation – omni	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
Base station installation – 3 and 4 sector	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
Base station installation – 6 sector	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000

Table 3 CAPEX unit costs for WiMAX in the 3.5 GHz frequency band

OPEX	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Site rental – new site	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000
Site rental – existing site	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
IP cost per subscriber – yearly	25	25	25	25	25	25	25	25	25	25
Network operation cost per subscr. – yearly	20	20	20	20	20	20	20	20	20	20
Sales & marketing	60	60	60	60	60	60	60	60	60	60
Support, billing etc.	100	100	100	100	100	100	100	100	100	100
Network maintenance – % of acc. investment	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %

Table 4 OPEX unit costs for WiMAX in the 3.5 GHz frequency band

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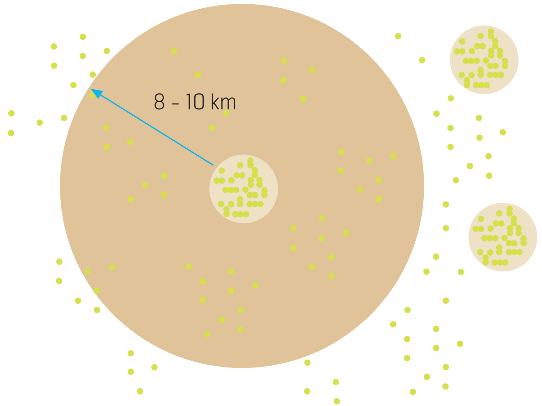

Figure 2 WiMAX coverage of small town/village and surrounding scattered households

2.1 Techno-economic evaluations – rural town/village

In the following, the total average investment per subscriber after five years of service and the internal rate of return (IRR) for a ten-year period is calculated for different sizes of the town/village and the amount of households in the surrounding area within the range of the WiMAX base station(s).

For rural towns/villages, we assume LOS (line of sight) due to the geography and dwelling structure (single family houses). Therefore, a WiMAX cell is assumed to have a range of 8–10 km. According to Norwegian statistics, the range of clusters, e.g. towns, is often within 1.5 km or less in radius. In this case, a single omnidirectional base station antenna should be adequate to cover the town/village and in addition scattered households in the surroundings. The situation is illustrated in Figure 2.

We consider a small rural town/village with 20 (small village) – 1,500 households (large town), the amount of businesses/SOHOs is 10 % of households and 100 – 1,500 additional households scattered in the surrounding area as shown in Figure 2.

In the "Complementary" scenario, DSL is already assumed to be in place and in that case, WiMAX being introduced later in time is assumed to get subscribers in the residual market segment only e.g. the households and business units in the town/village in addition to the scattered households in the surrounding area. The latter belong to very small Remote Switching Units (RSUs) without any ADSL offering.

In the "Alternative" scenario, DSL is not in place or planned in the near term. In that case WiMAX is assumed to serve all the households and business units in the town/village as well as the scattered

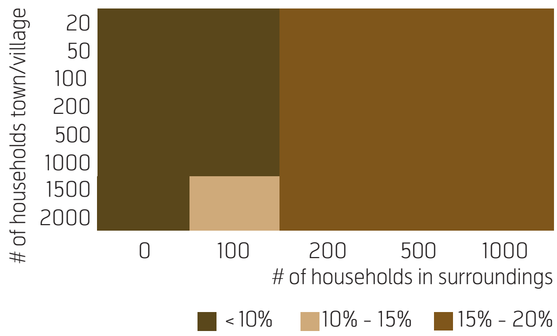

Figure 3 IRR, "Complementary", 100 % market share

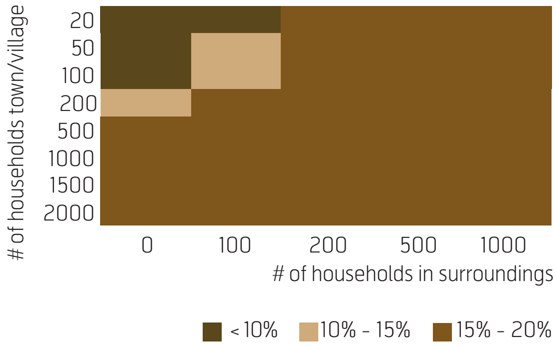

Figure 4 IRR, "Alternative", 100 % market share

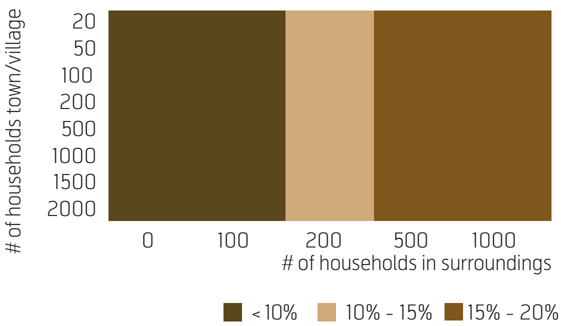

Figure 5 IRR, "Complementary", 50 % market share

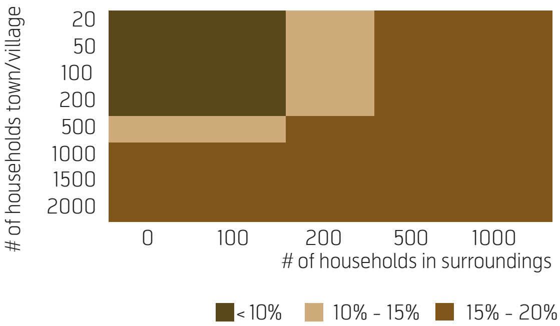

Figure 6 IRR, "Alternative", 50 % market share

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households in the surrounding area (belonging to very small RSUs and with no ADSL offering).

It is assumed that all subscribers use outdoor antennas, which are more costly than indoor antennas (350 EUR compared to 250 EUR). In the following, the network operator has the cost of ownership of receiver antennas at the subscriber.

Figure 3 to Figure 6 summarise the calculated IRR over a ten-year period.

For large towns with sufficiently populated surroundings, profitability, i.e. with an IRR over 12 %, is obtained under the given assumptions even with 50 % market share and in the "Complementary" scenario.

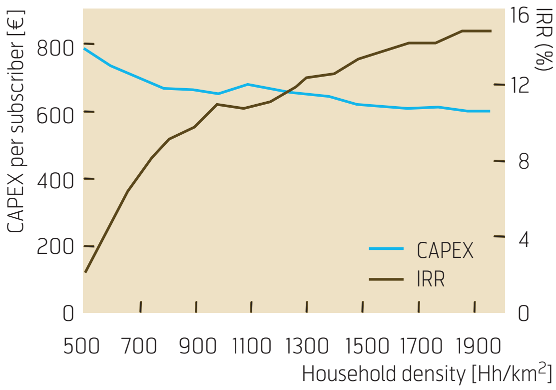

Figure 7 Urban area: Scenario 1, coverage radius = 1.5 km

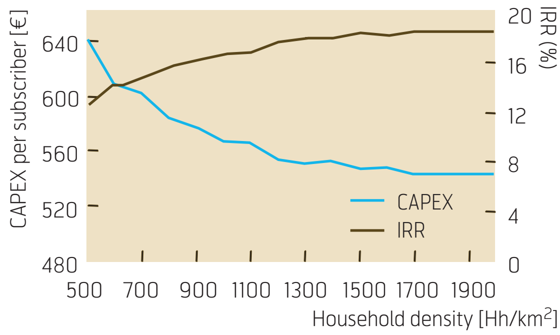

Figure 8 Urban area: Scenario 1, coverage radius = 2.5 km

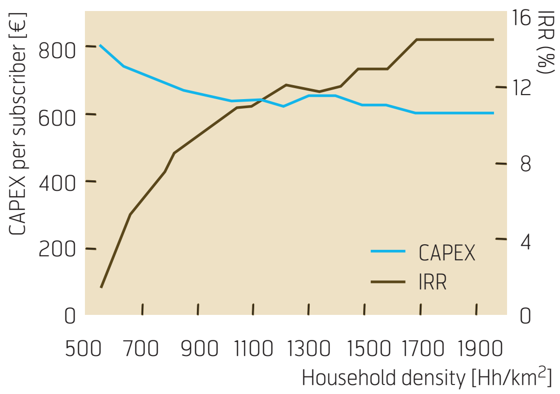

Figure 9 Urban area: Scenario 2, coverage radius = 1.5 km

In the "Complementary" case, the number of households in the surroundings is critical because the residual market in the town is very small.

For small (and isolated) towns and villages, profitability cannot be obtained even in the monopoly situation due to the small amount of potential subscribers to share the fixed investment (wireless coverage, backhaul etc.)

The profitability and cost levels are very dependent on population size and market share. In the "Alternative" scenario, the total average investment per subscriber after five years of service is in the area of 600 EUR for large towns in most cases. For smaller towns and villages, the investment per subscriber in many cases exceeds 1,000 EUR. Subsidisation or other financing schemes are therefore required in such areas.

2.2 Techno-economic evaluations – urban and suburban areas

In urban and most suburban areas, wireline solutions are already in place. Therefore, only the "Complementary" scenario is investigated. For suburban areas, the household density is between 100 and 500. For (dense) urban areas, the household density is between 500 and 2,000.

It is assumed that 5 % of suburban and 10 % of urban subscribers use indoor antennas.

For the suburban area and urban area considered, the number of households is 20,000 and 200,000, respectively.

The CAPEX per subscriber after five years of service and the IRR over the ten-year period 2006–2015 are calculated when varying coverage radius and household density for four residual market scenarios:

1 5 % potential for residential (95 % ADSL coverage), 5 % potential for business (95 % ADSL coverage)

2 5 % potential for residential (95 % ADSL coverage), 2 % potential for business (98 % ADSL coverage)

3 2 % potential for residential (98 % ADSL coverage), 2 % potential for business (98 % ADSL coverage)

4 2 % potential for residential (98 % ADSL coverage), 0 % potential for business (100 % ADSL coverage)

Urban Area

The results for the urban area are summarized in Figure 7 – Figure 14.

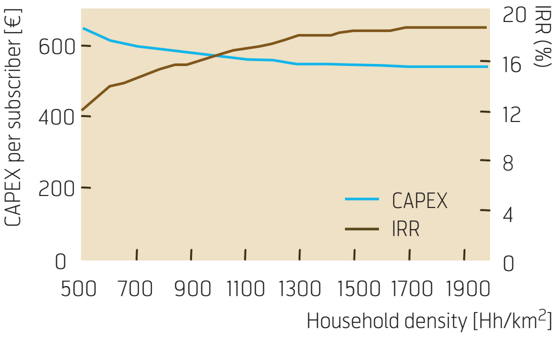

Figure 10 Urban area: Scenario 2, coverage radius = 2.5 km

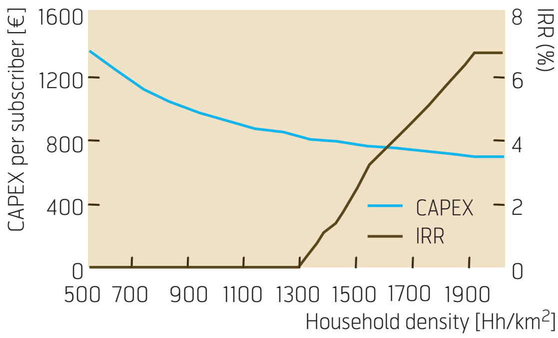

Figure 11 Urban area: Scenario 3, coverage radius = 1.5 km

Suburban Area

Due to the (much smaller) density compared to the dense urban area combined with the generally small size of the residual market for "ADSL-like" services, WiMAX as a fixed broadband access technology only is not profitable in suburban areas under the given assumptions. IRR a little below 10 % is however obtained for the highest density of 500 households per km^2, when the coverage radius is 2.5 km and only for Scenarios 1 and 2.

As there are no LOS conditions in general, four sector base stations are required (as in the urban areas) in order to improve antenna gain and therefore coverage. The possibility to pay-as-you-grow, starting with an omni-directional base station antenna, and benefit from the cost reduction of equipment does therefore not exist as in the town/village case.

Household density and coverage radius/range have a significant impact on the investment level. Profitability is not obtained in either area even for the highest densities as WiMAX is only a complementary technology. There is simply not sufficient subscriber mass in the suburban areas under the given assumptions to break even.

Due to the small residual broadband market in suburban and urban areas, other services such as nomadic, hotspot and mobile applications will be required in order to make WiMAX (more) profitable.

3 BFWA in the 42 GHz band – High Frequency BFWA

For more advanced services than "ADSL-like" services, the bandwidth requirment is more pronounced. If high frequency BFWA (HF-BFWA) for the consumer is commercially available in the short to medium term, there is a window of opportunity to get a fair slice of the broadband market. We assume that the operator launches Triple Play services with multicast IPTV over HF-BFWA in 2008 in areas where

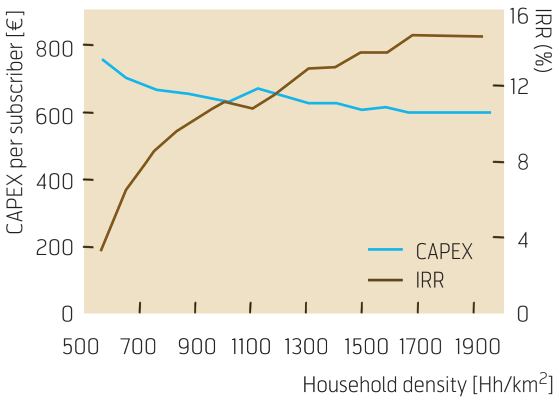

Figure 12 Urban area: Scenario 3, coverage radius = 2.5 km

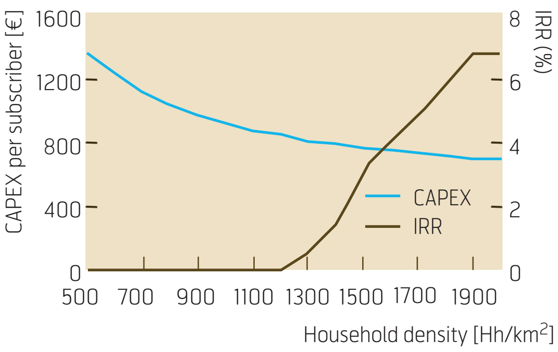

Figure 13 Urban area: Scenario 4, coverage radius = 1.5 km

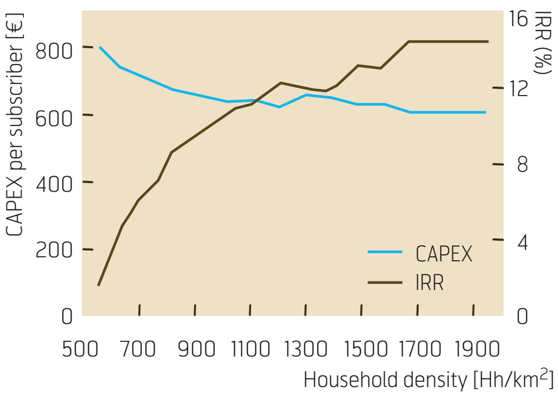

Figure 14 Urban area: Scenario 4, coverage radius = 2.5 km

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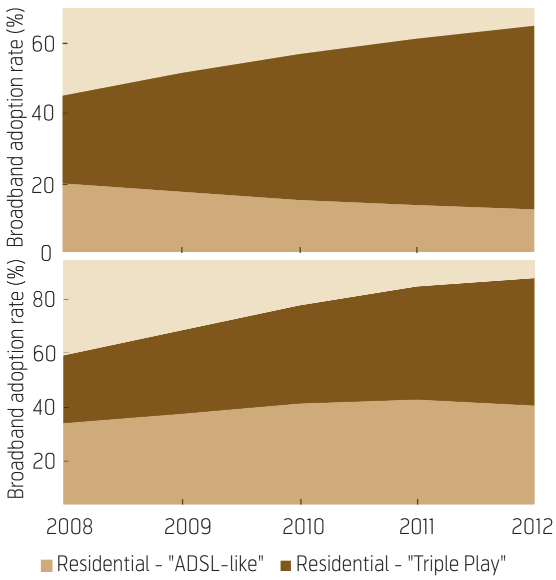

Figure 15 Broadband take rates

extended coverage of DSL and fibre is too costly. 2008 is assumed to be a realistic timing for commercial HF-BFWA gear for the mass market.

We consider two categories of services for both residential and business subscribers. The broadband take rates are shown in Figure 15.

The main service assumptions are as follows:

Residential subscribers

"ADSL-like":
Throughput first year: 0.5 Mb/s
Yearly traffic increase: 30 %, for seven years
Contention rate: 20:1
ARPU (monthly): 35 EUR

"Triple Play":
Throughput first year: 1.0 Mb/s
Yearly traffic increase: 30 %, for seven years
Contention rate: 20:1
ARPU (monthly): 50 EUR

SME subscribers

"ADSL-like":
Throughput first year: 0.7 Mb/s
Yearly traffic increase: 30 %, for seven years
Contention rate: 5:1
ARPU (monthly): 55 EUR

"High speed symmetric":
Throughput first year: 2.0 Mb/s
Yearly traffic increase: 30 %, for seven years
Contention rate: 2:1
ARPU (monthly): 90 EUR

CAPEX	2008	2009	2010	2011	2012	2013	2014	2015
Base station (BS) – 4 sectors	25 000	23 279	21 676	20 184	18 794	17 500	16 295	15 173
Base station (BS) – basic costs	5 000	4 656	4 335	4 037	3 759	3 500	3 259	3 035
Base station (BS) – omnidirectional	5 000	4 656	4 335	4 037	3 759	3 500	3 259	3 035
BS channel	5 000	4 656	4 335	4 037	3 759	3 500	3 259	3 035
HF – BFWA CPE – residential	800	666	555	462	384	320	266	222
HF – BFWA CPE – business	800	666	555	462	384	320	266	222
Radio link 34 Mb/s – incl. installation	17 000	17 000	17 000	17 000	17 000	17 000	17 000	17 000
Radio link 155 Mb/s – incl. installation	20 000	20 000	20 000	20 000	20 000	20 000	20 000	20 000
Radio link 1 GbE – incl. installation	22 000	22 000	22 000	22 000	22 000	22 000	22 000	22 000
CPE installation – town	400	400	400	400	400	400	400	400
CPE installation – urban (antenna sharing)	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000
Micro DSLAM – basement (stackable)	1 026	975	926	880	836	836	836	836
Micro DSLAM – basement – installation	800	800	800	800	800	800	800	800
Fibre backhaul cost per km	50 000	50 000	50 000	50 000	50 000	50 000	50 000	50 000
1 GbE optical interface – SH	1 620	1 539	1 462	1 389	1 389	1 389	1 389	1 389
Site installation – co-siting	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000
Site installation – new site	60 000	60 000	60 000	60 000	60 000	60 000	60 000	60 000
Installation – new sector/channel	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000

Table 5 CAPEX unit costs for BFWA in the 42 GHz frequency band

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OPEX	2008	2009	2010	2011	2012	2013	2014	2015
Site rental – new site	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000
Site rental – existing site	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
IP cost per subscriber – yearly	25	25	25	25	25	25	25	25
Network operation cost per subscr. – yearly	20	20	20	20	20	20	20	20
Sales & marketing	60	60	60	60	60	60	60	60
Support, billing etc.	100	100	100	100	100	100	100	100
Network maintenance – % of acc. investment	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %

Table 6 OPEX unit costs for BFWA in the 42 GHz frequency band

A channel capacity of 160 Mb/s is assumed. Urban four-sector base stations can handle up to ~2.5 Gb/s if more frequencies are used and if we assume up to four channels per sector.

Table 5 and Table 6 show the CAPEX and OPEX cost assumptions respectively.

3.1 Techno-economic evaluations – rural town/village

The same town/village + surroundings as treated in section 2.1 is analysed for HF-BFWA. LOS is assumed, but the coverage radius is now only 5 km in the 42 GHz frequency band compared to the 8–10 km for WiMAX in the 3.5 GHz band. The amount of additional households in the surroudings that can be covered from a single base station in the town centre is therefore smaller than for WiMAX, as can be seen by comparing Figure 2 and Figure 16, Broadband take rates.

The investment level and profitability have been determined for optimal base station configurations. Small low-cost omnidirectional base stations are used for very small villages and towns. For larger towns, base stations with more sectors are used. Additional sectors are added over time with increasing capacity.

For small (and isolated) towns and villages, profitabilty cannot be obtained even in the monopoly situation due to the small amount of potential subscribers to share the fixed investment (wireless coverage, backhaul etc.). For medium and large towns, profitability is easier to obtain than for the WiMAX in section 2.1. The reasons are the (much) larger residual market with no wireline alternative, the much higher capacity offered by HF-BFWA compared to WiMAX (so that capacity limitation is not occuring until later in time) and the higher ARPU levels for advanced services.

The profitability and cost levels are very dependent on population size and market share. In case of 50 % market share, profitability is only obtained for large towns and in the "Alternative" scenario. The total average investment per subscriber after five years of service is in the area of 1,000 EUR for large towns. The CPE cost (variable cost) is the dominant factor. For smaller towns and villages, the investment per subscriber in many cases exceeds 1,500 EUR. Subsidisation or other financing schemes are therefore required in such areas.

3.2 Techno-economic evaluations – suburban and urban areas

As in section 2.2, we vary the coverage from 1.5 to 2.5 km in the calculations. The same service and equipment cost assumptions as in section 3.1 are used.

It is assumed that 20 households/businesses per building in suburban areas and 40 households/businesses per building in urban areas can share a receiver antenna placed on the rooftop. This cost sharing is beneficial for the business case. The HF-BFWA receiver feeds small stackable Ethernet-based

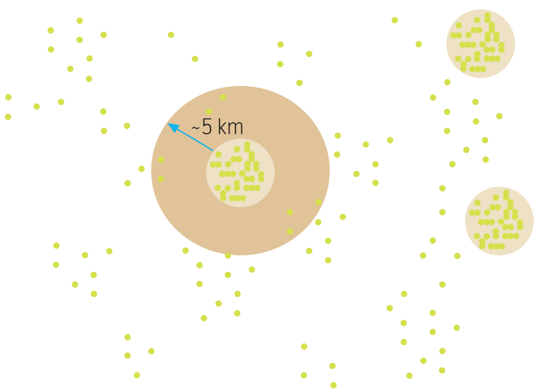

Figure 16 HF – BFWA coverage of small town/ village and surrounding scattered households

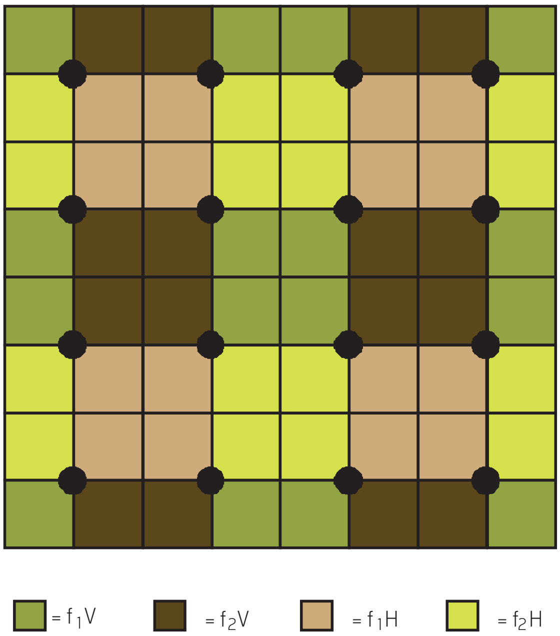

Figure 17 Frequency plan – four base stations with four sectors each

mini/micro DSLAM in the basement by using fibre cable internally in the building between the HF-BFWA receiver and the mini-DSLAM. DSL is used over last copper drop to the customer. It is assumed that the property owner incurs the costs of internal cabling in the building.

In order to increase the area coverage probability, a configuration of four base stations and frequency reuse as shown in Figure 17 has been assumed.

The economic results are summarised in Figure 18.

As can be seen from Figure 18, household density and coverage radius have a significant impact on the investment and the profitability. Profitability e.g. an IRR above 12 % is obtained in most cases. Dense urban areas show high profitability under the given assumptions due to a higher degree of cost sharing of both base station equipment and receiver antennas compared to the suburban areas.

9 Conclusions

WiMAX has the potential as a profitable fixed broadband access solution under certain conditions:

- As an alternative to wireline access in a town/village of sufficient population (incl. surrounding area within the coverage range of a base station);
- As a niche solution in urban areas of sufficent density of households and businesses; a critical mass is possible even with a moderate market share. The possibility to offer nomadic, hotspot and mobile services will be a unique selling point when competing with a traditional DSL or cable modem servcie offer at low/medium speeds e.g. below 2 Mb/s downstream;
- As a main solution in emerging markets e.g. countries with a poor copper network infrastructure.

However, WiMAX at 3.5 GHz has limited potential as a broadband access substitute for ADSL in mature markets with high broadband coverage. When WiMAX is used as a complementary fixed access solution in areas with partial wireline coverage, the market potential is not sufficient to secure break-even because of the existing high coverage levels of DSL.

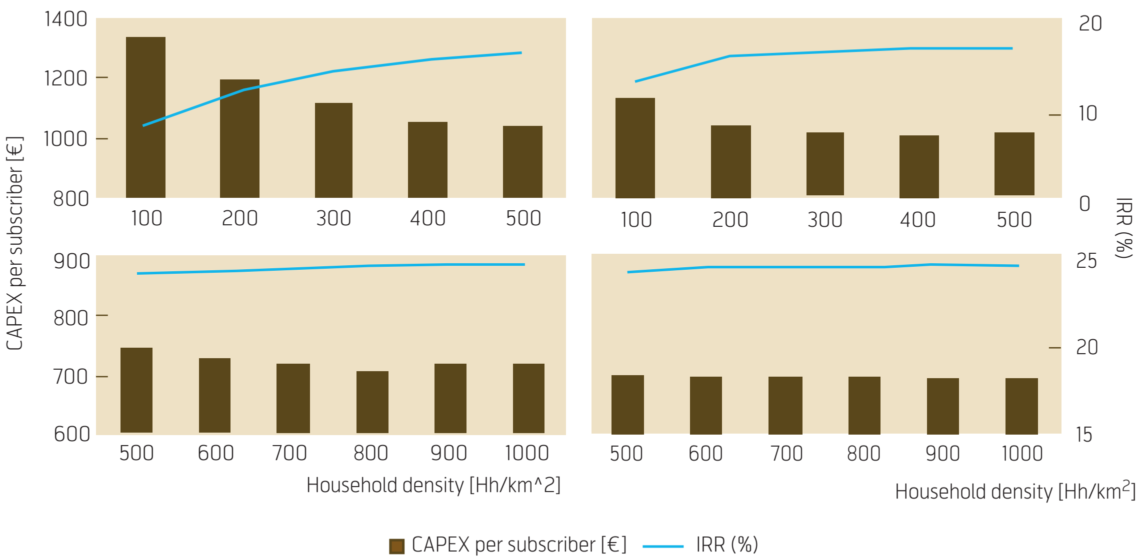

Figure 18 HF-BFWA as an alternative technology – suburban and urban areas

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High frequency broadband fixed wireless access at frequencies above 20 GHz is interesting due to the larger residual markets for high capacity broadband. In such areas, the deployment costs of FTTC + ADSL2+/VDSL2 will generally be prohibitive. Therefore an interesting window of opportunity exists for such wireless networks at high frequencies, e.g. the 42 GHz band.

Investment levels for broadband deployment are generally high in residual markets, however significant savings with the use of wireless access technologies and the option of hybrid architectures are possible compared to upgrading existing infrastructure with ADSL2+/VDSL2 in such areas.

Under the given assumptions, profitable deployment of BFWA in the 42 GHz band is possible in towns of sufficient size as well as in most of the urban/suburban areas being analysed except for suburban areas with coverage radius below 2 km and a household density below 300 households per km^2.

However, there is very little activity at present in the standardization of broadband wireless access networks above 20 GHz for the consumer market resulting in high CPE prices; estimated market prices range from below 1,000 EUR to significantly higher prices.

Although an interesting window of opportunity exists for 42 GHz BFWA, the limited activity in the industry makes it difficult to inititate mass market production with resulting reduction in equipment costs within the next few years. The CPE equipment price is the main cost driver at the moment.

Reference

1 EU Commission Sixth Framework Integrated Project BROADWAN. *Broadband Services for Everyone over fixed wireless access networks*. 2004 – 2006. URL: http://www.telenor.no/broadwan/

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Automated hybrid cost-optimised network design

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The design of wireless broadband networks is a complex optimisation problem that involves locating and configuring the network infrastructure in order to produce the best network performance. There are many constraints and objectives, which are often in direct competition. Network operators are obviously keen to reduce capital expenditure and operating costs, but at the same time need to ensure that the network covers enough potential subscribers, achieves the required quality of service and provides sufficient capacity. To accurately assess the technical and economic performance of the network requires detailed data concerning the demographics and propagation within the region. Due to the size and scope of the problem, it is hard for ad hoc or manual planning approaches to produce an optimal network design. This paper describes a mathematical model and automated software tool developed for planning hybrid wireless networks for broadband access. By making use of metaheuristic optimisation algorithms, the tool is able to produce high quality solutions in a reasonable time. The process is demonstrated using a case study based on planning a hybrid 40 GHz and WiMAX access network for Oslo using detailed demographic data. The benefits arising from a detailed planning model are illustrated by considering a WiMAX deployment in the city of Oxford in the UK for various degrees of data accuracy.

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Introduction

The use of automated tools in designing wireless communications networks has become widespread (see [1,2,3] for example), although this is primarily in the area of mobile telephony. Developing tools, models and algorithms to design Fixed Wireless Access (FWA) networks introduces new challenges compared to GSM and UMTS network planning. The business case for deploying FWA is often far from clear-cut, with many competing technologies, as well as competing operators. The lack of user mobility means accurate assessment of signal coverage is very important. Finally, due to the diverse requirements of the market (business users, home users, Small to Medium Enterprises), it is unlikely that a single technology or architecture can most effectively supply the entire network. Instead, hybrid combinations of technology should be deployed where appropriate, for example, using WiMAX at low frequency to supply residential subscribers, with high frequency systems providing high bandwidth, high availability services to business users. Different layers may also interact, with the higher frequency system providing the backhaul for the WiMAX base stations. The choice of technology introduces a further layer of complexity into the design process.

By making use of state of the art combinatorial optimization algorithms, automated planning tools are able to produce near optimal network designs in a fraction of the time that would be needed by a manual planner. They are also more capable of handling the complex input data necessary to accurately assess individual cell plans. The complex interactions between decision variables and competing design objectives and constraints are beyond the scope of a manual planner. Although the automated planning tool's main use is in producing and configuring individual networks, they can also play a wider role in the design process, as their repeated use allows operators to accurately asses the impact of key design choices such as the use of different architectures, frequency bands, channelizations, etc., without the need for simplifying assumptions.

This paper describes a software tool, called *Echo (Efficient Cell plan Heuristic Optimizer)*, for the automated planning of hybrid wireless access networks, developed as part of the BROADWAN project [4]. Echo uses combinatorial optimization algorithms together with an accurate model of network performance to automate the design process. In contrast to most published work in this field, the model behind the tool takes detailed account of both the technical and economic aspects of the network in driving the optimization, illustrated in Figure 1. This combination allows the tool to be used to investigate possible deployment scenarios and accurately assess the potential business cases for rival architectures and technologies.

We first present an overview of the mathematical model used to represent wireless access networks within the Echo planning tool. We will illustrate the

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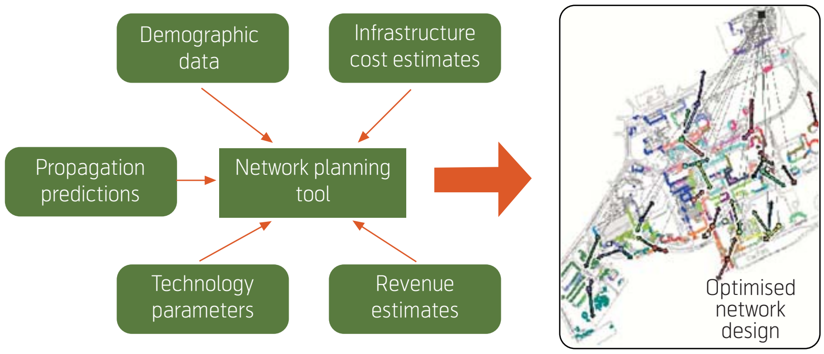

Figure 1 Overview of Echo planning tool

range and detail of the required inputs, as well as the decisions that can be successfully automated. The algorithms used to optimize the network design will then be described at a high level, with some comparison to alternative approaches. Two case studies are presented for the cities of Oslo in Norway, and Oxford in the UK. The first of these illustrates the hybrid planning of a 3.5 GHz WiMAX network in combination with a 42 GHz system. The second illustrates how the level of detail in the input data for the planning process affects the applicability of the final cell plans produced.

Modelling broadband networks

The aim of the cell planning process is to produce an optimal network configuration with respect to some measure(s) of operational performance. To facilitate this, a mathematical model of the potential networks is required. This model has been defined within the BROADWAN project and encapsulates the key planning decisions in deploying hybrid wireless systems and allows the evaluation of individual network designs.

Decision variables

The basic model is defined by the following decision variables:

Select base station sites and cells
Each scenario defines a set of candidate base station locations at which network infrastructure can be located. These vary in their financial costs and their propagation environment (for example, potential sites on high buildings will cover a larger area, but could have higher acquisition and maintenance costs). A subset of the candidates must be selected in the cell plan. Each selected site can have a number of cells defined, which must also be specified as part of the planning process.

Select technology to deploy at each selected site
For example, a choice could be made between WiMAX at 3.5 GHz, high capacity 40 GHz BFWA systems or a combination of both.

Select equipment for each selected site
Within each technology, different equipment will be available for deployment, each with significantly different performance and cost profiles. Each planning scenario must specify the range of antenna models that are available for deployment. With the inclusion of directional antennas, the model also requires the three dimensional radiation pattern associated with each model in order to evaluate the coverage from each sector.

Configure base station equipment
Each cell has a range of tuneable parameters:

- Azimuth (only used for directional antenna);
- Tilt;
- Transmit power;
- Frequency channel assignment.

The range of permitted values for each is dependent on the choice of equipment and technology for each site.

Assign users to cells
In order to calculate measures of the traffic capability of a potential network design and the expected subscription revenue, a nominal assignment of the potential subscribers (termed users in the model) in the network area onto the cells of the design is needed.

Network evaluation

The economic viability of a cell plan is the primary driver of the optimization in the Echo planning tool, and is quantified by calculating the expected *net present value (NPV)*. This measure is the sum of the discounted cash flow (where cash flow is the expected revenue generated by the proposed network, minus the capital and operational expenditure) over the return period. The discount rate is a factor that relates future monies in today's terms. An NPV of zero indi-

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cates that the network is expected to break even over the given return period. Where the NPV is greater than zero, the operator can expect to make a profit above expectation.

Calculating the NPV for a given cell plan requires two stages and many detailed inputs. Firstly, calculating the expenditure for the infrastructure selected in a cell plan requires capital and operational costs to be specified covering:

- The installation, lease and maintenance of base station sites (not including the equipment installed at each cell) including the provision of backhaul to the site;
- Purchase, installation and maintenance of equipment at each site, i.e. the individual sectors;
- Purchase and maintenance of customer premise equipment[1)].

These costs will vary significantly over time; for example, equipment costs will generally reduce in price as the technology matures. Also, as the demand for the service grows, more equipment will be sold, allowing economies of scale to be made in its manufacture. Therefore, the model allows both capital and operational values to be specified for each year within the overall return period.

The second factor in the NPV calculation requires an estimate of the expected revenue for each year of the networks operation. This in turn is dependent on the number of users that are capable of subscribing to the network, requiring a more detailed consideration of the technical performance of the proposed cell plan.

Estimating subscribed users

Central to the technical evaluation of a cell plan is the concept of Reception Test Points (RTP). Each RTP specifies a location (in three dimensional spatial coordinates) at which the signal strength from all cells can be evaluated. As such, propagation predictions are required from each candidate base station site to each RTP. These can be generated by empirical formula, such as specified in [5], or by more accurate means (for example, making use of digital maps for path-profile or ray-tracing techniques [10]). The input data for a planning scenario defines a relationship between the users and the RTP within the network area. This may be many-to-one (for example, individual households within a block of apartments may share a single access point situated on the roof) or one-to-many (for example, a given household may have potential locations identified on each side of the building). The later introduces a further decision variable (selecting the RTP to use for each household) but raises the potential to use the subscribers premises to shield the receiver from some interference.

The received signal strength at a given RTP from a given base station can then be calculated as seen in the box below.

An individual user can only subscribe if *all* of the following three tests are satisfied at their selected RTP:

Coverage: A cell covers a user if the predicted signal strength from the cell at the user's selected RTP is above the required sensitivity for the service. The coverage of the network design is the percentage of all users that are covered by at least one cell.

C/I: A user satisfies the C/I constraint if both:

1 They are covered by a cell;
2 The signal to interference ratio required by the service is satisfied at their selected RTP.

Service: Service builds on the concept of coverage by taking account of the capacity of each cell. As such it cannot be applied to individual users, but must consider the total demand within a cell. A set of users are all served by a cell if:

Received signal (dBm)

=	Transmit power of cell (dBm)	(decision variable determined by optimization)
–	Propagation loss (dB)	(input parameter specified for each RTP/base station pair)
+	Transmit/receiver gains (dB)	(determined by optimization through the choice of antenna at the cell and user sites)
–	Transmit/receiver losses (dB)	
–	Vertical loss (dB)	(dependent on choice of antenna, azimuth and tilt at cell site and angles between user and site)
–	Horizontal loss (dB)	

1) *This could be zero for a self install system.*

1 They are all assigned to the cell;
2 They are all covered by the cell;
3 Their C/I ratio is satisfactory;
4 Their combined traffic demand is not greater than the total capacity of the cell.

The service of a network design is the percentage of all users that are served.

All interfering signals are combined in calculating the signal to interference ratio at a user's RTP (that is, I consists of signals from all cells in the network other than the user's serving cell). An appropriate attenuation factor is included for each adjacent channel, so the frequency channel plan selected during optimization can mitigate the effect of interference. The attenuation factors are input parameters and will vary depending on the frequency band, modulation and coding scheme used. In high frequency bands (26 or 40 – 42 GHz), each frequency channel may also specify that either a horizontal or vertical polarization is to be used, in which case an additional attenuation factor is included to reduce the effect of interferers using cross polarized channels. Attenuation due to rain can also have an important effect at high frequencies, requiring the addition of an extra margin to the required sensitivity. The magnitude of this will depend on the service availability required by each user.

Modelling traffic

Coverage and interference are straightforward to assess, but calculating the service introduces some problems since it can only be calculated once all subscribers in the network have been identified. To overcome this, we instead consider the *expected service* of the network. Each user has a probability of subscription defined, representing the likelihood they wish to subscribe to the network and hence generate traffic (if covered and their interference is acceptable). The traffic demanded by each user is weighted by this probability to give their expected traffic demand. For example, a user requiring a 1 Mb/s service with a 0.1 probability of subscription is assumed to only consume 0.1 Mb/s of the capacity of their serving cell, rather than the full 1 Mb/s. Thus, for the purposes of this model, a cell with a capacity of 40 Mb/s can support up to 40 users demanding 1 Mb/s who will definitely subscribe, or 160 users who will subscribe with a probability of 0.25 (i.e. only a quarter of the potential subscribers are expected to take up the service).

Market predictions are used to generate the required probabilities. The product of the take rate (probability that a user desires the service offered) and the network operator's market share is calculated for each user to generate their subscription probability. In practice, it is usual to group the users into broader classes that all share similar input parameters and requirements, for example, high use residential, business, small-to-medium enterprises or to classify users by their location using post code data. The market share, take rate and subscription revenues for each class of user will vary considerably over time and should be specified individually for each year under consideration.

The traffic requirements of the potential subscribers need to be carefully specified in the input data. Firstly the contention ratio offered must be taken into account, so that a user on a 1 Mb/s service with a 20 to 1 contention ratio is only guaranteed an average throughput of 0.05 Mb/s with peak rates up to 1 Mb/s in bursts. The model handles this by using the peak rate to determine the required sensitivity and interference constraints for the user, but using the contended data rate to dimension the cell capacity.

Where a heterogeneous distribution of user requirements is present in a scenario, it is useful to use a more detailed model of traffic that takes account of the usage patterns of different classes of user. As an example, business users are primarily active during office hours, whereas residential users mainly use the service during evenings and at weekends. This is modelled in the Echo tool by the definition of requirements in multiple time slots, as shown in Table 1 for example. The capacity of a cell is compared to the expected demand for each individual slot. If the demand exceeds capacity for any single slot, the cell is overloaded and the number of users assigned to the cell must be reduced.

Traffic constraints in hierarchical networks

Many hybrid networks operate under a layered architecture where users may connect to the Point of Presence (PoP) via multiple hops, where each hop may also involve a different technology. The model han-

	6 am – Noon	Noon – 6 pm	6 pm – midnight	Midnight – 6 am
Home User (kb/s)	16	10	120	110
Business User (kb/s)	1,059	1,412	176	176

Table 1 Variable traffic requirements according to time of day

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dles this by imposing an extra constraint in assessing the service. To be served, not only must a users traffic requirement be consistent with the capacity of the cell and the demand of all other users within the cell, but the capacity constraint for all higher layers must also be satisfied. With this in mind, the route from user to PoP clearly has an effect when multiple layers are present in a network.

Optimization framework

The cell planning problem requires the selection of all decision variables described in the previous section in order to meet any constraints and optimize the objectives. Echo uses the NPV of a network as the objective function to be maximized, but allows hard constraints to be specified on other metrics. For example, where coverage requirements may be imposed by regulators as a condition of the license.

The number and range of the decision variables mean that it is intractable to use exhaustive algorithms[2)] for any problem of practical size. Instead, an algorithm that can obtain near optimal solutions within a reasonable time is required. One such class of algorithms is based on the concept of neighbourhood search. This is an iterative procedure that explores the search space of all possible cell plans in an intelligent manner. The exploration takes place via a sequence of cell plans, each of which is constructed by making some small modification to its predecessor.

Application to cell planning

A neighbourhood of similar cell plans to the current design is generated by applying *modifiers* to the current configuration. Each modifier makes a small change to the current cell plan. Examples include: adding a single site, changing one or more physical parameters at an existing site or assigning a subset of the users to a different cell. A range of modifiers are defined and used in the optimization framework, and can be broadly classified as follows:

Intelligent deterministic: Network metrics for the current cell plan are used to identify areas for improvement and changes are made by simple heuristics that mimic the operations a manual cell planner may use. For example, the cell that generates the lowest subscription revenue may be removed, or a new cell may be added directed towards a large group of uncovered users. During the initial phase of the optimization, this group of modifiers will often produce a positive effect on the quality of the cell plan.

Random deterministic: The cell to be modified is chosen at random, but the modification includes some intelligence. For example, such a modifier may select the optimum power (in terms of the NPV of the cell plan) at a randomly chosen cell, or add equipment to increase the capacity of an overloaded cell.

Random: The cell to be modified and the modification are both generated at random, for example, changing the azimuth of a random cell to a random value, adding a new cell at a random site with a random configuration.

The combination of modifiers from the three classes balances the need for diversity in the search (via random modifications) while still providing rapid improvements early in the optimization (via "intelligent" modifications). The optimization algorithm in Echo uses a selection of 35 types of modifier.

Hill climbing

Hill climbing is one of the simplest neighbourhood search techniques. At each step, a random modifier is selected and applied to the current cell plan. The new network is evaluated, and if it produces a better NPV then it becomes the new "current" network. If it does not produce an improvement, the new network is discarded and the next iteration continues with the current cell plan.

The main flaw with hill climbing is that it only accepts new cell plans that improve the current network, and so has no way of escaping from local optima which are not globally optimal.

Tabu search

Tabu search is a metaheuristic algorithm that maintains a memory of previous modifications to avoid

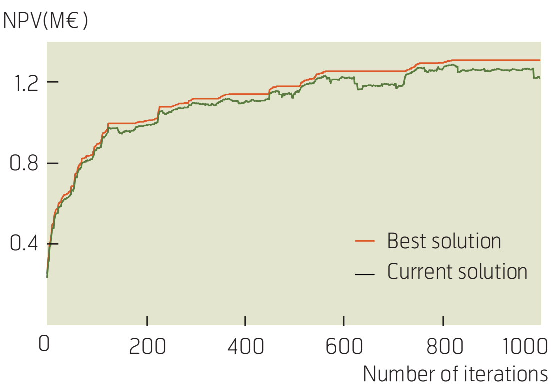

Figure 2 Progress of NPV during tabu search algorithm

2) *Exhaustive algorithms guarantee finding an optimal cell plan, through exploration of the entire search space.*

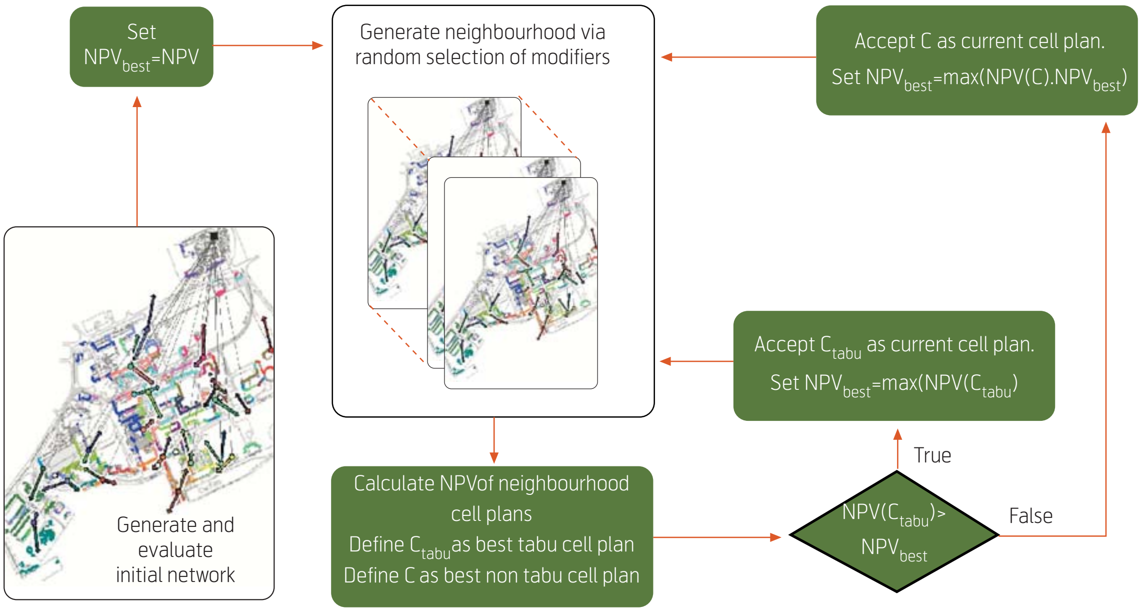

Figure 3 The tabu search algorithm used in Echo

cycling around local optima that are not globally optimal. The memory is used to selectively disallow certain moves during optimization. As in hill climbing, at each iteration a neighbourhood of moves is constructed and the resulting solutions are evaluated. Tabu moves are discarded, and the move from the remainder that produces the best solution is selected to form the next solution. Aspiration criteria allow the algorithm to override the tabu status when this is beneficial to the search. The most commonly used aspiration criteria will select a tabu move if it leads to the best solution found during the search so far.

At each iteration, a neighbourhood is constructed by selecting a specified number (10 for the results in this paper) of modifiers at random. Each is applied to the current network to produce a range of new cell plans, each of which are evaluated to calculate their NPV. The algorithm produces the next cell plan by applying the modifier that produces the best improvement in NPV over the current cell plan, provided it is not marked as tabu. The type of the selected modifier is then marked as tabu for a specified number of iterations (10 for the results in this paper). This optimization procedure is illustrated in Figure 3. Figure 2 shows the typical progress of the NPV of the cell plans considered during the tabu search process. Note how the algorithm frequently accepts new cell plans that temporarily decrease the NPV, which guides the process to new areas of the search space and leads to overall increases within a short number of iterations.

Generating initial networks

Although such metaheuristic algorithms are powerful, they are not particularly suited to generating good solutions quickly when starting from an empty or randomly constructed cell plan. Hence, we use simplistic sequential methods to generate a reasonable starting network that can reduce the time the tabu search takes to generate good solutions, termed *Build and Repair*. A random selection of sites are deployed with a specified configuration at each. Usually this consists of a “clover-leaf” of four sectors directed towards NE, NW, SE and SW. An iterative process using a reduced set of network operators continues until any hard constraints (such as minimum coverage limits) are met. The repair phase takes no account of the economic performance of the network.

Greedy heuristics

Echo includes two further simple greedy heuristics. These use constructive techniques to generate reasonable cell plans quickly, and are modelled on the typical steps a manual cell planner would follow. They can be used to benchmark the overall performance of the tabu search approach, and also provide an alternative means of generating initial solutions. However their simplicity means they are not compatible with all of the features of the network model.

Full then prune: The *full then prune (FTP)* algorithm deploys a clover-leaf configuration at all potential base station sites in the network. All users are assigned to the cell that provides the strongest signal. After each removal, those users who were assigned to the cell are re-pointed to the best server among those that remain. This continues until no sector remains, storing the NPV of each resulting cell plan. The cell plan with the best NPV is selected.

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Build then prune: The *build then prune (BTP)* algorithm is similar to that presented in [9] and aims to use a simple constructive procedure to select "good" initial sites. It starts by ranking all of the potential base station sites at zero. Each user is considered in turn, and their closest site has their rank increased by one. When all users have been polled, the current unused site with the highest ranking is chosen, and a clover-leaf configuration is placed at the site. Each user is then re-pointed at their best server to ensure that these new sectors provide service. The process then begins again for all users that remain uncovered, with the newly deployed site removed from consideration.

This site activation continues until the addition of a new site causes the NPV of the cell plan to decrease. In general, the first few sites should have large positive benefits to the NPV as we are placing sectors in regions where there are many uncovered users, so the revenue of the new sectors is likely to outweigh the expense of deployment. However, as more sites are added, the number of users served by each new cell becomes smaller and at some point the activation of a new site will not be economically justifiable.

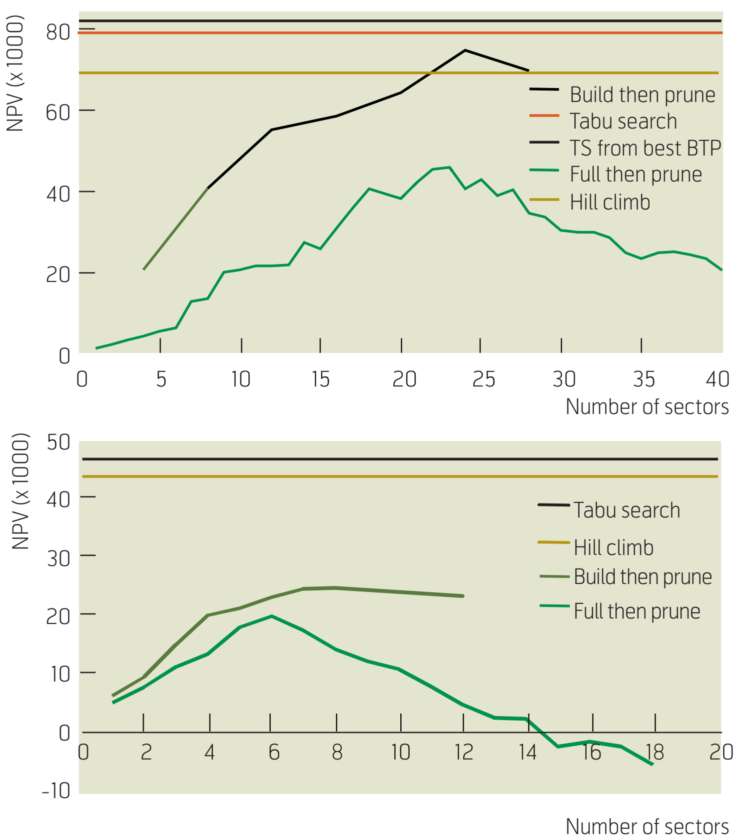

Figure 4 Comparison of algorithm performance

At this point, the build phase ends by removing the last site (the first site that causes a decrease in NPV), and the prune phase begins. Even though these sites have been deployed in areas where there are many users, there can still be some sectors that do not provide large financial returns, for example, sectors at the edge of the network area that are directed outside the network area. The prune phase ranks the sectors by their individual NPV values, and removes them individually in this order. After each removal, the users are assigned to their strongest server and the NPV of the network is calculated and stored.

Comparison

Typical results are shown in Figure 4, showing two cases based on deploying a WiMAX network in Oslo and Oxford respectively[3)]. The hill climb results were obtained after 50 minutes on a typical 2 GHz PC, while the tabu search took 8 hours to generate the final results. The BTP procedure typically completes within five minutes. In all cases the tabu search produces the best result, irrespective of the initial network, showing a clear advantage over hill climbing. Similarly, BTP consistently outperforms FTP, and depending on the scenario (in particular the homogeneity of the user classes), can outperform hill climbing. The main algorithm used in the Echo tool is Build and Repair followed by tabu search. Although it is outperformed by BTP and tabu search in some cases, its performance is consistently good across the majority of scenarios.

Case studies

The use of the Echo planning tool will be demonstrated using two case studies arising from practical network regions.

Hybrid network in Oslo

This case study considers deploying a wireless access network in Oslo, Norway. The region under consideration covers 6 km east to west, and 4.3 km north to south. 7,658 RTPs are distributed across the region based on building information from a digital map, and partitioned into four classes of potential subscriber:

Business: Characterized by high data rate requirements with low contention ratios and low churn. Approximately 200 users in total (2.5 % of scenario).

Household: A high data rate service is considered (capable of offering triple play services). Approximately 2,000 potential household subscribers are distributed across the region (27 % of the scenario).

3) *The user and base station locations are the same as the later examples in this paper, however the user requirements are different for these results.*

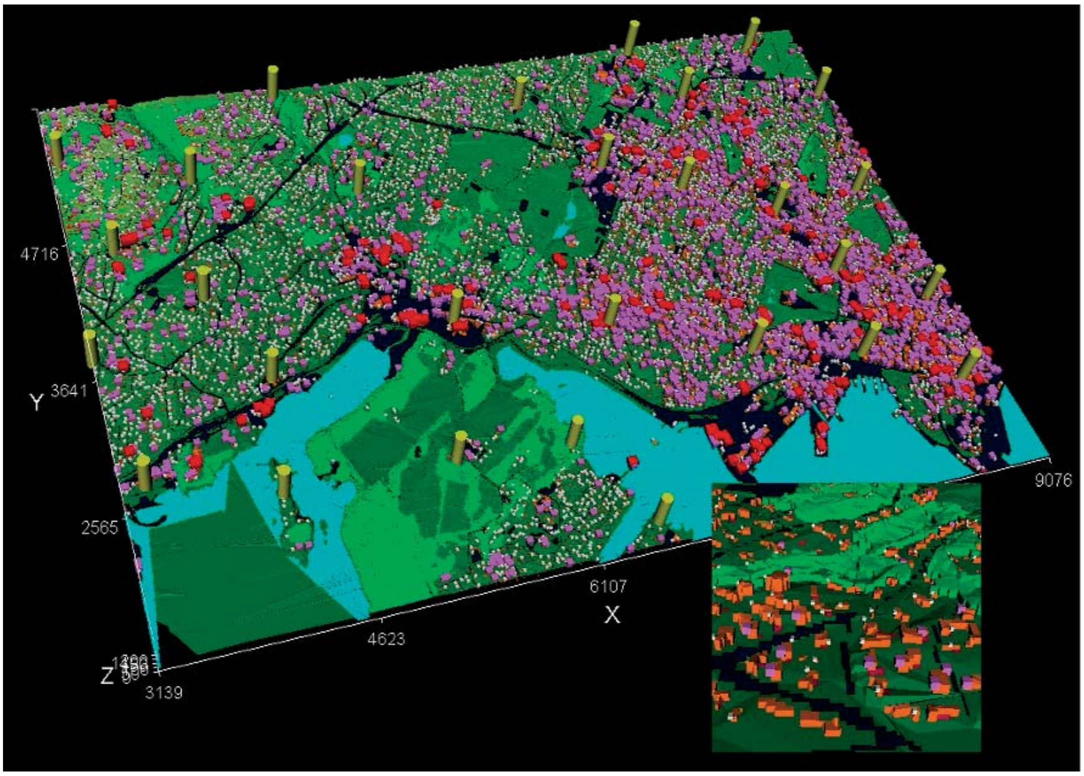

Figure 5 User and potential base station distribution. White denotes nomadic users, purple denotes households and red denotes business users. The yellow cylinders show the potential base stations

Year No.		1	2	3	4	5	6	7	8
	CPE CapEx (€)	350	231	152	100	66	44	29	19
	CPE OpEx (€)	0	0	0	0	0	0	0	0
	RTP CapEx (€)	0	0	0	0	0	0	0	0
	RTP OpEx (€)	0	0	0	0	0	0	0	0
	Connection tariff (€)	0	0	0	0	0	0	0	0
Nomadic-bundled user	Annual subscription (€)	300	270	243	219	197	177	159	143
	Number of users type	3774							
	Take rate (%)	5.6	9.6	14.5	20	25.6	31.1	36.1	40.5
	Market share (%)	100	96	91	87	83	79	74	70
	Churn rate (%)	10	10	10	10	10	10	10	10
	Required availability (%)	99.9							
	Service bit rate (kb/s)	1024							
	Contention ratio	30							
	CPE CapEx (€)	350	231	152	100	66	44	29	19
	CPE OpEx (€)	0	0	0	0	0	0	0	0
	RTP CapEx (€)	0	0	0	0	0	0	0	0
	RTP OpEx (€)	0	0	0	0	0	0	0	0
	Connection tariff (€)	50	45	41	37	33	30	27	24
Nomadic only user	Annual subscription (€)	600	540	486	437	393	354	319	287
	Number of users type	1618							
	Take rate (%)	5.6	9.6	14.5	20	25.6	31.1	36.1	40.5
	Market share (%)	70	64	59	53	47	41	36	30
	Churn rate (%)	20	20	20	20	20	20	20	20
	Required availability (%)	99.9							
	Service bit rate (kb/s)	1024							
	Contention ratio	30							

Table 2   Parameters for nomadic users

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Year No.		1	2	3	4	5	6	7	8
HH (heavy) user	CPE CapEx (€)	100	757	573	434	329	250	250	250
	CPE OpEx (€)	50	38	29	22	16	13	13	13
	RTP CapEx (€)	150	150	150	150	150	150	150	150
	RTP OpEx (€)	0	0	0	0	0	0	0	0
	Connection tariff (€)	50	45	41	37	33	30	27	24
	Annual subscription (€)	1200	1080	972	875	788	709	638	574
	Number of users type	2072							
	Take rate (%)	20	25.6	31.1	36.1	40.5	44.3	47.4	50
	Market share (%)	100	93	86	79	71	64	57	50
	Churn rate (%)	10	10	10	10	10	10	10	10
	Required availability (%)	99.9							
	Service bit rate (kb/s)	25000							
	Contention ratio	20							
BUS user	CPE CapEx (€)	1000	757	573	434	329	250	250	250
	CPE OpEx (€)	50	38	29	22	16	13	13	13
	RTP CapEx (€)	150	150	150	150	150	150	150	150
	RTP OpEx (€)	0	0	0	0	0	0	0	0
	Connection tariff (€)	375	338	304	274	247	222	200	180
	Annual subscription (€)	9000	8100	7290	6561	5905	5315	4784	4306
	Number of users type	194							
	Take rate (%)	20	25.6	31.1	36.1	40.5	44.3	47.4	50
	Market share (%)	70	60	55	50	50	50	50	50
	Churn rate (%)	5	5	5	5	5	5	5	5
	Required availability (%)	99.99							
	Service bit rate (kb/s)	10000							
	Contention ratio	5							

Table 3 Parameters for business and households

Nomadic (bundled): Represents nomadic users who are subscribed to a bundle of services from the network operator. Each RTP represents four co-located nomadic users. Approximately 3,800 such users are included in the scenario (49 % of the scenario).

Nomadic (only): Users who are subscribed only to the nomadic service of the operator. Each RTP represents four co-located nomadic users. Approximately 1,600 such users are included in the scenario (21% of the scenario).

Detailed inputs for each class of user derived from [7] can be seen in Tables 2 and 3, and their distribution can be seen in Figure 5.

A dual layer network is considered. Nomadic users will obtain access through a set of 3.5 GHz base stations. A 42 GHz layer will serve business and household users, while also providing the backhaul for the 3.5 GHz base stations. The economic parameters used for each layer are detailed in Tables 4 and 5 respectively, while the radio parameters can be seen in Table 6. Twenty-nine candidate base stations have been identified across the region, situated on high buildings or 30 m masts. For the purposes of this cell plan, all base stations sites are assumed to have equal rental and acquisition costs.

The path loss predictions between each candidate site and RTP were calculated using ray-tracing and digital maps of the area. Enhancements to ITU-R P. 452 were used, as detailed in [10]. An additional loss of 20 dB has been applied to each RTP representing a nomadic user to account for building shading and uncertainty in the precise user position.

Results

Details of the final optimized cell plan produced by Echo can be seen in Tables 7 and 8, while the cell plans themselves can be seen in Figure 6. Note that the optimization has deployed both WiMAX and 42 GHz equipment at eight of the sites and provide access to both layers. The remaining sites each oper-

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Year No.		1	2	3	4	5	6	7	8
Number of years for NPV calculation		8							
Discount rate (%)		12							
Base site CapEx (€)	Installation	30000	26584	23609	21159	19038	17205	17205	17205
	Backhaul establishment fee (via 42 GHz)	0	0	0	0	0	0	0	0
	Establishment fee	750	750	750	750	750	750	750	750
Base site OpEx (€)	Annual maintenance	1200	1080	972	875	788	709	638	574
	Backhaul (via 42 GHz)	0	0	0	0	0	0	0	0
Sector CapEx (€)	Installation & equipment	5000	4347	3781	3291	2867	2500	2500	2500
	Establishment fee	72	72	72	72	72	72	72	72
Sector OpEx (€)	Annual maintenance	250	217	189	165	143	125	125	125
	Rental for placement	483	483	483	483	483	483	483	483

Table 4 Economic parameters for 3.5 GHz WiMAX layer

Year No.		1	2	3	4	5	6	7	8
Number of years for NPV calculation		8							
Discount rate (%)		12							
Base site CapEx (€)	Installation	15000	13710	12423	11223	10023	8823	8823	8823
	Backhaul establishment fee	12500	12500	12500	12500	12500	12500	12500	12500
	Site establishment fee	750	750	750	750	750	750	750	750
Base site OpEx (€)	Annual maintenance	750	686	621	561	501	441	441	441
	Site rental	0	0	0	0	0	0	0	0
	Backhaul maintenance	625	625	625	625	625	625	625	625
Sector CapEx (€)	Sector cost	7000	6300	5600	4900	4200	3500	3500	3500
	Sector establishment fee	72	72	72	72	72	72	72	72
Sector OpEx (€)	Annual maintenance	350	315	280	245	210	175	175	175
	Rental for placement	483	483	483	483	483	483	483	483

Table 5 Economic parameters for 42 GHz layer

ate as part of the WiMAX or 42 GHz layer only. Service levels are high across all classes of user. The tool can also be used to design single layer networks at both 3.5 and 42 GHz, and comparison with the dual layer plan demonstrates that the hybrid solution is preferable. The 3.5 GHz only solution cannot meet the peak data rate required by the business and household users (although it can meet their contended requirement), while the 42 GHz cell plan is close in terms of NPV but provides much reduced coverage and service levels.

WiMAX network Oxford

This case study considers three sets of input data, each representing (to various degrees of accuracy) the

Channel frequency (GHz)	3.5	42
Channel bandwidth (MHz)	3.5	112
OFDM modulation scheme	64 QAM 3/4	QPSK 3/4
Channel bit rate (kb/s)	13,370	134,400
Max no. of channels per sector	6	8
Required C/I (dB)	30.3	17.1
Receiver sensitivity (dBW)	-103	-101
Adjacent channel rejection	4	34

Table 6 Radio parameters for both layers

	3.5 GHz layer	43 GHz layer
Coverage (%)	86.6	90.4
Service (%)	85.8	90.2
Single layer base sites	5	4
Dual layer base sites	8	
Sectors	35	33
NPV (M€)	1.593	1.584

Table 7 Summary of final cell plan

User class	Discounted subscription revenue over return period (k€)	Service (%)
Nomadic bundled	2,048	86.2
Nomadic only	1,014	84.9
Household	2,087	90.4
Business	4	87.1

Table 8 Per user class statistics of final cell plan

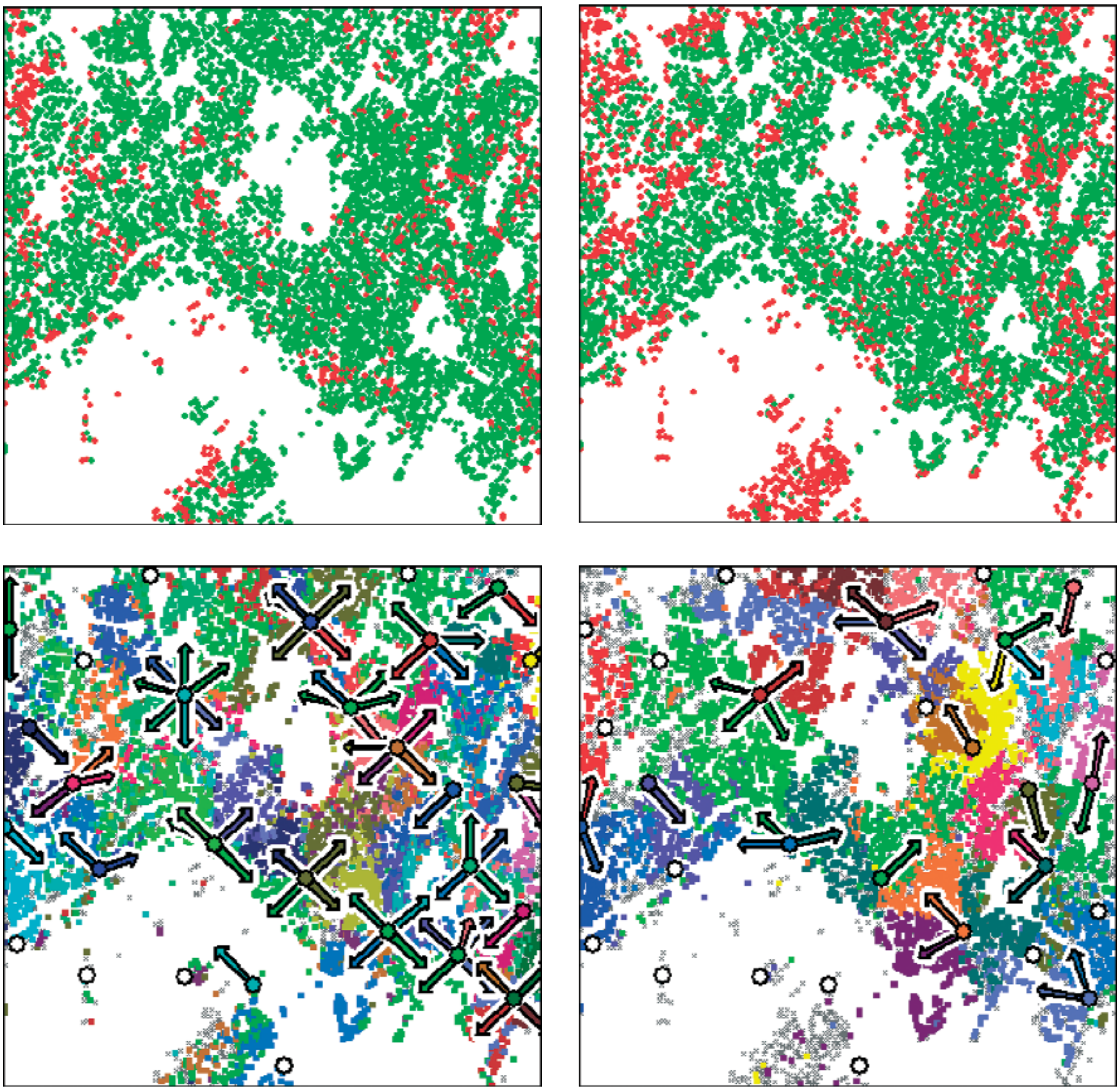

Figure 6 Service (top) and cell structure (bottom) for the WiMAX layer (left) and the 42 GHz layer (right) optimized cell plan

city of Oxford in the UK, with the aim of dimensioning the infrastructure requirements for a WiMAX network operating at 3.5 GHz. The network covers an area of 8.5 km^2, and contains 5,421 households that make up the potential subscribers (an average household density of 638 HH/km^2).

Low quality: No information about the potential households is assumed beyond their density; hence a random distribution of users across the network area is made. Without detailed building information, an empirical propagation formula is used to generate the input data, as given in [5][4)].

4) *It is assumed the area is mostly flat, with light-to-moderate tree densities. Base stations are at 30 m while all user equipment is at 6 m.*

Available bandwidth at 3.5 GHz (UK)	2 x 17 MHz blocks (17 MHz uplink, & 17 MHz downlink)			
Channel bandwidth (MHz)	7		3.5	
OFDM Modulation scheme	16-QAM	64-QAM	16-QAM	64-QAM
Channel bit-rate (kb/s)	17,455	26,182	8,727	13,091
Max no. of channels per sector	2	2	4	4
Required C/I (dB)	18.2	24.2	18.2	24.2
Receiver sensitivity (dBW)	-103	-97.2	-104.7	-98.5
Adjacent channel rejection (dB)	-11	-4	-11	-4

Table 9 The four possible radio configurations

Medium quality: This data set uses actual locations for the user and potential base station sites, but uses the same propagation model as the low quality data set.

High quality: Actual locations are again used, but in this data set, the propagation values are calculated using ray-tracing techniques [10] based on digital maps. RTP are located at the peaks of the household roofs, while the potential base stations are a combination of high buildings and 30 m masts.

The Echo tool is used to plan a network for each scenario, for a range of potential radio configurations (as shown in Table 9), with the resulting NPV of the final network shown in Table 10.

The results show that the detail present in the input data has a large, and potentially detrimental, effect on the conclusions that can be drawn from the dimensioning process. The lowest quality data, most typically used in dimensioning and assessing business cases in practice, leads to the conclusion that the area cannot be served in a cost-effective manner (since it yields a negative NPV in all configurations). The higher quality results show that this is not the case, both producing positive NPV cell plans. Furthermore, comparing the medium and high quality results shows the danger of applying a single radio configuration across all networks, since the most effective settings are highly dependant on the local environment.

Conclusions

This paper has presented a model and optimization algorithm based on tabu search for the automated design of hybrid wireless access networks. The model makes a technical and economic assessment of the network performance, allowing the optimization to find high quality cell plans. Two case studies have been presented that show the benefits of an automated planning tool. Firstly, they can be used to design cost-effective individual networks. Secondly, they can be used as part of the network dimensioning process to investigate the effect of the key design decisions. Case studies show that the planning process should use as accurate inputs as possible to avoid erroneous conclusions.

References

1 Louta, M D, Demestichas, P P, Loutas, E D, Kraounakis, S K, Theologou, M E, Anagnostou, M E. Cost-efficient design of future broadband fixed wireless access systems. *Wireless Personal Communications*, 27, 57–87, 2003.

2 Molina, A, Athanasiadou, G E, Nix, A R. The automatic location of base-stations for optimised cellular coverage: A new combinatorial approach. *IEEE Vehicular Technology Conference*, 1999.

3 Reininger, P, Caminada, A. Model for GSM radio network optimization. *2nd ACM Intl Conf. Discrete Algorithms and Methods for Mobility*, Dallas, TX, 1998.

Channel bandwidth (MHz)	7		3.5	
OFDM Modulation scheme	16-QAM	64-QAM	16-QAM	64-QAM
Low quality data				
NPV(K€)	-27.6	-153.8	-6.2	-37.3
Coverage (%)	90.1	87.7	92.3	93.2
Base-stations (Sectors)	4(8)	7(14)	4(10)	7(12)
Medium quality data				
NPV(K€)	26.1	-52.0	-4.3	-0.8
Coverage (%)	90.4	90.5	91.5	93.1
Base-stations (Sectors)	5(5)	6(9)	5(9)	6(10)
High quality data				
NPV(K€)	34.1	91.1	26.6	60.7
Coverage (%)	95.9	93.7	95.4	97.1
Base-stations (Sectors)	4(4)	3(3)	3(3)	2(2)

Table 10 Statistics for final cell plans after optimization

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4 Tjelta, T, Bråten, L E, Howson, C, Montalant, T. Broadband services for everyone over fixed wireless access networks (BROADWAN) – a project presentation. *IST Mobile and Wireless Summit*, Lyon, France, 2004.

5 IEEE. *IEEE Standard for Local and metropolitan area networks – Part 16: Air Interface for Fixed Broadband Wireless Access Systems- Amendment 2: Medium Access Control Modifications and Additional Physical Layer Specifications for 2-11 GHz.* IEEE802.16a-2003 Part 16, 281–283, 2003.

6 Hull, J C. *The evaluation of risk in business investment*. Oxford, UK, Pergamon Press, 1980.

7 Montagne, R, Elnegaard, N K. *Broadband access roadmap based on market assessment and technical-economic analysis*. EU FP6 Broadwan project, Deliverable D15, 2004.

8 Taplin, R K, Ryan, D M, Hurley, S, Allen, S M, Thomas, N J. *A demonstration of an automatic heterogeneous network planning tool*. EU FP6 Broadwan project, Deliverable D18, 2005.

9 Unbehaun, M, Kamenetsky, M. On the deployment of picocellular wireless infrastructure. *IEEE Wireless Communications*, 70–80, December 2003.

10 Bråten, L E, Chira, L, Craig, K, Grøndalen, O, Habalau, C, Palade, T, Puschita, E, Thomas, N, Tjelta, T, Willis, M J. *Interference in and between wireless access systems*. EU FP6 Broadwan project, Deliverable D10, 2005.

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Technology outlook for broadband and mobile networks

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Broadband networks have exhibited strong growth in their subscriber base over the last few years as low-cost high data rate offers have rolled out over both DSL and cable networks. At the same time mobile networks continue to grow with more than 1.5 billion subscribers worldwide, a magnitude more than either fixed broadband or even digital TV networks. With the advent of 3G, mobile networks are even starting to offer the perspective of broadband performance. But what are the trends today and the underlying technologies that will fuel future growth in the broadband and mobile network landscape?

The current trend for broadband and mobile networks is for Triple Play. Hard wired DSL and cable networks offer TV, telephone and data services as do the latest generation of mobile phones. Indeed Triple Play is no longer the right term as innovative service offers abound. It is clear that all networks must incorporate the technologies that enable this multiplicity of services wherever the user may be. We are also experiencing fixed-mobile convergence today as technology offering seamless handover between GSM and fixed broadband networks is made commercially available. A second form of convergence sees the broadcast and telecommunications worlds coming together, both for TV content over DSL networks and in the implementation of DMB or DVB-H mobile TV deployments.

So the challenges for the technologies involved are clear. The user will demand ubiquitous access to multiple services demanding ultra-fast data rates. Technology must provide a solution everywhere, not just in the large cities and not just for those who are close to a DSLAM. Mobile networks will have to embrace multicast or broadcast technologies in order to avoid the risk of saturation. The user will expect seamless functionality over different physical network connections, be they fixed or mobile. In order to meet the aspirations of the user, increased use of optical, wireless and multicast technologies is to be expected.

1 Introduction

The last few years have seen strong growth in both the deployment of broadband networks and the subsequent subscriber take-up. At the same time the mobile telephone has become a pervasive possession in the modern world. As the means to communicate evolve, so too do the services offered and consumed. The basic internet connection via modem over a switched telephone line has evolved to become a broadband connection offering the possibility of not only Internet browsing, but also IP telephony and full definition television. A similar evolution is evident with the mobile telephone. Initially used only for voice calls, we now have a myriad of services offered including live TV.

The increased prevalence of television and other video services is indicative of one of two forms of convergence that may be noted today. In the past broadcast and telecommunications actors operated in their own isolated worlds but they are now brought together by the implementation of what were traditionally broadcast services over telecommunications networks. This cooperation is set to continue as new mobile TV networks, based on standards such as DMB or DVB-H, are rolled out using both the mobile telephone networks and a specific broadcast technology.

Fixed-mobile convergence has also started to become a reality. Mobile telephone operators are already offering services which allow seamless handover from a GSM network to a fixed line home or office connection. The notion of a portable terminal containing our favourite content is epitomised by the iPod and wireless connectivity to both mobile and fixed networks is clearly a must for such devices.

In the next section of this article an overview of today's broadband and mobile landscape will be presented. In Section 3 some of the current trends will be examined together with the underlying technologies. The outlook for the implementation of different technologies will be the subject of Section 4.

2 The Broadband and Mobile Landscape

Over the past few years the number of subscribers to broadband service offers has risen significantly and it is expected that the trend will continue for the years to come. Figure 1 shows data from IMS Research [1] showing that worldwide broadband subscribers doubled from 100 million in 2003 to 200 million in 2005. They also predict that the subscriber base will double again by 2009 resulting in more than 400 million broadband subscribers worldwide.

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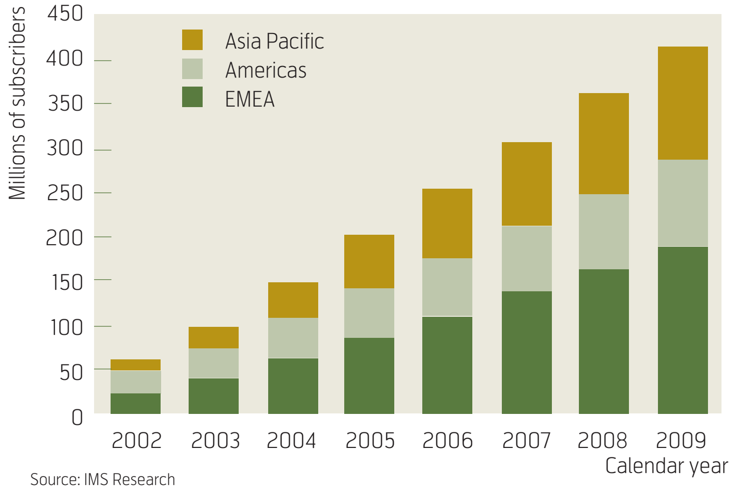

Figure 1 Broadband subscriber growth.
IMS Research show that the worldwide broadband subscriber base has doubled from 2003 to 2005 and they predict a further doubling to attain more than 400 million subscribers by 2009

We have also witnessed a shifting of the "broadband goalposts" over the last two years as the data rates offered to customers have evolved. A typical broadband subscription two years ago entailed a downstream data rate of 512 kbit/s. Today offers of up to 20 Mbit/s are the baseline for operators in countries like France, and at an equivalent price to that being paid two years ago for a mere 512 kbit/s.

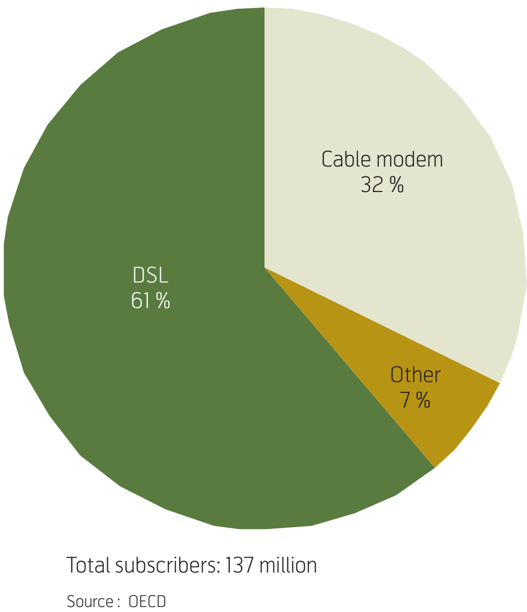

Figure 2 Broadband subscriptions by technology.
Most broadband subscribers access their service by DSL over copper telephone wires. Coaxial cable TV networks are also an important access means. The "other" category is dominated by optical fibre to the home technology which is already significant in Japan, for example

The technologies implemented for these broadband service offers are essentially twofold today. The majority of customers obtain their broadband service by means of Digital Subscriber Line (DSL) technologies over the copper telephone line network [2]. Telecommunications operators have introduced new equipment into their mainly existing networks to enable the broadband offer. In certain countries, and notably in North America, the coaxial cable networks, deployed for broadcast TV services, have become the leading technology for broadband take-up. Figure 2 shows the breakdown of broadband subscriptions by technology for the OECD countries [3].

So far, we have only considered fixed broadband services, so what about the mobile landscape? The first important feature to note is the huge number of subscribers to mobile phone services. There were already 1500 million subscribers worldwide in 2004 and it is anticipated that this figure will grow to around 2300 million by the year 2009 according to InStat. This is a much higher number of subscribers than either the broadband market or even the number of digital TV homes (Figure 3).

In a similar way to the fixed broadband offers, we have seen the data services over the mobile networks grow in speed from only a few kbit/s initially up to the 384 kbit/s offered today in 3G networks. Whilst this may be considered broadband for a mobile service it is still a long way short of the data rates commonly available in fixed broadband networks.

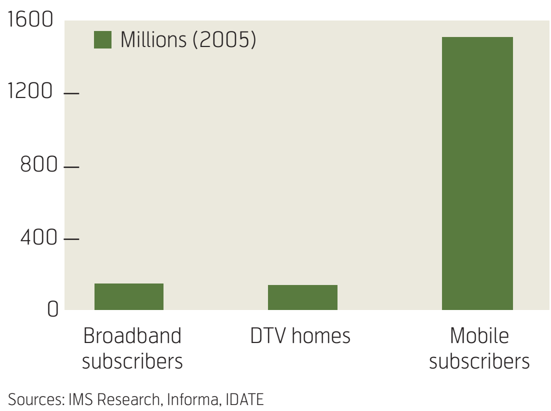

Figure 3 Mobile subscribers compared to broadband and digital TV.
The number of subscribers to mobile phone services greatly exceeds the numbers for broadband access or even the number of digital TV homes. This subscriber base is an important asset for telecommunication operators in the competition to provide new services

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3 Current Trends

At the same time as broadband and mobile networks have increased their penetration and improved their performance, the services offered have evolved. Today a number of important trends are evident concerning not only the services offered to the end user but also the interactions between the networks and their actors.

Not so long ago the consumer was connecting to the internet via a dial-up modem. The advent of broadband initially offered the advantages of both higher data rates and an "always on" connection. But now this broadband connection is not simply for internet use, it is also supplying full definition broadcast TV and enhanced telephone services. This Triple Play offer is already widespread in some European countries, such as France, and it will rapidly become the norm everywhere. As an example of the technologies underpinning such an offer we can take a look at the AOL box (Figure 4). This terminal incorporates a high speed ADSL2+ modem and voice over IP capability. Wireless connectivity for voice calls is supported via DECT whilst IEEE 802.11g Wi-Fi enables wireless connectivity for data. An Ethernet port allows connection to a set top box for TV. Such terminals are used for offers in France whereby a subscriber has high speed internet access, a broadcast TV offer and unlimited local and national telephone calls for less than 30 Euro a month.

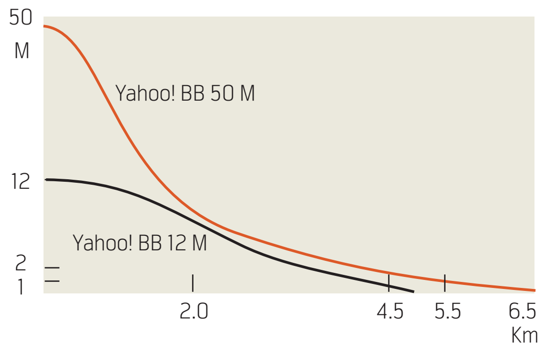
A similar evolution in services is also taking place on the mobile telephone where a Triple Play offer is also available. It is now possible to access the internet, to receive regular broadcast TV and to undertake video calling. In Japan and Korea 3G penetration is already up to 40 % and, whilst this is not yet the case in Europe, such 3G networks are already used as the basis for such an offer. One interesting trend to be noted is that music and video are becoming key services on the mobile networks and a personalisation of the services consumed is evident. On the French Orange 3G network 73 % of the TV audience is for thematic channels.

Up to now we have been treating the fixed and mobile worlds separately but an important current trend is their convergence. The first services offering users seamless handover between their GSM mobile telephone and a wireless connection to their residential broadband modem are already on the market. Whilst outside the home the telephone is used as a normal GSM mobile terminal but once the user is within range of his broadband modem a connection is established via Bluetooth or Wi-Fi and the call is routed over the broadband network at a lower per minute cost to the user. One example of such a service is BT Fusion (Figure 5) which is offered in the United Kingdom.

Figure 4 The AOL Box.
Internet, TV and IP telephone services over broadband are enabled by such terminals incorporating a high speed DSL modem and wireless connectivity for voice and data connections in the home

The other notable convergence trend that we are witnessing today is the coming together of broadcast and telecommunications actors. Already we have seen that traditional broadcast content, notably TV, is being offered over both the broadband and mobile networks operated by telecommunications operators. It is also becoming clear that the existing unicast technology employed in mobile networks for TV delivery is likely to provide inadequate capacity as demand grows. This has led to the spawning of a number of multicast/broadcast technologies that are specifically designed for mobile TV services. Some of these technologies, such as DVB-H and DMB, are targeting the use of traditional broadcast frequencies

Figure 5 BT Fusion.
An example of fixed-mobile convergence: seamless handover is undertaken between the normal GSM mobile phone network and a wireless link to the residential broadband modem



Country	Loops < 1Km
USA	~10%
UK	~20%
Italy	~30%

Source: IEEE

Figure 6 The Local Loop Limitation.
In order to support data rates of 50 Mbit/s or more loop line lengths should be less than 1 km. This will require extensive re-engineering of the local loop in many countries

offering the perspective of terminals that operate in both broadcast and mobile phone frequency bands and necessitating cooperation between these networks to support interactive services. S-DMB TV and radio services in Korea already cover 90 % of the population and more than 500,000 users have signed up, whilst in Europe the first commercial DVB-H deployments are underway in Italy.

4 The Outlook

In order for the current service trends to become widespread reality, there are a number of technology pre-requisites. We have seen that Triple Play over broadband is a reality today but it is not yet available everywhere due to inadequate high speed network coverage. If we take 50 Mbit/s as a target value for high speed broadband connectivity we note that whilst 50 Mbit/s DSL offers are commonplace in Japan and Korea, this is not yet the case in most of the world. There is also a fundamental technological issue with the length of the line connecting the customer. In order to provide 50 Mbit/s using VDSL technology the line length should be kept below 1 km (Figure 6). This will require new technologies or extensive re-engineering of the local loop in most countries as few existing lines are as short as this. As a first step we are already seeing certain operators adding new DSLAMs to their networks in order to improve high speed DSL network coverage. There is also an opportunity for appropriate use of wireless technologies, such as WiMAX [4] which offers the added value of nomadic, or even truly mobile, services. It is interesting to note that WiBRO, a close relative of WiMAX, is already commercially deployed in Korea ... But perhaps the most important technological evolution to enable ubiquitous high speed access will be the increased deployment of optical fibre networks in the local loop. It is interesting to note that in Japan there are already 100 Mbit/s residential access offers built on fibre-to-the-building technology.

In the mobile world, widespread deployment of Triple Play services will require the implementation of broadcast technology. Figure 7 shows that broadcast technologies such as DVB-H will be needed to bring services to many users simultaneously and it is expected that such technology will be routinely incorporated in mobile phones together with 3G capability. However there are today a number of different broadcast technologies vying for a place in the future mobile TV market place. DVB-H [5] is a handheld derivative of the European digital terrestrial TV standard, DMB is a derivative of the Digital Audio Broadcasting (DAB) standard and MediaFLO [6] is a technology initially developed by Qualcomm. All three standards are technically able to provide mobile TV services effectively as numerous trials and initial commercial deployments have already demonstrated. One key issue that could hamper the rapid deployment of such technologies is the availability of spectrum. DVB-H in particular was designed for use in the UHF broadcast TV bands. This spectrum is currently heavily used with the simulcast of analogue and digital TV services. Once analogue TV is switched off (2010–2015) some spectrum will be freed up and mobile TV is one of a number of potential users, others including High Definition TV and mobile communications. In the meantime DMB services in Korea are operating at both S-Band and VHF frequencies, whilst DVB-H trials in the USA are using the L-Band (Figure 8). Each of the potential bands has its own advantages and disadvantages concerning antenna size, number of transmitter sites and ultimately cost per subscriber. The most likely outcome of the current situation is that all three broadcast standards will co-exist in the future with a number of different frequencies being employed.

5 Conclusions

We have seen that both broadband and mobile networks have exhibited strong growth in their sub-

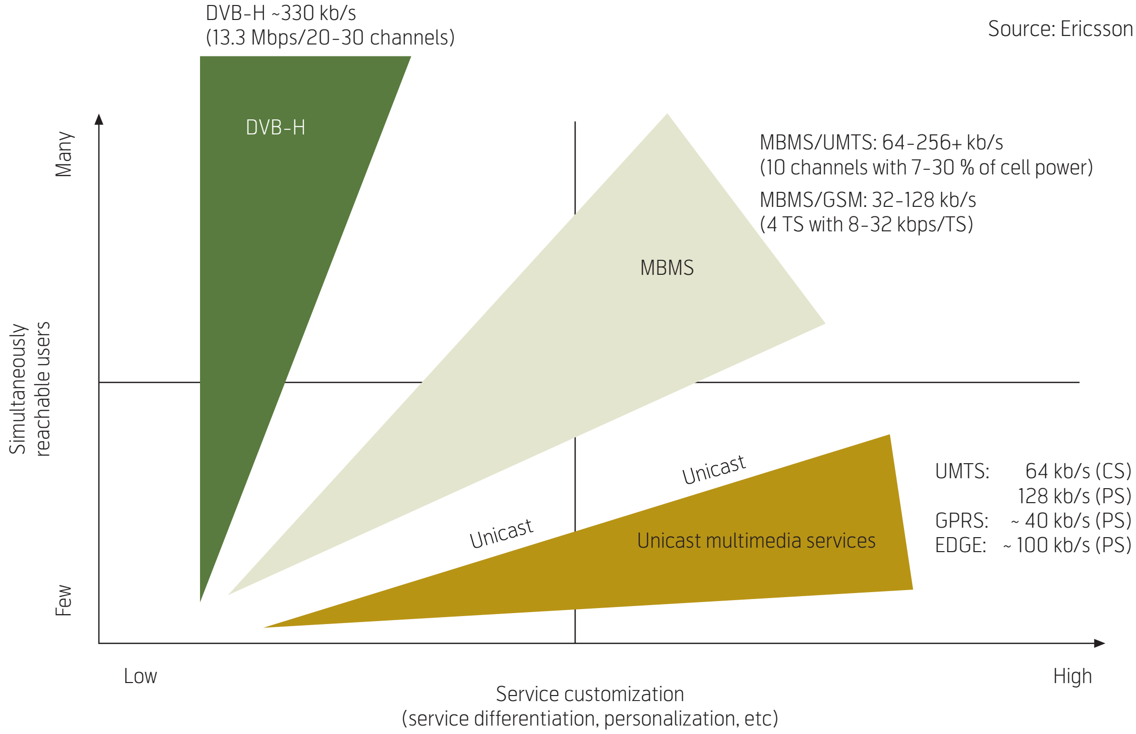


Figure 7 Broadcast technology as a key enabler for mobile services.
In order to support a wide variety of high data rate services (video, TV, etc) broadcast technologies such as DVB-H will be an essential addition to the world of mobile telephony

scriber base over the last few years. At the same time the service offer has evolved to embrace Triple Play with the packaging of TV, telephone and data services.

A number of important current trends have been identified. We are experiencing fixed-mobile convergence as technology offering seamless handover between GSM and fixed broadband networks is included in commercial offers. A second form of convergence sees the broadcast and telecommunications worlds coming together, both for TV content over DSL networks and in the implementation of DMB or DVB-H

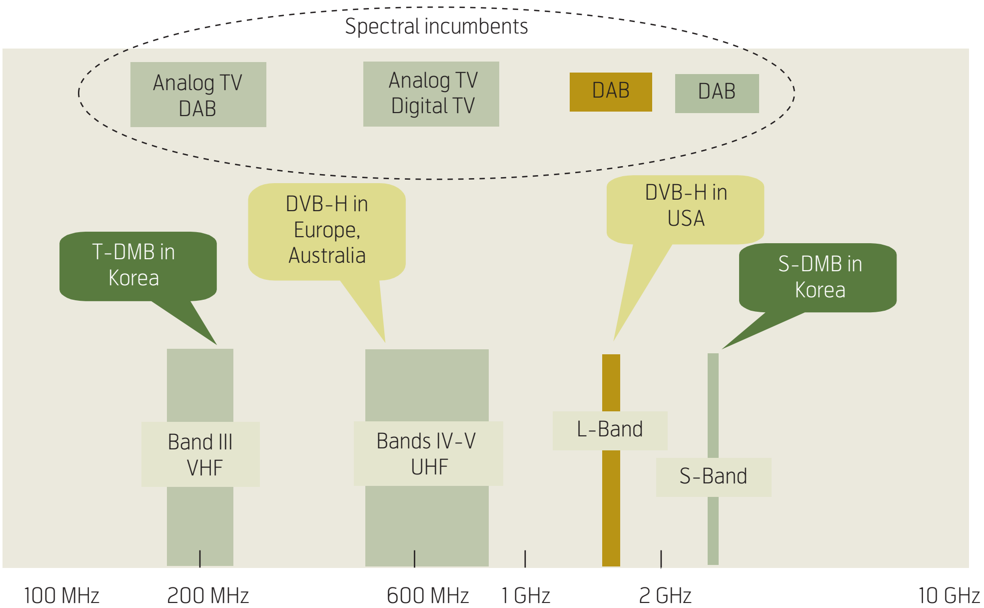


Figure 8 Which band for mobile TV?
TV broadcast bands IV and V are the main target for mobile TV deployment, but simulcast of analogue and digital TV leaves little room in the short term. Several other bands are also potential candidates and are already used in trial and commercial deployments today

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mobile TV deployments. Connecting to a DSL modem for TV services and the use of mobile telephones incorporating DMB or DVB-H are set to become commonplace.

The challenges for the technologies involved are clear. The user will demand ubiquitous access to multiple services demanding ultra-fast data rates. Technology must provide a solution everywhere, not just in the large cities and not just for those who are close to a DSLAM. Mobile networks will have to embrace multicast or broadcast technologies in order to avoid the risk of saturation. The user will expect seamless functionality over different physical network connections be they fixed or mobile.

In order to meet the aspirations of the user, increased use of optical, wireless and multicast technologies is to be expected. The local loop length limitation must be removed in broadband networks and the right regulatory decisions will be required in order to resolve the spectrum issue facing the development of mobile TV.

Acknowledgement

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References

1 *IMS Research Broadband Access Database.* August 2, 2006 [online] – URL: www.imsresearch.com

2 *DSL Forum.* August 2, 2006 [online] – URL: www.dslforum.org

3 *OECD Broadband Statistics*, June 2005 [online] – URL: www.oecd.org

4 *WiMAX Forum.* August 2, 2006 [online] – URL: www.wimaxforum.org

5 *DVB-H, Global Mobile TV.* August 2, 2006 [online] – URL: www.dvb-h.org

6 *MediaFLO.* August 2, 2006 [online] – URL: www.mediaflo.com

7 *Broadband services for everyone over fixed wireless access networks.* August 2, 2006 [online] – URL: www.broadwan.org

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Next generation Broadband Wireless Access systems

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This paper presents the status and anticipated development of Broadband Wireless Access (BWA) systems operating at high and low frequencies. The high and low frequency BWA systems are on different stages in their development. Low frequency systems have attracted much attention and are already on the market. The next generation of such systems is only a few years away.

The first generation high frequency systems, on the other hand, have not been a commercial success. The reasons for this are discussed, as well as the roles the two types of BWA systems are expected to play in the future broadband access market. Based on this a list of requirements for next generation high frequency BWA systems is made and the implications for the choice of some of the key system parameters are described.

Introduction

Broadband Wireless Access (BWA) is an attractive alternative to wire or fibre based broadband access solutions. The main benefits of BWA are rapid deployment, limited environmental intervention and the possibility to offer nomadic, portable and mobile services. BWA can also be a complement to wired access solutions, e.g. to offer the customers an additional nomadic or mobile service or as a backup system with different outage characteristics.

BWA systems can be divided into two classes based on their operating frequencies. Low Frequency BWA (LF-BWA) systems operate at frequencies below 20 GHz and High Frequency BWA systems (HF-BWA) operate at frequencies above 20 GHz.

This paper will present evaluations and results on LF-BWA and HF-BWA systems based on work in the project BROADWAN, partly funded under the Information Society Technologies (IST) priority of the European Commission Sixth Framework Programme.

Some fundamental differences of operating at high and low frequencies

Radio communication at frequencies above 20 GHz has until now mainly been used for point-to-point (P-P) radio links and to a much lesser degree for point-to-multipoint (P-MP) radio access. But due to high equipment costs, P-P links can only be a good access solution for large users, e.g. large companies. Using P-MP radio systems to provide access implies sharing some of the equipment costs between the users. In addition, the much higher number of users associated with access systems gives better economy of scale and hence cheaper equipment.

Radio access systems operating at high frequencies have some fundamental differences from lower frequency systems due to their different radio propagation characteristics.

At high frequencies the radio waves experience great attenuation when going through objects like walls and vegetation. In practice these systems should be considered as requiring that there are no obstructions between the transmitter and receiver antennas, usually referred to as the line-of-sight (LOS) requirement. Since not all users in an area are able to obtain LOS with the base station antenna, the coverage of high frequency systems will be lower than for low frequency systems which can operate also under non-LOS conditions. In order to obtain the same coverage with HF-BWA, the coverage in an area can be increased by using local distribution from a common terminal; a solution that can also be economically attractive for the customers.

High frequency radio waves will also be significantly more attenuated by precipitation than lower frequency waves, which is one factor that limits the range of such systems. Based on meteorological statistics for different kinds of precipitation, the systems can be designed to have a given availability as expressed as the minimum percentage of time the service will be available. In each case, the operator must make a trade-off between range and availability.

In addition to precipitation, there are many other parameters that determine the range of the system, like transmitted power, the size of the antennas used and the robustness of the signal formats used to represent the data. The range of high frequency radio access systems will typically be between 2 and 5 km. This should be compared to the range of lower frequency systems like fixed WiMAX systems operating

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at 3.5 GHz, which typically have a range from 3 to 10 km under non-LOS conditions.

Another important difference between high frequency and lower frequency radio access systems is the width of the customer antenna beam. For the same antenna size, the beam gets narrower as the frequency gets higher. At frequencies above 20 GHz the beams are very narrow; the opening angle is typically only a few degrees. At lower frequencies the opening angle is much wider. Also, in order to operate in non-LOS conditions, especially for portable and mobile use, the opening angle of the antennas must be wide enough to receive all the strongest signal components (which might for example have been reflected by buildings and arrives at the receiver antenna from directions different from the one towards the transmitting antenna). The narrow customer antenna beams in high frequency systems reduces interference in the network.

The roles for LF-BWA and HF-BWA systems

The very different characteristics of LF-BWA and HF-BWA systems make them suitable for different roles in tomorrow's communication networks.

The main application for LF-BWA will probably be for providing personal broadband services to nomadic, portable and mobile users having terminals such as laptops, PDAs and smartphones. In addition LF-BWA will be used for fixed broadband access, e.g. in certain niche markets.

One concern using LF-BWA systems for providing fixed broadband access is the limited amount of spectrum available. It is expensive for an operator to buy more spectrum to increase the capacity offered to each user. Alternatively, the operator can increase the base station density (decrease the cell sizes), but this is also expensive. Hence, at some point the cost of increasing the capacity will be very high.

There is still a lot of potential for making LF-BWA systems more spectrum efficient as will be exemplified in the next sections. And this will make it possible for LF-BWA systems to nearly match the capacities that will be offered to typical users with wired access technologies in the near future. But experience has shown that the bitrates the average user is offered from fixed wired broadband access systems seem to follow a Moore's law for bandwidth characterized by a doubling every 1.9 years (44 % increase each year) [1]. Hence, when the potential for spectrum efficiency improvements has been taken out, it will be difficult to match the wired access bitrates with LF-BWA systems. For example, if the spectrum efficiency potential corresponds to an improvement by a factor of 10, LF-BWA will only be able to match wired access bitrates for about 6–7 years. If the improvement factor is 5, LF-BWA will lag behind after about 4–5 years.

HF-BWA systems will only be used for providing fixed and nomadic services since operation at these high frequencies require LOS conditions between the base station and user antennas. In contrast to LF-BWA, there are very large portions of yet unused bandwidth available at frequencies above 20 GHz. For instance, there are 3 GHz of continuous bandwidth (40.5 – 43.5 GHz) reserved for BWA (Multimedia Wireless Services – MWS) in Europe. Since these frequencies will be used for LOS communication, the available bandwidth can be doubled by employing polarization discrimination. These portions of spectrum represent an enormous potential transport capacity. Hence, HF-BWA systems will be able to match wired access bitrates for many years to come.

The main drawback of HF-BWA systems is the LOS requirement which reduces coverage for these systems. But HF-BWA can be used for providing broadband access to a neighbourhood if there is a place within the neighbourhood having LOS with the base station. The individual users can then be provided with broadband by a local distribution network, e.g. a local Wi-Fi or Ethernet network.

Status of LF-BWA

Most of the interest on wireless broadband access solutions today focuses on systems operating in frequency bands below 6 GHz for providing fixed, nomadic, portable or mobile services. For providing mobile services, the operating frequency should be below 3 GHz. The capacity that can be offered matches that which most customers get with ADSL and cable access today, i.e. about 1 Mbit/s.

The interest in LF-BWA was initially inspired by the success of Wi-Fi. The success of Wi-Fi is reflected in the fact that it is integrated into most laptop computers sold, and millions of homes have installed a Wi-Fi access point. Much of the success of Wi-Fi is due to the certification program that is being carried out by the Wi-Fi Alliance, which ensures that equipment from different manufacturers work together and that the equipment conforms to the standard.

The LF-BWA systems that have attracted most of the attention are based on the IEEE 802.16 standard, which is a cousin of the IEEE 802.11 standard which

Base Station from Aperto　Outdoor subscriber station from Alvarion　Indoor subscriber station from Airspan

Figure 1 Examples of certified fixed WiMAX equipment

is the basis for Wi-Fi. And with the Wi-Fi Alliance as a model, the LF-BWA industry has established the WiMAX Forum, which runs a certification program similar to that run by the Wi-Fi Alliance.

Over the last years two main types of LF-BWA systems have crystallized. The first type of system is targeted for fixed and/or nomadic use and is typically used as ADSL or leased line replacement for the consumer and business markets. The services are typically Ethernet based and several users are often connected behind each terminal.

The other type is targeted for portable and mobile usage and is used to provide the users with high speed data services often referred to as personal broadband. The terminals are laptops, PDAs, and smartphones. The services are typically IP based and each user has his own terminal. Some consider such LF-BWA systems as competitors to 3G, others consider them as complementary solutions.

The two types of systems are both based on the IEEE 802.16 standard, but they use different options from the standard, for example for the air interface.

The fixed/nomadic equipment was the one that reached the market first. The WiMAX Forum has since January 2006 certified equipment from several manufacturers, including outdoor and indoor subscriber units and micro and macro base stations.

The first portable/mobile equipment that became available was produced for the Korean WiBRO service. WiBRO was launched as a commercial service in Seoul in mid-2006. The users are offered up to 3 Mbit/s (typically 1 Mbit/s) for a monthly fee between $30 and $40. The system provides mobility up to speeds of 60 km/h, often referred to as simple mobility.

WiMAX Forum is currently preparing for certification of Mobile WiMAX equipment, which is expected to reach the market in 2007.

Next generation LF-BWA systems

In the next generation of LF-BWA systems we will see a wide range of improvements for increasing the systems' spectrum efficiency. This includes:

- Use of TDD
- Advanced Radio Resource Management (RRM)
- Advanced antenna solutions.

Use of TDD

In a radio access system, data are sent both from the base stations to the user terminals (downlink) and

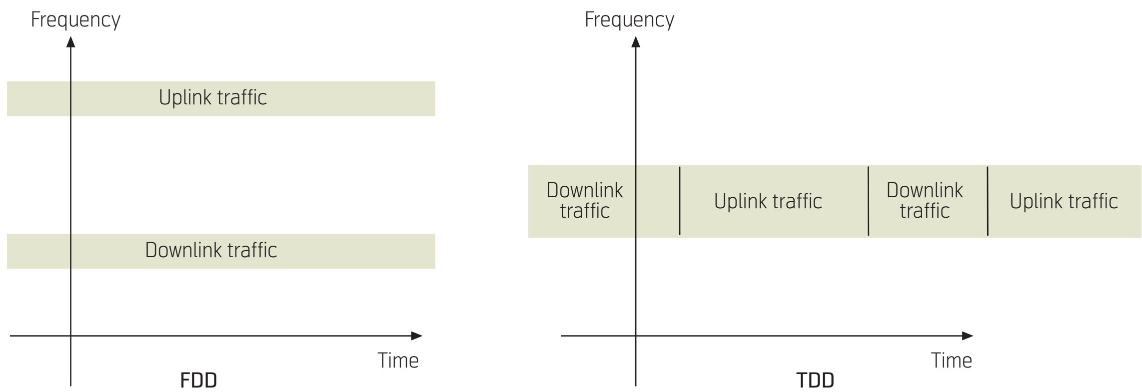

Figure 2 Principle of Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD)

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from the user terminals to the base stations (uplink). To avoid that the uplink and downlink transmissions disturb each other, the spectral resources must be divided between them in some way. The two most usual ways of doing this is called Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD).

In FDD systems the downlink and uplink signals are transmitted in different frequency bands, while in TDD systems the uplink and downlink signals are transmitted in the same frequency band but in different time slots as shown in Figure 2.

Use of TDD is not new; in fact several LF-BWA manufacturers produce TDD equipment today. The reason for including this bullet under next generation LF-BWA systems is that TDD is expected to play a more dominant role.

TDD has many advantages when compared to FDD, including:

- TDD enables adjustment of the downlink/uplink ratio to match the actual traffic pattern that occurs, while with FDD downlink and uplink always have fixed and generally equal DL and UL bandwidths. This flexibility might be limited due to interference problems, as described below.

- TDD assures channel reciprocity for better support of link adaptation, MIMO and other closed loop advanced antenna technologies.

- TDD simplifies antenna adjustment in nomadic systems. With TDD the antenna pointing direction can be optimized based only on the received (downlink) signal since this will automatically be the best direction for the uplink signal as well. In FDD systems the optimal pointing directions can be different for the uplink and downlink and finding the direction that gives the best performance takes much longer time and is much more difficult.

- Since TDD only requires a single channel while FDD requires two, it is much easier to adapt TDD systems to varied global spectrum allocations.

- Transceiver designs for TDD implementations are less complex and therefore less expensive than for their FDD counterparts.

The main drawback of TDD systems is that interference both within an operator's network and between different operators' is more serious than for FDD systems. Within an FDD operator's network, there can be no interference between the uplink and downlink since these use different frequencies. With TDD on the other hand, the uplink and downlink can interfere since they use the same frequencies. One way to avoid this interference is to synchronize all the base stations in the network so that they all transmit and receive during the same time intervals. In this way the interference situation will be the same as in a FDD network. But doing this partly takes away one of the main benefits of TDD, namely the adaption of the uplink/downlink ratio to match the actual traffic pattern. The uplink/downlink ration cannot be optimized for each base station individually, only for the network as a whole.

A TDD network will also interfere more into other operators' networks. This has traditionally been solved by introducing relatively large guard bands between the TDD operator's frequency allocation and the adjacent frequency allocations, which reduces the spectrum efficiency significantly. But the next generation LF-BWA systems are better prepared for reducing this problem.

The problem exists both between operators using the same frequencies in neighbouring areas (co-channel interference) and between operators in the same area using adjacent frequencies (adjacent channel interference).

In both cases the interference problems can be reduced if the operators synchronize their base stations. But there will also be cases where the optimal uplink/downlink ratio is very different for the two operators, e.g. if the operators target different types of customers generating different traffic patterns making it difficult for the operators to agree on a common ratio. Then the interference problem can be reduced if they cooperate on the placement of their base station antennas.

For the adjacent channel interference case, the problem can be reduced by improving the out of band emissions from the base stations and user terminals. This can for example be achieved by improving the filters on the transmitter outputs and using more linear power amplifier or improved pre-distortion techniques.

With these techniques studies have indicated that no or very narrow guard bands will be needed between different operators' frequency allocations [2, 3].

Advanced Radio Resource Management

The Radio Resource Management (RRM) consists of the network functions that decide how the available spectrum resources (often in the form of time/frequency slots) are shared between the user terminals and base stations in the network. The RRM can be centralized where all decisions are made by a single unit, or distributed where the decisions are based on sub-decisions different places in the network. In a distributed RRM system for example, a central unit can decide how much of the spectrum resources that are allocated to each base station and then each BS can decide how its spectrum resources are divided between the user terminals and the BS itself.

Up to today the usual approach has been to do frequency planning where each sector is allocated a fixed set of channels and no adjacent cells or sectors use the same frequency channels. Such schemes guarantee a minimum C/I ratio, but is not the most efficient way to use the frequency resources.

Future approaches will allocate the same frequency channels to all sectors and cells in an area. Each frequency channel is then divided into sub-channels where each sector is allocated a set of subchannels and different users in a sector are allocated to different sets of subchannels depending on the interference and channel conditions they experience. This allocation is done dynamically by the RRM to optimize the use of the spectrum. The RRM algorithm can be very advanced taking into account such factors as the traffic load and traffic type of each sector. This approach is much more flexible than the traditional fixed frequency planning approach and provides a much better use of the spectrum resources.

Advanced antenna solutions

Advanced antenna solutions can be grouped into three classes of methods; transmit diversity, beamforming and spatial multiplexing.

Transmit diversity is used to increase the robustness of signals by using several transmitting antennas. This is achieved by exploiting the fact that signals transmitted by spatially separated antennas will experience physical channels with different fading. Since it is unlikely that all the physical channels will experience deep fades simultaneously (more unlikely the more antennas that are used), the receiver will see a good quality signal most of the time. A simple yet efficient example of this is the Alamouti scheme where two antennas are used at the base station and one antenna at the user terminals. In transmit diversity schemes the data stream to be transmitted is encoded and distributed among spaced antennas and across time. The increased robustness of the transmissions can be used for reducing the fading margin and/or increasing the capacity. To increase the capacity, higher order modulation schemes and/or higher rate forward error correction schemes can be used.

With beamforming the system uses multiple antennas to shape the antenna radiation pattern to improve coverage and capacity of the system and reduce outage probability. The beamforming can be performed in different ways depending on what the system tries to optimize. It can for example be used to optimize the size and shapes of sectors, to track moving devices or to maximize the signal-to-noise plus interference (C/(N+I)) ratio for individual users.

Spatial multiplexing is used to get higher peak bitrates and increased throughput. With spatial multiplexing, multiple streams are transmitted over multiple antennas. If the receiver also has multiple antennas, it can separate the different streams to achieve higher throughput than single antenna systems. If both the transmitter and receiver have N antennas, the throughput can theoretically be increased by a factor N if the channel has sufficiently rich multipath characteristics.

Advanced antenna solutions is an efficient way to increase the capacity of LF-BWA systems, and it is expected that such techniques will be used to increase the peak bitrates by a factor of 3 or more within the next couple of years.

Status of HF-BWA

Despite several previous attempts by various standardisation organisations to produce specifications for High Frequency BWA (HF-BWA) systems, these efforts have so far resulted in limited deployment of such systems. The main reasons for this are:

- The customers have not demanded very high bitrate services yet, since there have not been many interesting services available that required such high bitrates. And the HF-BWA systems have not been able to compete with other solutions for providing low to moderate bitrates.

- The equipment has been too expensive. The main reason is that the volumes produced have been low. The equipment has also often been based on manufacturers' existing radio link equipment which has been modified to be used as an access system. This has resulted in systems which are not optimized for access and thus do not have the best performance and flexibility for such usage.

The first reason of no demand for high bitrates will soon disappear. With the strong increase in bitrates fixed wired access operators offer their customers, attractive services exploiting high capacities will appear. Hence, a demand for high capacity solutions will come.

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But in order to make HF-BWA a success, it is also necessary to consider the other reason of too expensive equipment. The 40 GHz work in the BROADWAN project has aimed at outlining an economical high capacity radio solution that meets the demands for the next ten years. A strong focus has been kept on adaptive and efficient resource utilisation, on efficient on demand allocation and on advanced technology in every aspect. The results do not represent a complete specification of a BWA system, but outlines the architecture of such a system and recommends solutions for some of the key functions. The system outlined can be used as a basis for further work and standardization of a new BWA system.

Main requirements for next generation HF-BWA system

To have successful HF-BWA systems, it is necessary to develop better standards which have lower cost and better fit the demands of tomorrow's broadband access customers.

Some of the most important requirements for a new HF-BWA system are:

- **Low cost**:
  This is a key design objective. Low cost means affordable and easy to install customer premises equipment, low cost (per user) base stations and low operational costs.

- **High capacity**:
  The system must be able to provide demanding customers with high capacity in both directions (uplink and downlink) at a low cost per delivered bit. The average user should be offered a downlink bitrate not less than that corresponding to ADSL2/2+ with flexible resource allocation between up- and downlink; the demanding user requires 25 Mbit/s in both directions.

- **Spectrum efficient**:
  Spectrum has become a very valuable resource and the spectrum license costs can be very significant for an operator. Hence, it is very important that as many customers as possible can be served with a given amount of spectrum.

- **Flexible resource allocation**:
  A system which can adapt to different traffic patterns will significantly reduce the risks involved for an operator in deploying a network. For example, it can be difficult for an operator to determine the optimal split of the spectrum resources between the uplink and downlink. And to make it even worse, the optimal split may be different at different times of the day and might change over the years as new types of services gain popularity.

- **Good QoS and security support**:
  The system must be able to provide the QoS levels on the radio link necessary for a multiplicity of services including video, voice over IP and applications with even more stringent requirements such as online gaming.

- **Optimised for IPv6**:
  The general trend towards IP based networks must be taken into consideration and hence the system should be optimized for carrying IPv6 traffic. Basing it on IPv6 prepares the system for the future Internet with i.a. larger address space and better support for security and QoS.

- **Scalable**:
  The system must be designed so that it is easy to increase the system capacity as the number of customers and the bandwidth needs increase. This means that sectors and base stations can be added to the network without impact on existing customers.

- **Future-proof**:
  Sufficient flexibility must be built into the system making it able to use new protocols and new coding and modulation schemes that will be developed in the future.

- **Serve all types of customers**:
  The system must offer an attractive solution to different types of customers providing them with the services they require at a low cost per delivered bit. The system should primarily be targeted for operation in urban and suburban environments where it will be a replacement or complement to wire, cable and optical fibre.

  Serving all types of customers is important in order to allow the same network to be used by different types of customers at different times. For example, broadband access can be provided to both business users and households, where the business users dominate during the working hours and households during the evening, night and weekends. In this way the network can be more fully exploited at all times leading to lower costs for all.

These requirements have major impact on several of the system's main parameters like duplexing method, multiplexing format and channel bandwidths. In addition it is necessary to improve some of the functionality built into the system, for example for interference control. The next sections will describe the recommended choices and proposed solutions.

Duplexing method

One of the main choices that must be made when specifying a HF-BWA system is the duplexing method. This choice has major impacts on the system architecture.

The main arguments for choosing either FDD or TDD are the same as presented for LF-BWA systems. But since the user antennas have a much narrower opening angle in the HF-BWA case, the special interference problems in unsynchronized TDD systems are somewhat less serious and easier to control. Interference between user terminals becomes much more unlikely and interference between base stations can be controlled by careful deployment and/or by using interference suppression techniques as will be described later.

The main argument for using TDD in HF-BWA systems is the flexibility it offers in adapting the uplink/downlink ratio to the actual traffic pattern. The ratio can be optimized quite frequently, perhaps even on a frame to frame basis, and independently for all the base stations in the network. In this way the spectrum is utilized in the most efficient way. This type of TDD is often referred to as Dynamic TDD.

In the BROADWAN project Dynamic TDD was recommended as an important means to achieve the main goals of low cost and high capacity.

It is interesting to observe that both next generation LF-BWA and HF-BWA systems are expected to use TDD, but for slightly different reasons. In the LF-BWA case the main reasons are channel reciprocity for easier use of advanced antenna technology like MIMO and lower costs due to less complex transceiver design. Due to interference problems, the base stations in LF-BWA networks will usually be synchronized, hence the uplink/downlink ratio adaptation possibilities will be limited. In the HF-BWA case, the very high spectrum efficiency that can be achieved by adapting the uplink/downlink ratio is the most important reason for using TDD.

Modular based specification

The system specification should be based on a modular design with well-defined interfaces. This applies to both hardware and software components. In this way components from different manufacturers and software producers can be used in the same system, which will stimulate the competition between these and result in lower equipment costs.

The approach will be illustrated for the base station architecture.

Modular base station architecture

A modular approach is very suitable for the base station architecture since the number of sectors and number of channels per sector can vary depending on properties of the area to be covered. A modular design also makes capacity upgrade much easier. The transmitter and receiver need to be located close to the antenna to reduce losses at the high frequencies.

The basic architecture of the base station is shown in Figure 3. The BS controller runs the BS-level RRM, which contains all common resources for all sectors. The BS-level RRM coordinates Handover and Load Balancing. If a smart antenna with adaptive sector angle is used, this function is also controlled by the BS controller.

The sector controller is physically located at the sector card and runs the sector RRM. A distributed control scheme is recommended. In a distributed scheme the granted capacity is given per terminal, as opposed to per connection in a centralized scheme. Leaving more of traffic estimation and prioritising to the user terminal, gives a more flexible system regarding changes in traffic load and number of users. It is natural to locate the Call Admission Control (CAC) at sector level. Load balancing and handover are closely related to the CAC function.

The RRM functions at the sector level will be Call Admission Control (CAC), Handover/Load Balancing, Application identification, Traffic shaping, Packet scheduling, Congestion avoidance and Dynamic TDD.

Downlink and uplink multiplexing format

On the downlink, there are several ways to multiplex the data destined for different user terminals. The two most used methods are Frequency Division Multi-

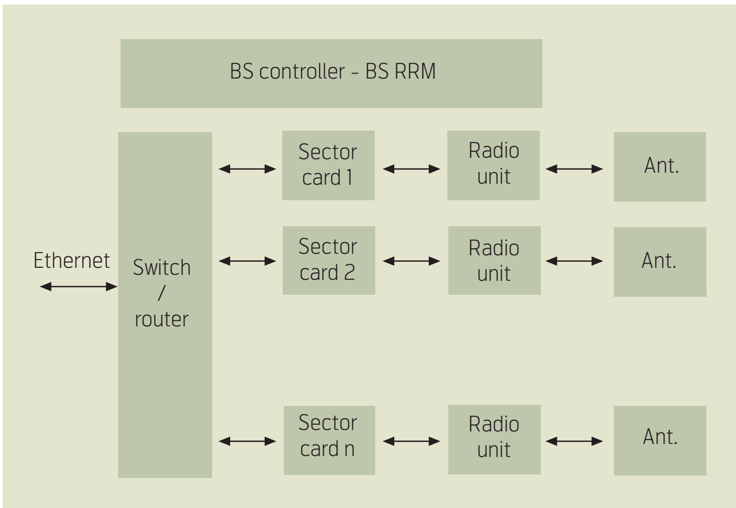

Figure 3 Basic base station architecture

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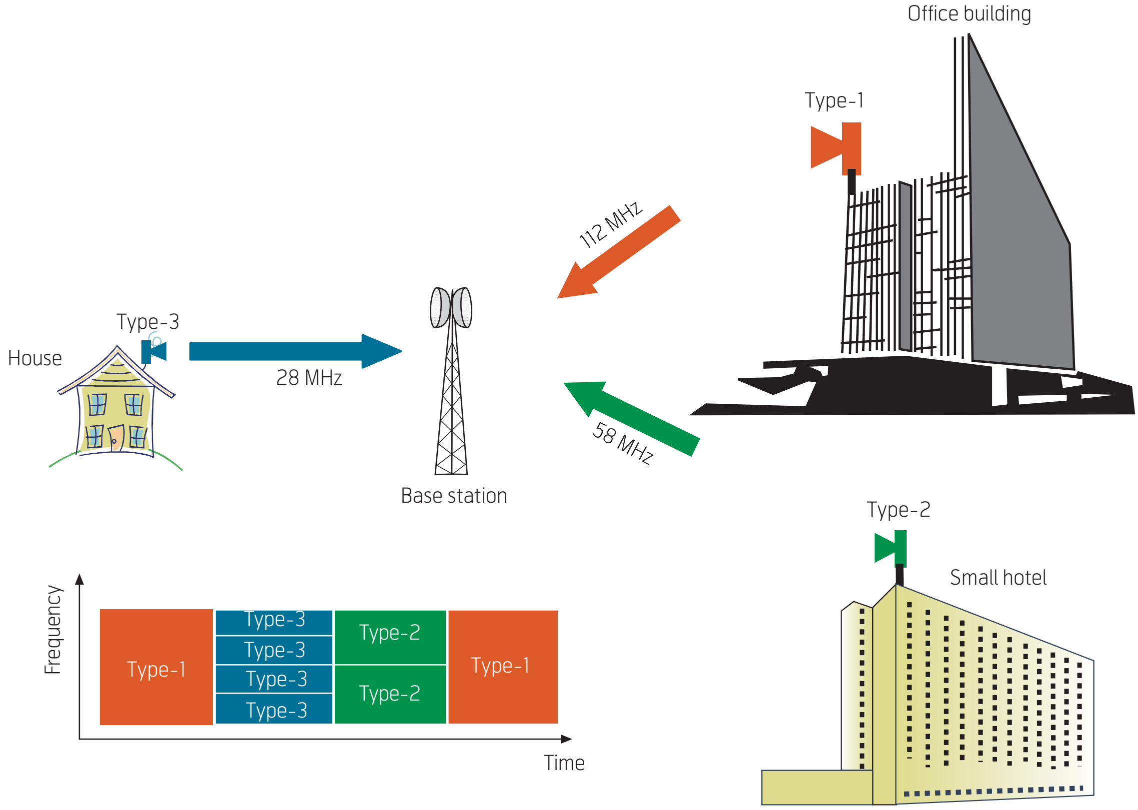

Figure 4 Example of using different terminal types. The time-frequency diagram shows how transmissions from different terminal types can be multiplexed

plexing (FDM) and Time Division Multiplexing (TDM). In FDM systems traffic destined for different user terminals are transmitted on different carriers, while in TDM systems data for different terminals are transmitted on the same carrier but in different time slots.

Since TDM is most flexible and gives better spectrum efficiency for typical data traffic, it is recommended on the downlink. On the uplink a TDMA scheme is recommended but with an option to divide the bandwidth into a small number of sub-channels. This will make it possible to design low cost terminals that transmit in a sub-channel for the consumer market and more powerful terminals that use the whole bandwidth for the business market.

For example, if the channel bandwidth is 112 MHz, the channel could be divided into four subchannels of 28 MHz. There could be three different terminal types: type 1 for large users (e.g. for serving an entire office building), type 2 for medium users (e.g. small businesses), and type 3 for households. The type 1 terminal would be a relatively expensive high speed terminal using the entire 112 MHz channel. The type 3 terminal would be a low cost terminal using only one subchannel of 28 MHz. The type 2 terminal would have medium cost and use 56 MHz subchannels. A BWA network could simultaneously serve all three types of terminals. In each time slot the total bandwidth could be allocated to either one type 1 terminal, two type 2 terminals or four type 3 terminals as illustrated in Figure 4.

Channel bandwidth

To determine the optimal channel bandwidth(s), there are two contradicting requirements that must be balanced.

The cost of user terminals increases with increasing channel bandwidths, since the cost of electronic components increases with increasing clock frequencies. One of the most critical components in this respect is the analogue to digital converter. Hence the channel bandwidth should not be too high.

On the other hand, the channel bandwidth should be wide enough to provide the most demanding users with the bitrates they require, both on uplink and downlink.

Also, it is not possible to provide the necessary capacity to a sector using only a single channel if its bandwidth is too low. This problem can be solved by allocating more than one channel to such sectors. But there are often several users behind each BWA termi-

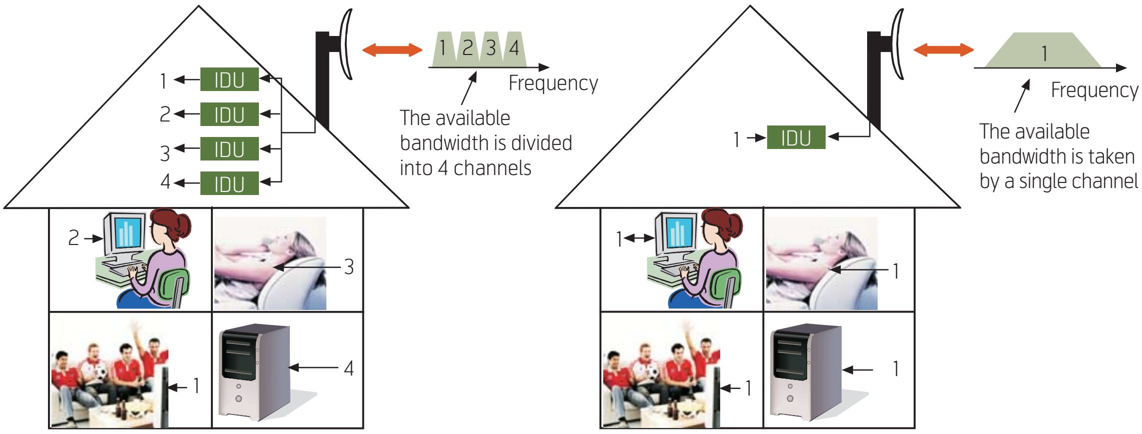

Figure 5 Example illustrating the advantage of using large channel bandwidths. The HF-BWA system is used for providing Internet access, TV and telephony services to a house. In the left picture the four services (web access, TV, telephony and multicast push) are transferred on four different channels, making it necessary to use four in-door units (IDUs). In the right picture all services are transferred in the same channel, and only one IDU is required. Also, multicast services might have to be transmitted simultaneously on several channels in the left picture, thereby reducing the spectrum efficiency of the system

	28 MHz	56 MHz	112 MHz	168 MHz	224 MHz
QPSK	44.8 Mb/s	89.6 Mb/s	179.2 Mb/s	268.8 Mb/s	358.4 Mb/s
16-QAM	89.6 Mb/s	179.2 Mb/s	358.4 Mb/s	537.6 Mb/s	716.8 Mb/s
64-QAM	134.4 Mb/s	268.8 Mb/s	537.6 Mb/s	806.4 Mb/s	1075.2 Mb/s

Table 1 Approximate total bitrates (uplink + downlink) for different channel bandwidths. The roll-off is 0.25 and the overhead due to forward error correction is not included

nal, each using different services. An example of this situation is illustrated in Figure 5.

Using more than one channel to serve a sector means in practice that users must have more than one receiver in order to simultaneously receive data from several carriers. The system can be designed so that the base station always knows which carrier the user is listening to and send all data destined for this user on this channel. But then all broadcast and many of the multicast data streams must be sent on all carriers, hence reducing the spectrum efficiency, increasing the interference and wasting power. Hence, from a spectrum efficiency viewpoint the channel bandwidth should be as large as possible.

In the BROADWAN project it was concluded that a channel bandwidth slightly above100 MHz would be suitable. Table 1 lists the total (uplink + downlink) approximate bitrates that can be offered by one channel for different channel bandwidths. If each sector is allocated one channel, this will be the sector capacities.

Interference control

The most serious interference situations are those that affect Base Stations (BSs). BS to BS interference is a specific case of this which has a high probability of occurring. How serious BS-to-BS interference is depends on several system parameters, but in many TDD networks it will probably be the main interference situation that must be handled.

In the BROADWAN project, a novel method for reducing BS-to-BS interference in HF-BWA systems has been proposed. The main idea of the scheme is to

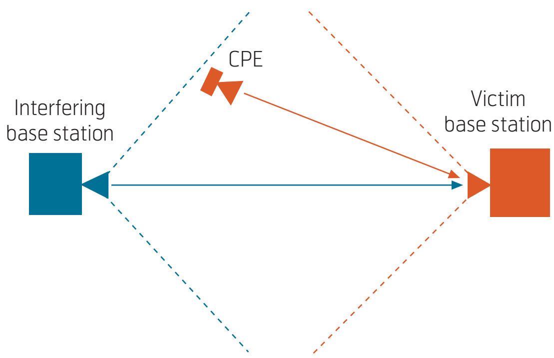

Figure 6 BS-to-BS interference

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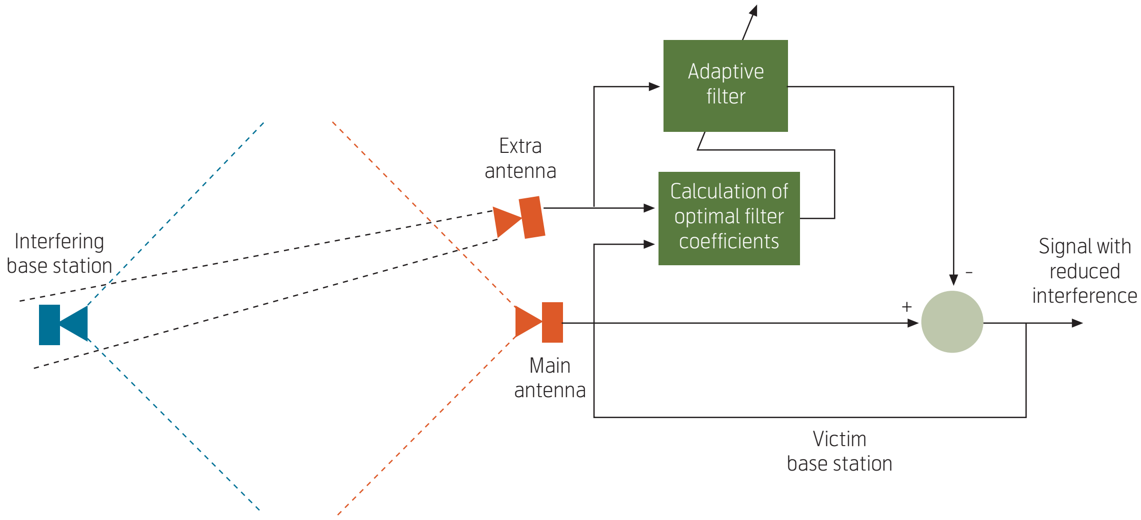

Figure 7 Principle of a BS-to-BS interference cancellation scheme

obtain a high quality (high Signal-to-Noise ratio and no multipath) copy of the interference signal, for example by using an additional highly directional antenna at the victim base station, and then somehow use this information to cancel out this interference component in the received signal.

In the simplest case the signal from the additional antenna could be weighted appropriately and subtracted from the signal received by the main antenna. But this will only cancel out the direct ray and not those that are reflected. And since both the interfering and victim BS antennas have wide opening angles, there will usually be reflected rays.

In order to also suppress the reflected rays, the interference signal received by the extra antenna should ideally be filtered with a filter having the same impulse response as the BS-to-BS channel. This motivates the structure of the interference cancellation scheme illustrated in Figure 7.

In practice the signal processing is better done on the baseband signals. In this case the interference cancellation scheme becomes as illustrated in Figure 8.

The optimization of the coefficients of the adaptive filter can be performed with one of the well-known algorithms from adaptive filter theory, e.g. the Least-Mean Square (LMS) algorithm.

A simulation study was performed in order to get an indication of what level of interference cancellation that can be achieved with the proposed interference cancellation method.

Figure 9 shows the results of a set of simulations for the case where the received interference signal consisted of a direct ray plus a reflection with a 1 dB lower amplitude. The symbol rate was 100 MBaud and the reflected ray had a delay of 6 ns. This delay corresponds to the main reflection for a scenario consisting of two base stations in a flat environment sep-

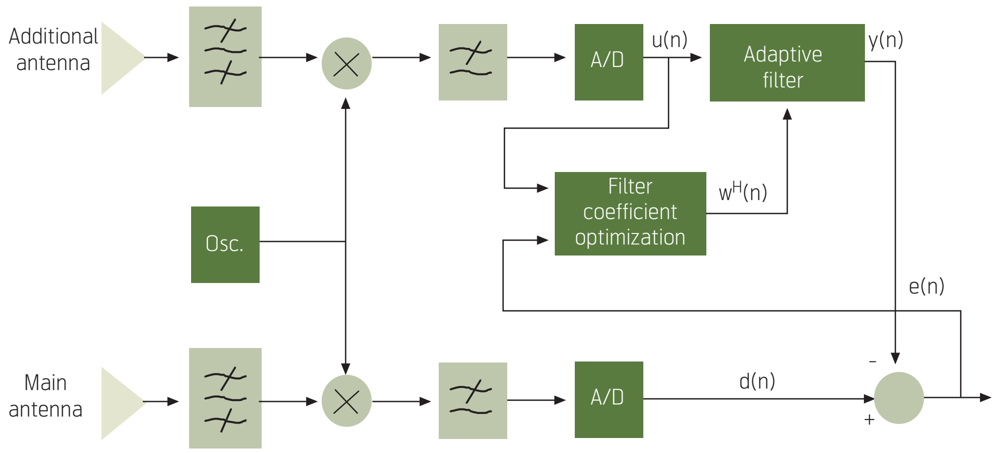

Figure 8 Practical BS-to-BS interference cancellation scheme

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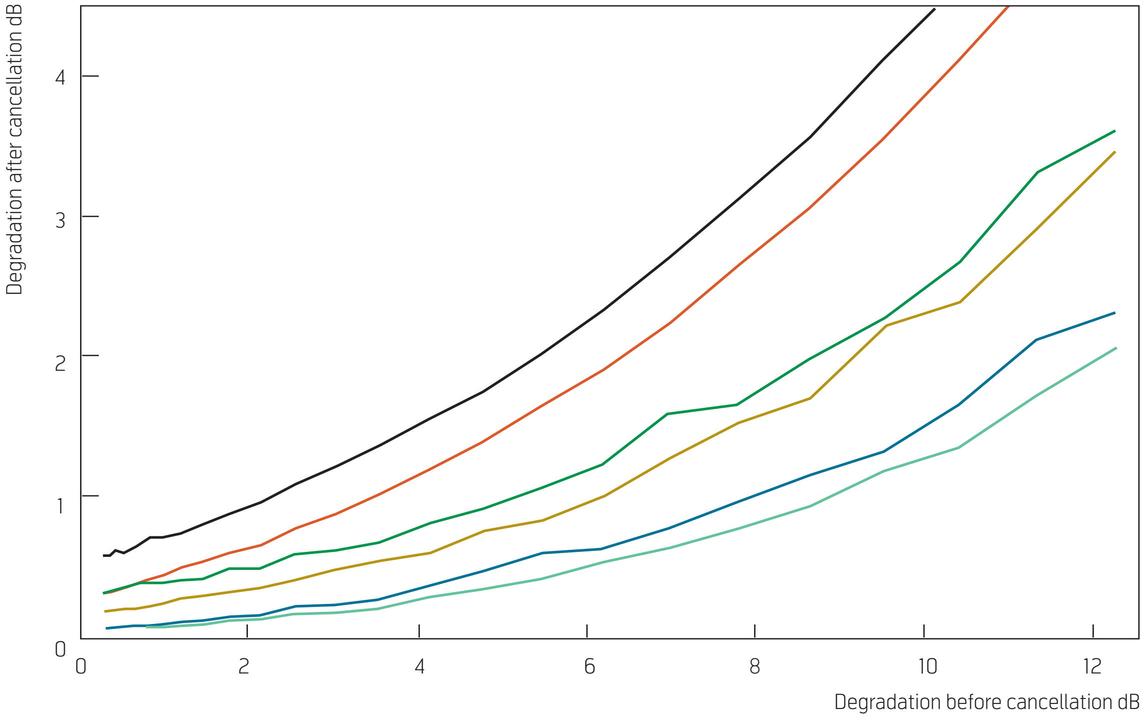

Figure 9 Performance degradation due to interference after interference cancellation as a function of degradation due to interference before cancellation. The optimization of the adaptive filter coefficients was performed over 16 (largest degradation), 32, 64, 128, 1024 and 4096 (lowest degradation) symbols

arated by 1 km and having their antennas mounted on 30 metre high towers.

In the simulations it was assumed that the optimization of the adaptive filter coefficients was performed over a given number of symbols and that only the interference signal and thermal noise was received during this interval. This corresponds to the case where the base station instructs its user terminals not to transmit during the optimization interval. The results show that the degradation due to interference can be reduced quite significantly using this technique.

Summary and conclusions

Broadband Wireless Access (BWA) systems can be divided into two classes depending on their operating frequency; Low Frequency BWA (LF-BWA) operating below 20 GHz and High Frequency BWA (HF-BWA) operating at frequencies above 20 GHz. The reason for this classification is the very different characteristics of these systems due to the different propagation characteristics at these frequencies. HF-BWA generally requires Line-of-Sight (LOS) between the base station and user terminal antennas, while LF-BWA systems can also operate under non-LOS conditions. On the other hand, spectrum for LF-BWA systems is scarce while there are large chunks of unused spectrum available for HF-BWA systems.

The different characteristics of LF-BWA and HF-BWA will make them play different roles. LF-BWA systems will mainly be used for providing nomadic, portable and mobile broadband access while HF-BWA systems will be used for providing users with high capacity fixed access.

LF-BWA systems are already on the market. The systems come in two flavours; fixed/nomadic systems and portable/mobile systems. Fixed/nomadic systems has been the first ones to reach the market and both base stations and different types of terminals are available from a wide range of vendors. Portable/mobile BWA equipment is currently only available from a limited number of vendors, but this is expected to change during 2007.

Next generation LF-BWA systems will include new features that will improve their spectrum efficiency and hence their capacity. Examples of such features are advanced radio resource management schemes and advanced antenna solutions.

Despite several attempts by various standardisation organisations to produce specifications for HF-BWA systems, these efforts have so far resulted in limited deployment of such systems. The main reason for this is that these systems are best suited for providing very high capacities at a low cost per bit, and not so well suited for providing moderate capacities. How-

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ever, it is expected that this situation will change as the customers demand ever higher bitrates.

The main requirement for HF-BWA systems is to provide high capacity at a low cost per bit. This can only be achieved if the systems have very good spectrum efficiency. One of the best ways to improve the spectrum efficiency is to use Time Division Duplexing (TDD) instead of Frequency Division Duplexing (FDD). Also, the channel bandwidth should be large in order to allow an efficient multiplexing of the different data streams avoiding parallel transmissions of the same streams on different channels and avoid expensive CPEs with several receivers.

The systems should also be able to support different types of customers. For example, the systems should be designed to allow simultaneous use of different user terminal types targeted at different types of users. The terminals could have different peak uplink capacity capabilities; low cost moderate capacity terminals for the consumer market and more expensive high capacity terminals for the business market.

One of the main challenges in TDD networks is to control the interference situation; especially interference into base stations, as this will affect a large number of users. A new method for reducing base station to base station interference in TDD systems is proposed, and simulations verify that this kind of interference can be significantly reduced.

References

1 Cherry, S. Edholm's law of bandwidth. *IEEE Spectrum*, July 2004, 41, 58–60.

2 ITU. *Coexistence between IMT-2000 time division duplex and frequency division duplex terrestrial radio interface technologies around 2 600 MHz operating in adjacent bands and in the same geographical area*. Geneva, ITU, 2003. (ITU-R Report M.2030)

3 ITU. *Mitigating techniques to address coexistence between IMT-2000 time division duplex and frequency division duplex radio interface technologies within the frequency range 2 500 – 2 690 MHz operating in adjacent bands and in the same geographical area*. Geneva, ITU, 2004. (ITU-R Report M.2045)

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Hybrid satellite and terrestrial wireless access for rural deployment in Spain

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Nowadays rural areas face a number of economic disadvantages compared to urban areas such as the cost of providing public services, which is often higher in rural than in urban areas, the lower incomes per capita, the population decline, the lower education attainment levels, the higher unemployment, etc. In this context, the widespread adoption of broadband in rural areas will have good effects in the long term helping businesses to be maintained in these regions, it will increase employment opportunities and services such as health care, banking etc., and will also improve the quality of life. In this sense, technologies like optical fibre, ADSL, and 3G are covering a minor part of these areas and new wireless technologies are needed in order to provide broadband services to end users. The Spanish region of Castilla-La Mancha has been a case study because of its geographical characteristics.

This paper explains the benefits of hybrid use of technologies, through an intelligent combination of wireless technologies as the most powerful and economic mechanism to provide services to users in rural areas.

This paper is based on work in the project BROADWAN, partly funded under the Information Society Technologies (IST) priority of the European Commission Sixth Framework Programme.

Introduction

In spite of its reputation as the Don Quixote domain, Castilla-La Mancha is a nice region which has had several places declared Patrimony of Humanity by UNESCO. Castilla-La Mancha has been one clear example for case study of the Information Society and is in the lower ranking of population density in Spain[1]. Because of its geographic characteristics, Castilla-La Mancha is a typical example of a rural area and is in the lower ranking of Information Society indicators. In Castilla-La Mancha the Internet penetration is below 25 %, and broadband is below 10 % [1].

In spite of these pessimistic indicators, some initiatives and projects are working to improve this current situation. In fact, examples like the BROADWAN project[2] or the new Plan Avanza[3] are helping to change this situation and over the last few years, the Information Society ratings are changing their tendency.

The development of broadband is one of the main European objectives to work as a key factor to improve the Information Society [2] [3] [4] [5]. The term 'broadband' is commonly used to describe Internet connections that are 'always-on' and that provide a speed which is significantly faster than dial-up connections, supporting the delivery of innovative content, applications and services. Most current definitions[4] link broadband to its transmission capacity. However, as speed evolves with the development of bandwidth demanding applications, the definition may quickly become obsolete.

The Commission release *"Connecting Europe at High Speed: National Broadband Strategies"* [6] defined broadband as a wide range of technologies that have been developed to support the delivery of innovative interactive services, equipped with an always-on functionality, providing broad bandwidth capacity that evolves over time, and allowing the simultaneous use of both voice and data services.

Some national strategies have been developed in order to improve the poor rates of broadband penetra-

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1) *Official data for 2005.*

2) *BROADWAN is a project co-funded by the European Commission under the IST Research and Technological Development VII Framework programme. The BROADWAN project aims to develop an economic network architecture to provide broadband services for all citizens in Europe and motivate advanced utilisation of broadband services at all levels of society by performing wireless demonstrations and trials in rural areas. Further information at www.broadwan.org*

3) *Plan Avanza is a Spanish initiative to support the equality of the regions and improve the Information Society. More information at www.planavanza.es*

4) *Definitions of broadband vary widely. According to ITU Recommendation I.113, broadband means transmission capacity that is faster than primary rate ISDN. The FCC considers broadband to have mean speeds in excess of 200 kb/s, and the OECD defines it as a service with downstream capacity of at least 256 kb/s.*

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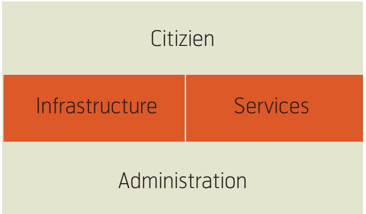

Figure 1 Main pillars to develop broadband

tion in many areas. The case of the Castilla-La Mancha region has four main axes, described in Figure 1.

The upper layer is focused on the citizen, who is the final objective of broadband. Several regional initiatives have been done to promote the use of Internet and broadband services to all kinds of citizens. To find killer applications and real services that could improve the quality of life for society is another core line of research. The infrastructure also has an essential role to complete this wheel. Where the cost of infrastructure deployment is not covered by any organisation, which is typical for rural areas, local and regional administrations have to make an effort to ensure deployment to all citizens.

In addition these are the three ways to develop broadband, which have to be closely coordinated: the infrastructure necessary to run the services, the focus on the real needs of the citizens, and a promotion to support people using new technologies [7] [8].

Studies and BROADWAN research

An ESA study[5)] found that services strongly demanded by users in rural areas would be:

1 Teleworking
2 On-line grocery shopping
3 *e*Commerce
4 *e*Government
5 Information and communications technologies (ICT) in schools
6 Learning
7 Interactive medical consultations.

Rural areas are facing a number of economic disadvantages compared to urban areas. The cost of living and the cost of providing public services in rural areas are often higher than in urban areas. In many countries, this is reflected in lower incomes per capita in rural areas than in urban areas, population declines, lower educational attainment levels, higher unemployment etc. In principle, the widespread adoption of broadband in rural areas could help to alleviate some of these disadvantages. The population density in rural areas is lower than in urban areas and therefore distances people have to travel are long. The cost of commuting and the cost of providing services in rural areas are therefore typically higher than in urban areas. As outlined in this ESA report, broadband can help to reduce these costs by enabling people to carry out these functions on-line. The resulting benefit per user is greater in rural areas than in urban areas. This is a direct quantifiable benefit of broadband in rural

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Benefits per Subscriber (rural), Euro	515	495	474	461	451	443	437	432	429	426
Benefits per Subscriber (urban), Euro	532	510	491	477	464	453	442	433	424	417
Total benefit (rural), bn Euro	1.7	2.9	4.3	5.7	7.1	8.4	9.5	10.6	11.6	12.5
Total benefit (urban), bn Euro	8.6	14.2	19.7	24.8	29.4	33.4	37.0	40.2	42.9	45.3

Table 1 Benefits per user will be higher in rural areas than in urban (ESA Study)

5) *Parts of this document have been extracted from the ESA report on the Digital Divide. The authors of such a document require the following disclaimer to be included in any document which may use part of the original report:* "Some sections of this document have been extracted from a report provided to the EC or ESA by PwC. This report was prepared on the instructions of the addressees and with only the addressee's interests in mind. To the extent permitted by law, PwC accepts no responsibility to any third party howsoever arising and shall not be liable for any loss, damage or expense of whatever nature which is caused by any use which a third party may choose to make of this document or which is otherwise consequent upon the provision of the document. Without conferring any greater rights than you would otherwise have at law, PwC accepts that this disclaimer does not exclude or indemnify us against any liability we may have for death or personal injury arising from our negligence or for the consequences of our own fraud."

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areas. There are also many examples around the world of broadband being used to provide these services already. These provide a model for further roll-out of similar services through Europe.

It is anticipated that widespread adoption of broadband in rural areas will have a number of knock-on effects in the long term. Better communications will help businesses relocate to rural areas, thereby maintaining employment opportunities. Better provision of services such as health care, banking etc. will also improve the quality of life in rural areas and alleviate problems of rural poverty and depopulation. The ESA report calculations conclude that the benefits per subscriber are higher in rural areas than in urban areas. However, the population in rural areas is smaller than in urban areas and the anticipated rates of broadband take-up is also lower. This means that the total value of benefits to rural subscribers is lower than to urban subscribers.

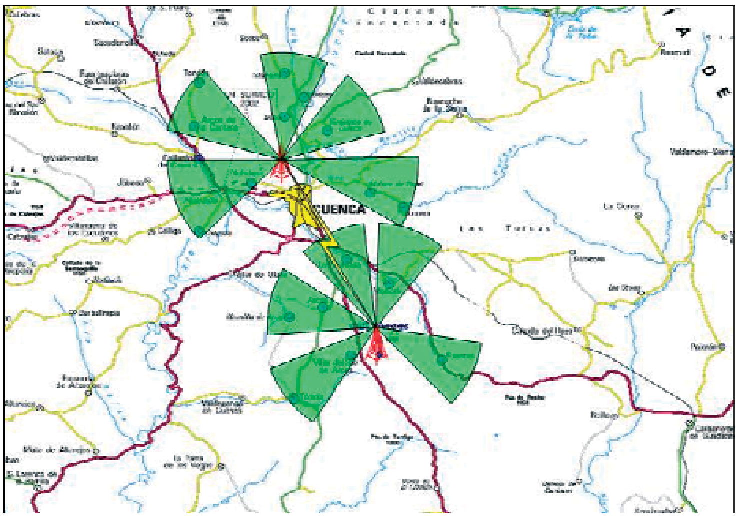

Figure 2 Telecom Castilla-La Mancha map of coverage using hybrid networks

This ESA study was useful in supporting the BROADWAN point of view, which is that research to provide broadband in rural areas is a key issue for the Information Society. Because of that, in this Spanish region the public operator Telecom Castilla-La Mancha (TCL) did some demonstrations in 2004 – 2005 in the context of the project. These demonstrations consisted in providing broadband access to rural areas using wireless technologies. TCL used hybrid wireless networks, like the combination of satellite infrastructure and Wi-Fi, or pre-WiMAX and Wi-Fi. The result is that nowadays, TCL is able to provide broadband access to more than 400 villages, bearing in mind that more than 1,000 villages and 20 % of the population require these kinds of solutions in this region; this has been a complete success. Determining the optimal mix of technologies is complex. Many factors have to be considered, like:

- Capabilities of each technology
- Geographic areas being served (population density, rural/urban, topography, wealth)
- Mix of user types (residential/business)
- Bandwidth requirements of the users
- Backhaul infrastructure already in use
- Service pricing and user affordability.

In spite of this complex process, these kinds of hybrid technologies are the most intelligent way to use the main powerful part of each technology.

One example of a hybrid technology is shown in Figure 2. This example shows the terrestrial wireless way to provide broadband by TCL. One part of the infrastructure is the point-to-point links at 5.4 GHz, which are part of the transport layer. From these points, using pre-WiMAX infrastructure, the signal is distributed to some villages where the access layer is completed by a Wi-Fi network providing broadband to end users. This is a clear low-cost network and a complete wireless solution.

Another wireless solution has also been demonstrated in the Castilla-La Mancha region. This solution is composed of a satellite infrastructure, which completes the transport layer, and uses the same Wi-Fi network for the access layer as mentioned before. This complete wireless network uses satellite infrastructure in order use its global coverage. Figure 3 shows this network.

The use of a satellite system and Wireless LAN independently to serve users located in sparsely populated areas does represent a big challenge, mainly from an economic point of view. Efforts are being made by a number of organizations in Europe and elsewhere to develop wireless systems which would be capable of satisfying the demands of the users, and which are frequently based on an optimal ratio performance/

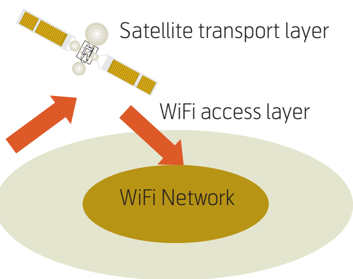

Figure 3 Hybrid network using satellite and terrestrial wireless solution

cost. In many circumstances, the problem related to the rural areas relies on the lack of suitable infrastructure in the telecom field. This is why a very pragmatic technological approach has to be followed when investigating technical solutions: the cost of the user terminal is of paramount importance.

The satellite systems providing broadband communications in the return channel (upstream) used to be costly. In order to solve this problem related to the satellite networks, two paths are being followed by the research community:

- The exploration of cheaper solutions for the satellite user terminal;

- The development of combined solutions, satellite and terrestrial, to fully exploit the advantages of each network technology aiming at identifying affordable solutions to the end user.

The second solution is what TCL has been developing to provide wireless solutions to more than 300 small villages in the Spanish region of Castilla-La Mancha.

Besides these TCL solutions, other hybrid networks are currently under study and will be relevant in the short and medium term. Table 2 shows the relationship between them. As can be seen from the table the WiMAX + Wi-Fi networks' main strength is the low cost solution. The Satellite + Wi-Fi infrastructure costs are higher but uses the satellite global coverage, which is essential in many remote areas. The combination of Satellite + Digital TV will be very useful in the near future; this will benefit the total penetration of the television in order to provide basic solutions and reduce the digital divide. Finally and also in the near future, Satellite + WiMAX will be a low cost solution, using personal WiMAX chipsets as an access technology.

Feed-back from the end users has been very useful and TCL has seen some killer applications in these areas, like:

1 Broadband Internet access (industrial, residential)
2 *e*Learning applications (business, remote schools, residential individual learning)
3 *e*Health services (tele-assistance, remote primary health centres)
4 *e*Government applications to remote citizens or tele-advertisement
5 Tele-command
6 Telemetry

This study has to be delivered in each region, mainly because each culture and society has got different customs. For instance, in the Castilla-La Mancha region, videoconferences have been useful for immigrant people to communicate with their families, mainly in Latin America.

Regarding the infrastructure development has followed a clear strategy in order to involve all the citizens. First of all, some public places were provided with broadband systems in order to provoke people to use these systems; for example libraries, telecentres, city councils, etc. Evidently, the telecentres had the main role, attracting more and more people to use new applications, chat, email and all kinds of information, supported by a teaching plan. This has been used to show the importance of this new virtual world called Internet, the most important discovery of the last century from the author's point of view. Because of the increasing demand for broadband access at home, TCL has set up a bid in order to provide connection at home for 40 Euro/month. The main objective has been successfully completed: to create needs and to improve the Information Society.

At this time the suitability founding in order to make a more competitive bid will be one of the major goals to consolidate this solution. In this sense, a close coordination within local and regional administrations will be essential for the complete development in the Castilla-La Mancha region.

Infrastructure	Rural areas			
	Costs	Coverage	Penetration	Broadband
WiMAX + Wi-Fi	Low	Medium	Medium	Medium
Satellite + Wi-Fi	Medium	High	Medium	Medium
Satellite + Digital TV	Medium	Total	High	Poor
Satellite + WiMAX	Low	High	Medium	High

Table 2 The main goals of different hybrid solutions

Conclusions

Broadband, as a whole, has a main role for the development of the Information Society. For this reason, new solutions are required in order to improve the quality of life for all citizens. The lack of broadband coverage in rural areas cannot be assumed as a natural fact. Technologies are available to use them in an intelligent and efficient way to extend coverage of broadband networks and related services. In addition, low cost solutions in order to provide broadband for all, in rural and urban areas alike, is an important research priority; using hybrid networks to get the most out of each technology. Actually that is what TCL has done during the BROADWAN project. Castilla-La Mancha, used several times as a case study for the Information Society in rural areas, has been the Spanish working place where TCL has been researching to provide new solutions for the citizens. With a strategy of coordinated services and applications, infrastructure, social needs of specific regional citizens and with a close organization of the administration, public and private founding, Castilla-La Mancha is noting how the digital divide is being reduced compared to other regions.

It is clear that this strategy will solve several kinds of problems for the citizens, improving their quality of life and reducing the differences between rural and urban areas. These initiatives should be taken to less developed regions or regions where the population is spread over vast geographical areas. *The results of technology research bring new opportunities for a dual purpose: new businesses niches and equal opportunities for access to modern ICT networks and services.*

Acknowledgment

This paper is based on work in the project BROADWAN, partly funded under the Information Society Technologies (IST) priority of the European Commission Sixth Framework Programme. This project was successfully completed with the collaboration of 25 partners, http://www.broadwan.org.

References

1 *Information Society*. Telefonica, Annual report, 2004 and 2005.

2 European Commission. *European Electronic Communication Regulation and Markets 2004 (10th Implementation Report)*. Communication from the Commission COM (2004) 759 final. Brussels, 2 Dec 2004.

3 European Commission. *Challenges for the European Information Society beyond 2005*. Communication from the Commission COM (2004) 757 final. Brussels, 19 Nov 2004.

4 *European Electronic Communications Regulation and Markets 2003*. 9th Report on the Implementation of the EU Electronic Communications Regulatory Package COM (2003) 715 final.

5 European Commission. e*Europe 2005: An information society for all*. Communication from the Commission COM(2002) 263 final. Brussels, 28 May 2002.

6 European Commission. *Connecting Europe at high speed: National broadband strategies*. Communication from the Commission COM (2004) 369 final. Brussels, 12 May 2004.

7 ITU. *Promoting Broadband: Background paper*. Geneva, ITU, 2003.

8 Ramos, S, Feijóo, C, Pérez, J, Castejón, L, González, A, Rojo, D. New perspectives on broadband development and public policies. *The Journal of the Communications Network*, 3 (1), 28–33, 2004.

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Experience of Low-cost 26 GHz Fixed Wireless Access System in Japan – WIPAS

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This paper describes the Wireless IP Access System (WIPAS); a point-to-multipoint (P-MP) fixed wireless access (FWA) system that provides broadband IP service for both business and home users with low charge. First, its concept and features are presented. WIPAS exclusively uses the 26 GHz, a frequency with significant bandwidth available for FWA suitable for providing highly-reliable broadband service. The transmission rates of radio and Ether frame data are up to 80 and 46 Mbit/s, respectively. Its compactness and light weight enable easy deployment in various places. Two types of the commercial services based on WIPAS currently provided in Japan, are presented. One is compatible with the optical fiber service called Fiber-To-The-Home (FTTH). WIPAS is used as a highly promising last one hop to the subscriber's building in this service. The other is Nomadic Wireless Access (NWA) service, where WIPAS is used as the broadband backhaul link connecting wireless LAN base stations to the core network.

1 Introduction

Broadband service is rapidly spreading all over the world. There are several access methods to provide the service, such as optical fiber, coaxial cable, metallic cable, and wireless. Optical fiber is regarded as the most promising medium.

There are several problems to expanding the broadband service via optical fiber to all urban and rural areas. In some urban areas, deploying optical fiber from the nearest connection to the subscriber's building costs a lot and some old apartment buildings do not have cable ducts. This is called the "last one mile problem". Subscribers are widely dispersed in most rural areas, so deployment of optical fiber is not economical. There is an urgent need for a countermeasure that can resolve the digital divide issue.

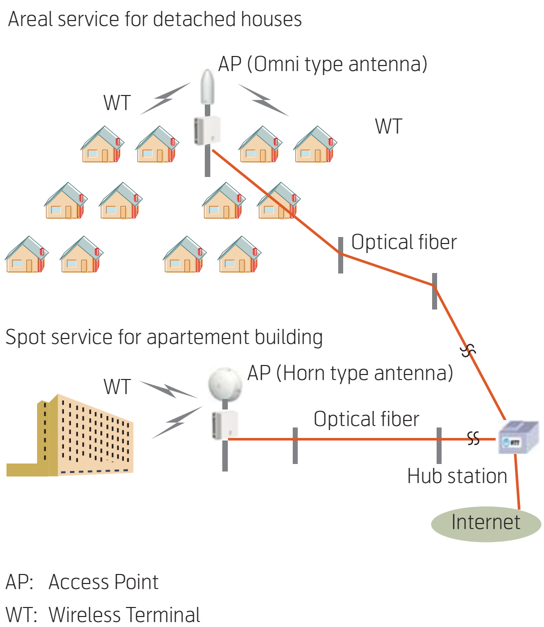

Figure 1 Concept of WIPAS

NTT has developed the fixed wireless access (FWA) system called *Wireless IP Access System (WIPAS)*, which resolves the above problems [1], [2]. WIPAS and optical fiber complement each other. The convergence of fiber and radio realizes a broadband IP service for home users and small office/home office (SOHO) users with low charge.

2 Concepts and features of WIPAS

Figure 1 shows the concept of WIPAS. WIPAS consists of an access point (AP) and wireless terminals (WTs). An AP deployed near the subscriber's buildings is connected to the public network, e.g. Internet by optical fiber. The AP converts optical IP signals into 26 GHz band radio signals and transmits them to the WTs. The WTs receive the radio signals, demodulate them into IP signals, and pass them to the subscriber's PC etc. via Ethernet cable. In short, WIPAS can be used as the last one hop when optical fiber cannot be used.

There are two service topologies. The first one is areal service for houses not yet connected. The omni type antenna is used for this type of service as the service area is usually circular. It is a very cost-effective way of constructing broadband networks in rural areas. The other is spot service for apartment buildings. As the service area is usually limited to a particular building, a horn type antenna is used for this service.

Figure 2 shows the key WIPAS components. The AP consists of an AP Radio Frequency Unit (AP-RFU) and AP Interface Unit (AP-IFU). There are two types of AP-RFU to suit the different types of antennas, omni type and horn type. The WT-adapter connects the WT to a PC. It supplies electric power to the WT via a powered Ether cable.

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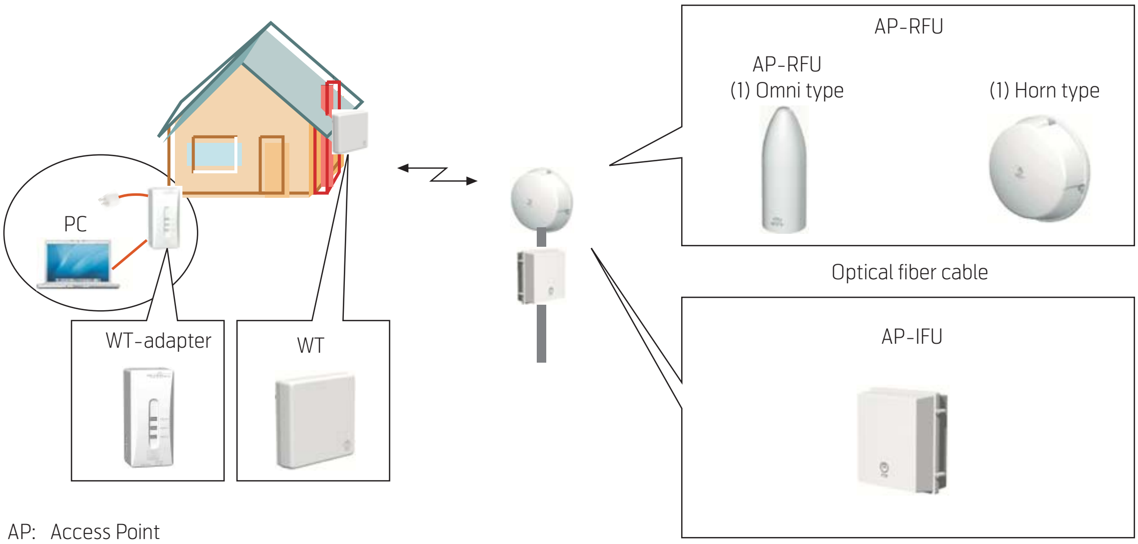

AP: Access Point
WT: Wireless Terminal
RFU: Radio Frequency Unit
IFU: Interface Unit

Figure 2 Configuration of WIPAS

Table 1 shows the major specifications of WIPAS. The 80/40 Mbit/s wireless transmission rate is available on one frequency channel of 30 MHz. WIPAS adopts the TDMA/TDD access scheme and the adaptive modulation function of QPSK or 16QAM. It is usually used in a Point-to-Multipoint (P-MP) topology, however, Point-to-Point (P-P) topology, using two WTs, is available as well. The transmission distance for the P-MP topology is 1–2 km in Japan on a line-of-sight (LOS) path. The actual distance depends on the availability objective and rain attenuation parameters.

WIPAS uses the 26 GHz licensed band. The key advantage of this band over the micro-wave band is that this has been exclusively assigned so that areal

Frequency band		26 GHz [for Japanese market] (Frequency can be customized to other Quasi-Millimeter bands)
Communication Protocol		TDMA/TDD
Symbol Speed		20M Symbol/Sec
Modulation Scheme		Adaptive Modulation (16QAM/QPSK)
Radio transmission rate (Maximum Ether frame rate)		QPSK: 40 Mb/s (23 Mb/s) 16 QAM:80 Mb/s (46 Mb/s)
Transmission Power		QPSK: 14 dBm 16 QAM: 11.5 dBm
Maximum Number of Subscribers		239 Suscriber Stations per Access Point
Network Interface		100 Base-T or 100 Base-FX (Interactive service can be attained by one optic fiber)
User Interface		100 Base-T or 10 Base-T
Antenna Gain	AP	Horn Antenna (5.5 dBi) Omni Directional Antenna (6 dBi)
	WT	18 cm Flat Antenna (31.5 dBi)
Transmission Range		1–2 km (Line of Sight)
Bandwidth Control		- Fairness Queuing Control by Round-robin - Minimum Bandwidth Grant by Priority Queuing

Table 1 Major specifications of WIPAS

deployment is possible with many radio frequency channels. Moreover, high quality and stable service can be provided as there is no interference.

Both AP and WT are much more compact and lighter than conventional FWA equipment. The sizes and weights of the WIPAS equipment are presented in Table 2.

Type of equipment	Size (mm)	Weight (kg)
AP-RFU (Omni type antenna)	Ø150x600	7
AP-RFU (Horn type antenna)	Ø254x125	2.9
AP-IFU	270x320x160	7
WT	190x190x55	2

Table 2 Size and weight of WIPAS equipment

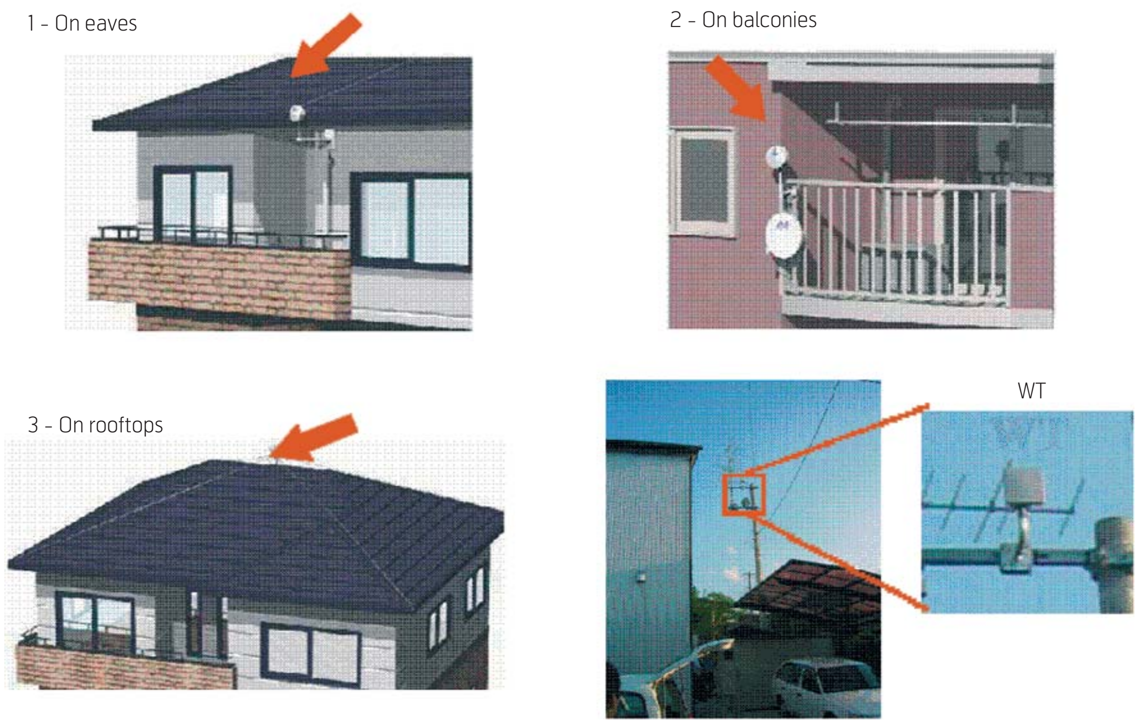

Figure 3 WT installation configurations

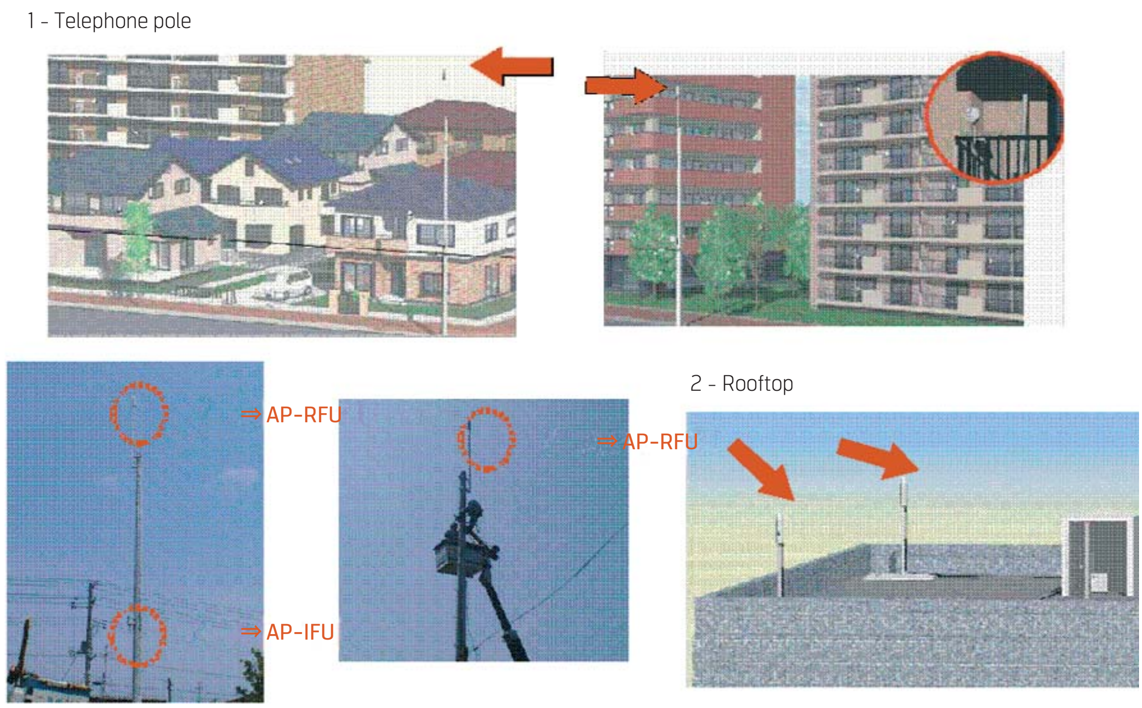

Figure 4 AP installation configurations

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These dimensions allow installation of the AP on an electricity pole, and the WT on a balcony or rooftop of ordinary buildings. Consequently, installation costs are drastically lower and more installation locations are possible.

Figures 3 and 4 show installation configurations of WT and AP, respectively. Several kinds of attachments and mounts have been developed.

3 Commercial Services using WIPAS in Japan

There are two types of commercial service using WIPAS in Japan. One is the Fiber-To-The Home (FTTH) service; here WIPAS is used as the last one hop to the subscriber's building. The other is Nomadic Wireless Access (NWA) service, such as wireless LAN service. WIPAS is applied as the backhaul link connecting the wireless LAN base stations to the core network; it offers nomadic service to laptop PCs or PDAs.

Category of area	Deployment area	Advantages
High demand area	New town*	High demand for broadband service as many young residents
	Outlet mall, attraction park	Demand for broadband service for e-commerce
Local government specified area	Digital divide area	Utilization of common land and subsidy of local government Contribution to local government
	Industrial complex	Utilization of land and subsidy of local government
	Resort area	Contribution to local government

New town*: Town planned and built all at once with the help of government/local government funds.

Table 3 Classification of areal WIPAS deployment area

Figure 5 An example of a high demand area: a new town

3.1 FTTH service

NTT East and NTT West are actively promoting FTTH services in Japan under the generic name of *B FLET'S* service [3], [4]. There are two B FLET'S services that use WIPAS as the last one hop to the subscriber's building: *B FLET'S wireless family type* service and *B FLET'S wireless type* service.

B FLET'S wireless family type, which has been offered since 2004, provides areal broadband service to houses. This service has a monthly cost of about 35 Euros and the initial cost of normal setup and contract rate is about 150 Euros, assuming 1 Euro = 143 Yen. The number of subscribers is rapidly increasing, particularly in rural areas where the ADSL service is not available.

Table 3 shows the two categories of areal WIPAS deployment areas. One is high a demand area, where there is no broadband service infrastructure despite the demand for broadband service. The other is the local government specified area.

Figure 5 shows an example of a "high demand area" in a new town. Many new towns are being built in rural areas far from the city. Residents of new towns are relatively young (thirties – fourties) and they have a strong demand for broadband services. There is no optical fiber infrastructure and the ADSL service is not available as the new towns are too far from the network operator's end nodes. These new towns are well served by B FLET'S wireless family type service using WIPAS.

Figure 6 shows an example of *local government specified area*. A broadband IP service based on WIPAS was started in this city in 2003. Approximately 50 APs covers approximately 900 WTs in a 10 x 10 km area. Though most APs are located on the optical fiber cable network, some APs are connected to the core network via the wireless entrance.

The development of broadband municipal networks is one of the measures taken by local governments; they are intended to provide convenience to local residents and companies. Local governments in rural areas are seeking cost-effective network solutions that can be deployed immediately. The combination of optical fiber and WIPAS reduces the cost of constructing a broadband network by 90 %. Many local govern-

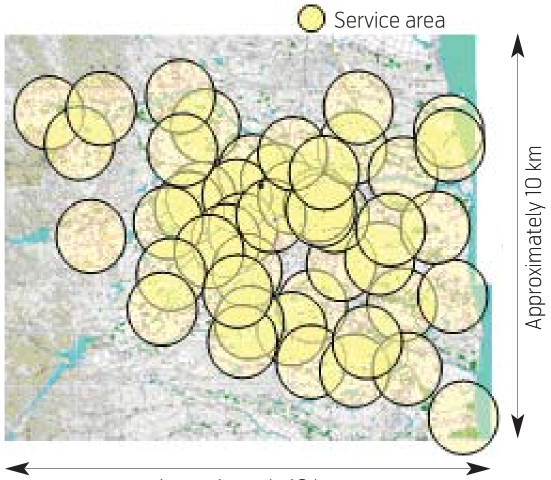

Figure 6 An example of local government specified area

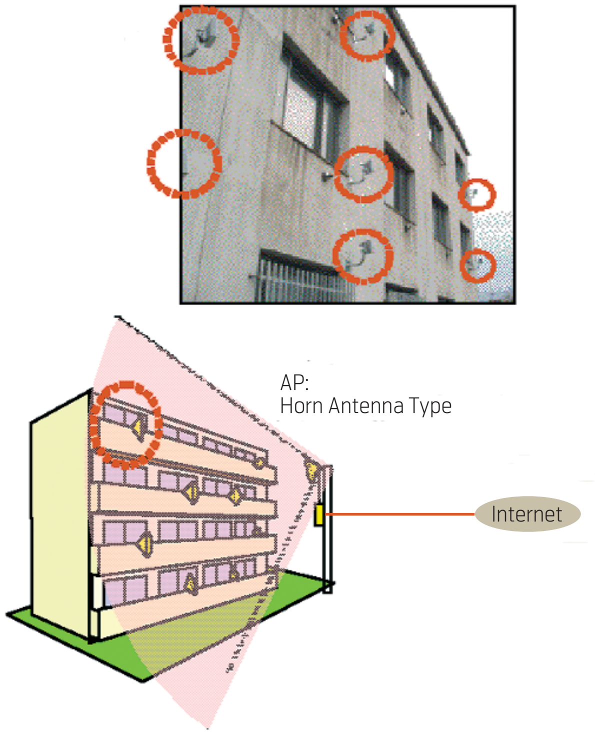

Figure 7 An example of a spot service area

ments are supporting the construction of municipal networks by providing common land. Some of them are utilizing subsidies from the national government for constructing these networks. Some of their service areas are larger than "high demand area" as local governments are requested to provide equal services to the residents in their whole area.

Figure 7 shows an example of the spot service, so-called *B FLET'S wireless type* service. The horn type AP-RFU is used for a particular building. Typical targets are apartment buildings without a Main Distributing Frame (MDF) room, nor cable conduits which means that broadband services, such as Very-high-speed Digital Subscriber Line (VDSL) or FTTH services, cannot be provided. This service has been offered since 2003. The initial cost and monthly cost are almost equivalent to those of *B FLET'S wireless family type* service.

3.2 NWA service

Figure 8 shows how the NWA service applies WIPAS as the backhaul link. WIPAS' high data rate achieves easy deployment of wireless LAN service areas far from the core network. This service is very useful also for temporary NWA service for event spots or construction sites.

Figure 9 shows an NWA service experiment. The NWA service was provided at a camping site. The service area radius of wireless LAN was 80 m.

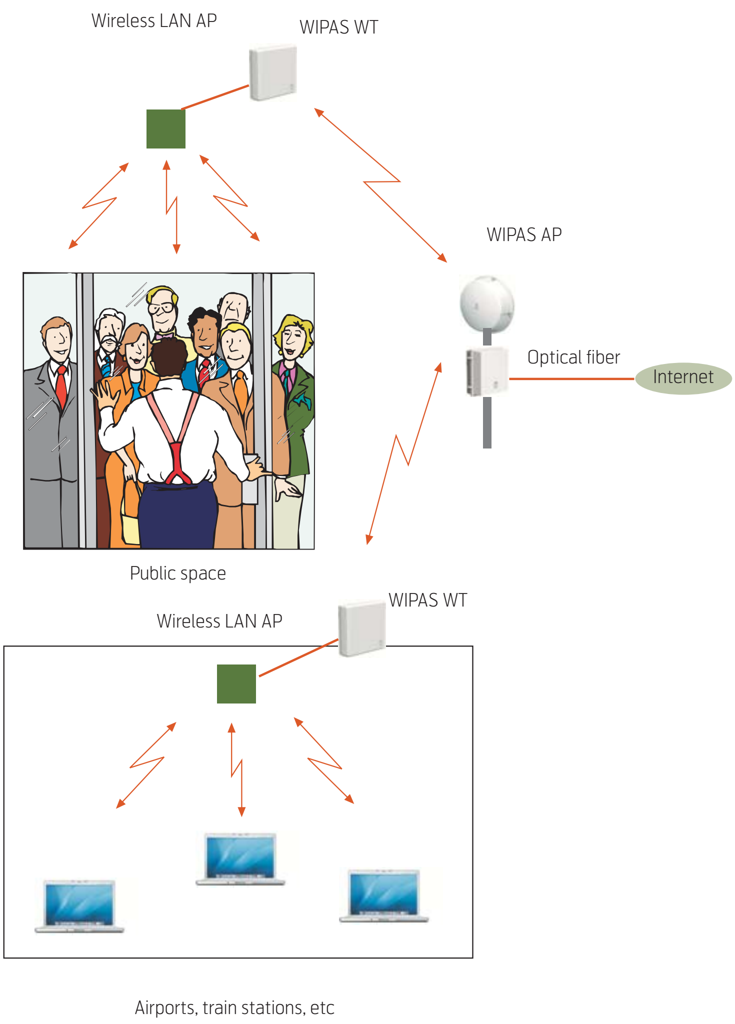

Figure 8 NWA service applying WIPAS as backhaul link

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Figure 9 NWA service experiment

4 Conclusions

WIPAS has been used in two commercial services, FTTH compatible service and NWA service, in Japan since 2003. Its advantages of high data rate, compactness, and easy deployment enable broadband services to be provided to home users and SOHO users at low cost. WIPAS is a promising solution to the digital divide. The demand for WIPAS is expected to grow in the future.

References

1 Nidaira, K, Shirouzu, T, Baba, M, Inoue, K. Wirelss IP access system for broadband access services. *2004 IEEE International Conference on Comminications*, WC15-1.pdf, June 2004.

2 Uwano, S, Ohmoto, R. Application Area Expansion in Quasi-millimeter Wave Band Fixed Wireless Access System. *4th International Conference on Networking*, April 2005.

3 *B FLET'S*. June 19, 2006 [online] – http://www.ntt-east.co.jp/product_e/05/index.html

4 *NTT West: B FLET'S*. June 19, 2006 [online] – http://www.ntt-west.co.jp/service_guide/5great/great02.html.

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Radiowave propagation models for improved performance and use of spectrum

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Broadband fixed wireless delivery systems may be organised as point-to-multipoint or mesh networks with the typical requirement being to provide high quality, high speed data links to terminals at low heights over ranges of ~100 m to 10 km. The delivery mechanism is assumed to be terrestrial. Satellite systems are not considered owing to the unacceptable latency of geostationary systems. The network planner needs a system to transfer data via a radio link and requires accurate propagation models to design this system efficiently. For various reasons, the models available at the beginning of the BROADWAN project were not ideal. They were either strictly only applicable to an environment significantly different from that found in practice or did not give sufficient information at a fine enough resolution to allow optimisation of the network design. While there is not sufficient space here to detail each model, more extensive details are available within the BROADWAN project documentation.
This paper is based on work in the project BROADWAN, partly funded under the Information Society Technologies (IST) priority of the European Commission Sixth Framework Programme.

Introduction

The parameters that are of most interest to the designer are coverage, path loss, channel quality, channel variability and the level of interference. A new set of models is needed for use in the design and optimisation of broadband fixed wireless access systems.

The closest relatives to broadband fixed wireless access are broadcast television and GSM/3G mobile telephony and the propagation models designed for these services have been used in planning deployments. While a good starting point, neither broadcast nor mobile propagation models are ideal as the operational environment of broadband wireless access systems are distinct from that assumed for broadcast and mobile systems.

In broadcast systems, the main transmitter is usually favourably located with a tall mast providing good coverage over a relatively large area. The broadband wireless systems where a base station is included in the design, practicality dictates that the height of the base station must be low. This is common in mobile systems, but mobile systems tend to rely on non-directional antennas whereas broadband wireless systems can more easily use directional antennas to make the best use of limited spectrum.

Mobile systems have path lengths that are broadly the same as those of broadband wireless systems. The location of nodes within the local environment is also similar. The quality of service requirements are very different, mobile systems are not expected to be highly reliable in all locations, whereas fixed wireless systems are expected to work as reliably as wired services.

Until recently, the majority of mobile and broadcast propagation modelling work has understandably focussed on the frequency bands allocated to these systems which are, for terrestrial services, almost all below 3 GHz. Spectrum below 3 GHz is in strong demand and consequently there is very little spare for new broadband wireless systems. Broadband wireless systems are able to make use of the higher bandwidth available in higher frequency bands above 3 GHz. While the current broadcast and mobile models [1][2] may be usable for planning broadband wireless systems below 3 GHz, they can not be reliably used for planning systems operating in the 5.7 GHz, 10 GHz, 28 GHz and 42 GHz bands.

It is therefore timely to look at new models applicable to broadband wireless access at frequencies above 3 GHz. The nature of the service requires models for terminals at low heights, with path lengths generally below 10 km. The models should predict the dynamic characteristics of the channel and the amount and nature of outage time. In order to achieve high reliability, many systems include propagation impairment mitigation techniques, including adaptive power control, adaptive modulation and link diversity. It would be useful for models to also predict the improvement attained through mitigation.

When attempting to make efficient use of spectrum by reusing channels, it is important not to neglect the effect of unwanted propagation paths. A mass market deployment with a high density of terminals leads to the close packing of links and interference between them. Models for this are also needed.

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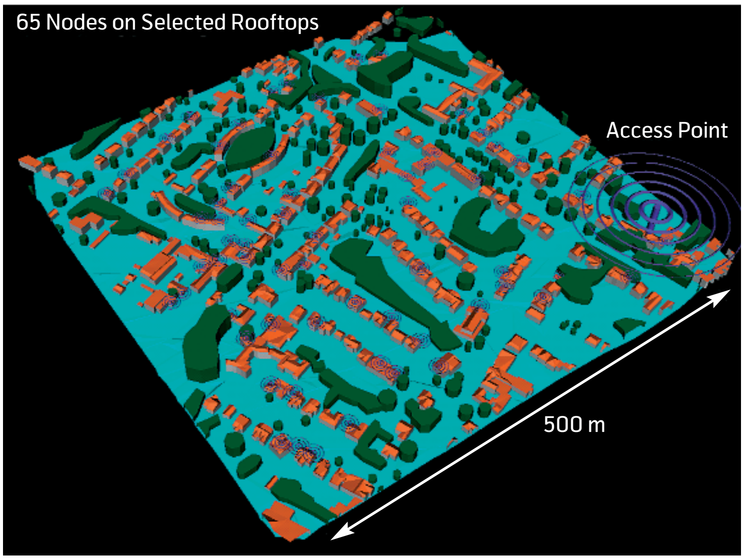

Figure 1 An example of modelling a broadband wireless deployment

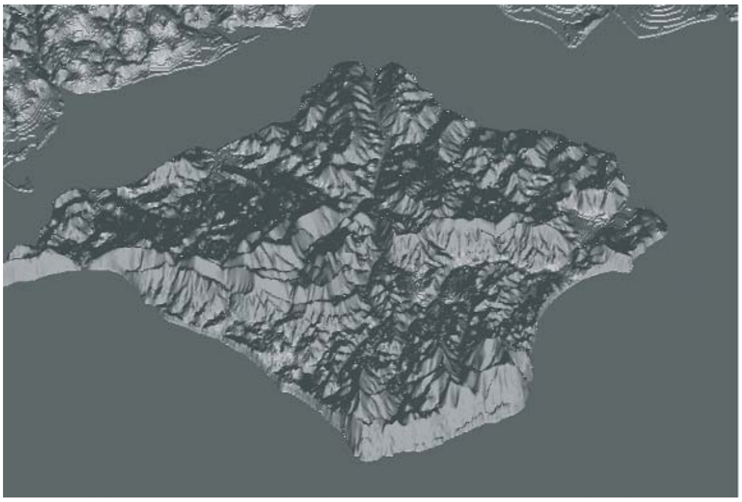

Figure 2 Example of digital terrain data

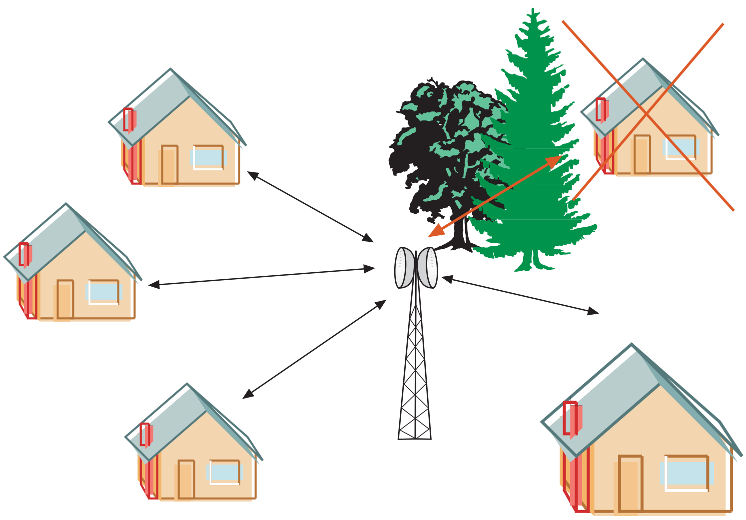

Figure 3 Clutter Blockage

Input parameters

Any model is only as good as the input parameters. Especially for short range paths in urban and suburban areas a prediction based on local and detailed knowledge of the significant features of a path has the potential to be much more accurate than one based on generalised parameters. The level of detail of input parameters should match the detail required of the prediction. So, for example much more accuracy is required in predicting propagation on a path between two specified locations than when considering the relative coverage from potential sites.

Being able to make precise coverage predictions like those in Figure 1 is a relatively new development. Through improvements in computational performance and with the availability of digital terrain and clutter data it is now realistic to be specific and to optimise a deployment to make the best use of the resources available.

Terrain

High resolution terrain height data in a common format is now available for much of the world. The Shuttle Radar Topography Mission [3] has produced a database of spot heights on a 2 arc second grid (~90 m resolution). This database which covers points between latitudes ~60°N and 60°S is currently available for free public download and a sample plot showing the Isle of White in the UK is shown in Figure 2.

The SRTM data contains artefacts caused by the method of collection, for example some shadows occur in mountainous regions and the height data is the height of the first object, so buildings and vegetation my be recorded as terrain height.

Despite these issues the data is useful for modelling. All propagation modelling work can now assume that at least 2 arc second terrain data will be available.

This data is sufficient for estimating coverage and interference on longer paths, but is not useful in urban areas where detail at around 1 m resolution is needed. Much higher resolution terrain data may be purchased for most regions and for the Polar Regions that were not covered by the SRTM.

Clutter

We are generally interested in clutter that blocks the radio path as in Figure 3. Clutter in this sense means objects that may effect radio propagation that are not terrain. Blockage by clutter is bad news for a wanted path but is good news for an unwanted interference path. In broadband wireless systems, clutter can improve spectral use by enabling closer frequency re-use [4].

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Common examples of clutter effecting broadband wireless systems are buildings, vegetation, street furniture and vehicles.

By its nature, accurate clutter data is difficult to obtain and can date rapidly, especially the data for vegetation.

A system deployed in the winter may become unreliable in the spring when leaves appear on trees, or maybe a few years after installation on a new estate when the newly planted trees have grown.

Buildings have a large effect on the radio channel. They provide an opportunity to site an antenna and can block the line of sight. Reflections and diffraction around buildings can increase coverage and can cause multipath. To predict the likelihood of coverage to an area, only a statistical distribution of building characteristics is needed, ranging through for example a simple categorisation, "Urban", Dense Urban", Village" or parameterised data concerning the number of buildings per sq km, their height distribution the space between buildings etc. Models have been developed, including ITU-R P.1410 [5] that predict coverage probability based on this type of input data. The models can also be used in evaluating interference, which is analogous to unwanted coverage, though usually modelled to greater distances than the intended coverage.

Coverage likelihood is useful in the system design stage, but when attempting to determine if a given customer can be served a more specific prediction is needed. In order to make predictions to individual locations, detailed building data must be obtained to allow more advanced simulations, for example ray tracing techniques, to be used [6][7].

Until recently, detailed building vector data had to be produced by a manual extraction process based on stereo aerial photography; an expensive and time consuming task. Figure 4 shows a section of Malvern in the UK produced using this method.

The development of airborne Lidar surveying [8] has improved the availability of building data, which is now available for many major towns and cities or can be obtained quickly. Figure 5 shows an example of a Lidar dataset being used to simulate the coverage from a base station.

Climate

Radio links in the higher frequency bands are effected by fading when there is heavy rain. This generally limits the overall availability of the link. There is a well established and accurate rain fade model

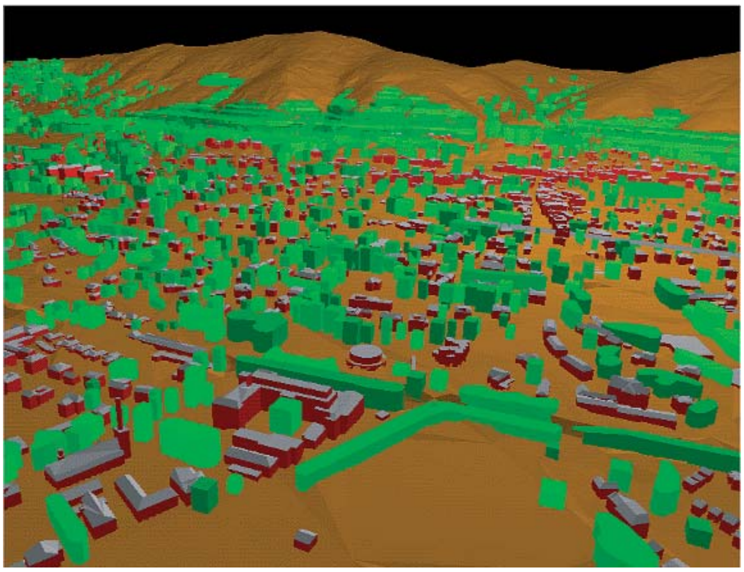

Figure 4 An example of a vector database of terrain, buildings and vegetation

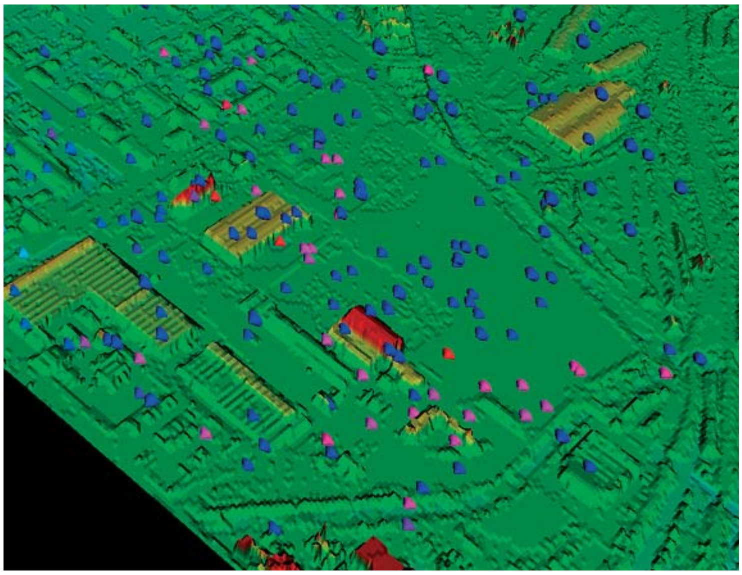

Figure 5 An example of Lidar data

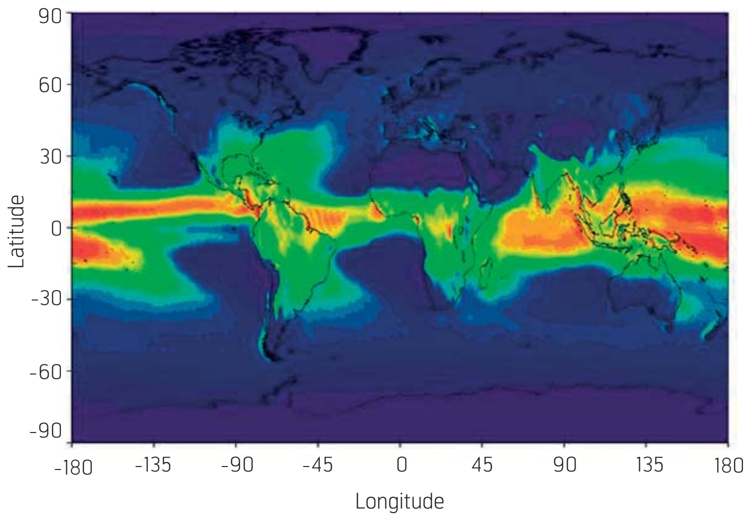

Figure 6 Map of 0.01 % rain rate (ITU-R)

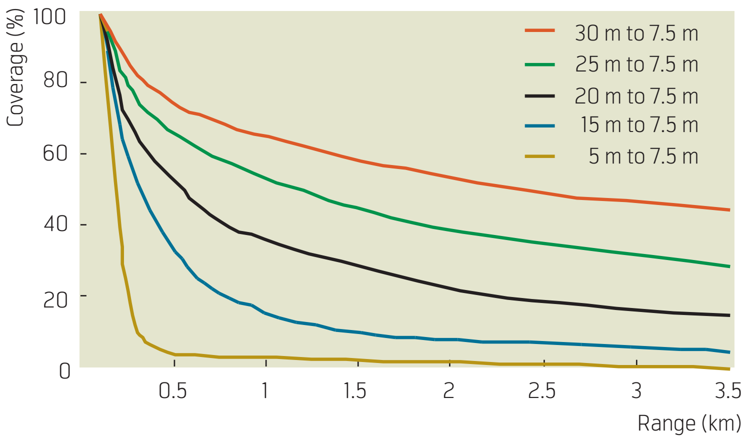

Figure 7 An example of a statistical coverage model – Coverage from selected antenna heights to antennas at 7.5 m from ITU-R P.1410

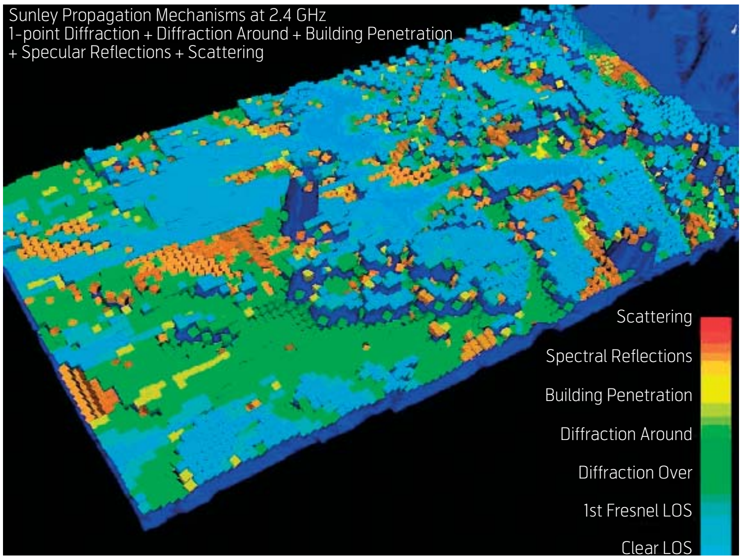

Figure 8 An example result from a ray tracing tool showing the dominant propagation mechanism to each point

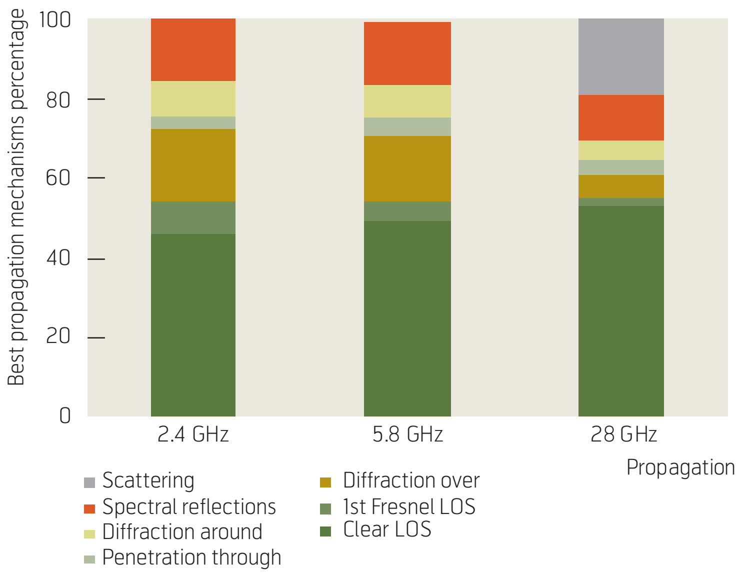

Figure 9 Results from the ray tracing tool showing how the dominant mechanism changes with frequency

within the ITU-R P.530 [9]. This model is based on the statistics of rainfall. As local climates can be so variable, rain rate statistics must be known or estimated for the area of interest based on rain rate maps, an example is shown in Figure 6 which represents the rain rate that will not be exceeded for more than 0.01 % of the year.

Other climatic parameters are important too, for example the incidence of fog where optical links are being used, and the incidence of sleet and snow which can strongly attenuate systems working above 10 GHz.

Unlike terrain and clutter data, there is no need to have data for climatic parameters on a fine grid of points. Point statistics of parameters at spacing of a few km are sufficient, which is fortunate as that is all that is available.

Models

Models for propagation effects are used in planning radio systems and for designing efficient ways of overcoming any limitations imposed by the path. Broadband wireless access systems tend to require models that cover link ranges of up to around 10 km [10] for the frequency bands where sufficient spectrum is available to provide high speed connections to many customers.

The main questions to be answered are; can a customer be served, what are the channel characteristics, and how does this vary over time. A secondary question that is very important if using spectrum efficiency concerns the interference environment. Systems need to be able to re-use spectrum and to do this a model for the relative strength of the wanted signal against all interferers is needed.

Models for Coverage

General statistical coverage models for broadband fixed wireless have been around for several years. The results of these models, for example Figure 7, are useful in the initial stages of planning a system, answering questions such as how coverage changes with antenna height, what range can be expected from a link in a rural area compared to one in an urban area, how many base stations are needed in a point-to-multipoint system to cover a typical town, etc.

Statistical models can be run on a simple spreadsheet and are very useful in initial system evaluation, but less useful when implementing a service where the likelihood of coverage to a site is not specific enough.

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With the availability of detailed data on the local environment, it is possible to use the ray trace technique to generate much more specific coverage predictions. Figure 8 demonstrates one of the tools developed by CCLRC Rutherford Appleton Laboratory within the BROADWAN project. These tools are not only able to predict signal strength; they are able to identify the propagation mechanisms.

Figures 9 and 10 illustrate the results of running the tool for a region of central Manchester.

By running the ray tracing tool over a large area it is possible to build up a table of dominant mechanism that can be used in statistical models where detailed building data are not available. This premise is based on the likelihood that areas with similar ground coverage will in general exhibit similar propagation channel characteristics.

Coverage models based on ray tracing are also useful in indicating coverage on other paths. In a multi-user network, the closest viable link is not necessarily the best one to use; it is good to have a choice to avoid congestion. When rain fading is a limiting factor, the ability to use a backup link may be crucial to meeting the reliability specification.

A joint probability of coverage model has been produced by CCLRC that can be used for optimisation of networks to include an element of diversity [4] [11] [12]. Figure 11 shows an example of the output from an optimisation tool produced by the University of Cardiff. This tool has been set up to favour deployments incorporating diversity. The optimisation includes ray trace derived path loss and is able to account fully for the system parameters including antenna characteristics, transmitter power, noise and interference. It also considers economic inputs and traffic models.

Models for Rain

Models for rain fading are well established and can readily be used for broadband wireless systems [13]. The ITU-R model has recently been updated to give better results in the higher frequency bands. While the new models are adequate for many simulations, better models [14] have been developed that account for varying rainfall types found in different regions, particularly the drop size and drop shape distributions.

Using these models it is possible to predict the level of fading, the rate of change of attenuation during an event and the duration and frequency of events. An example showing rain fade depth against path length for various exceedance probabilities is shown in Figure 12.

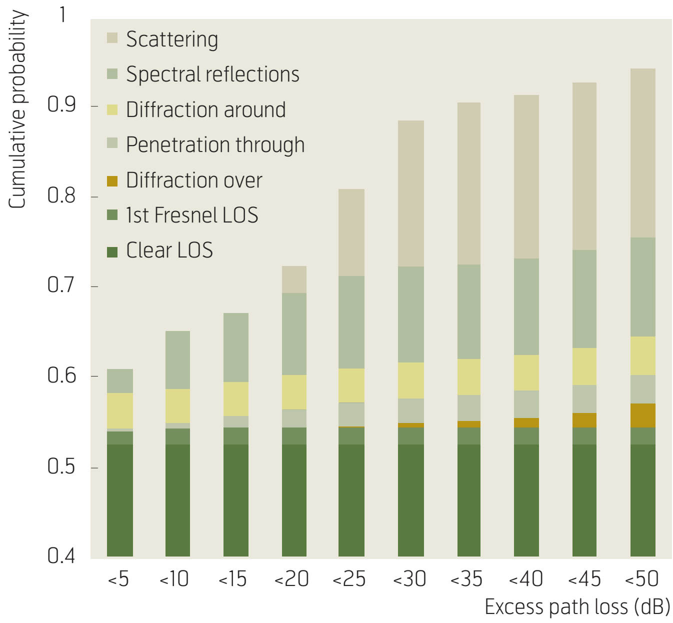

Figure 10 Results from the ray tracing tool showing cumulative excess path loss and mechanism

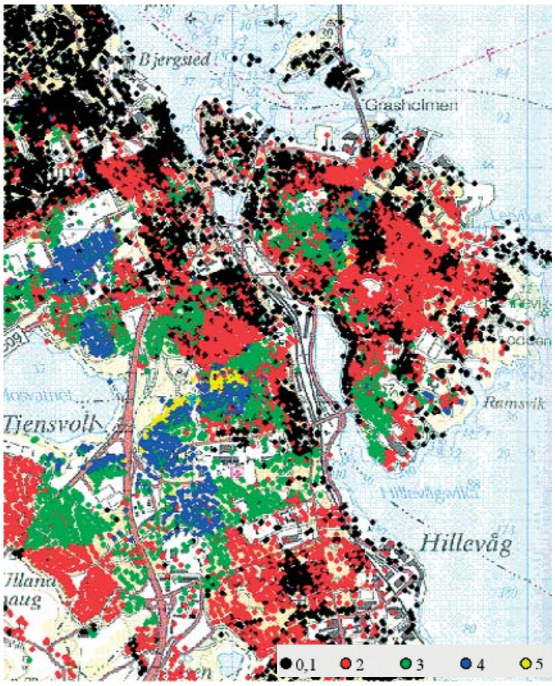

Figure 11 Deployment plan for 5 base stations serving a small town showing the number of base stations viable for use at each potential customer terminal

It can be seen from Figure 12 that in the UK where the rainfall climate is mild, the rain fade depth for high availability systems working over more than a few km is very high. A typical rain fading event is shown in Figure 13.

This is all that is needed for planning an individual link but these models say little about the structure of

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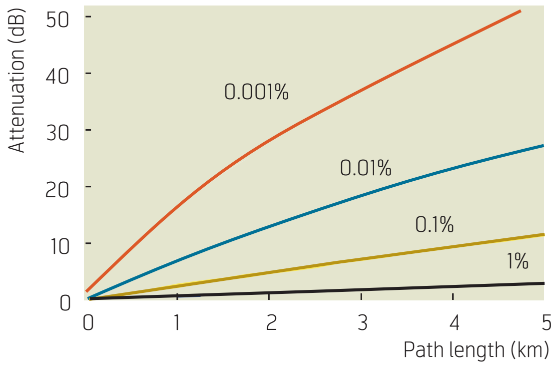

Figure 12 Rain attenuation versus path length at 42 GHz for Southern UK (ITU-R P.838)

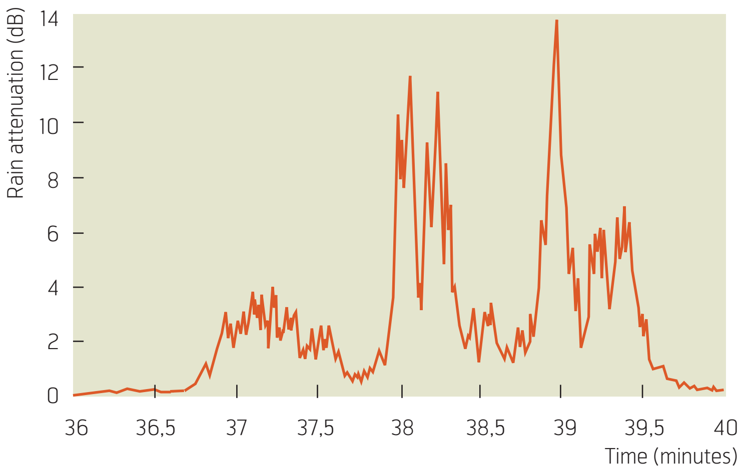

Figure 13 A typical rain fade event

rain events over an area and how this influences the concordance of fading on the links making up a network.

The rain radar data in Figure 14 shows that rainfall over an area is not uniform, especially for the extreme events that lead to link outages.

The radar data was used at RAL [15] to model the non-uniformity, and produce a diversity gain model for use in a fade mitigation system [16]. This model uses the path lengths and angular separation and estimates the diversity gain as a function of link margin or outage time.

For studying the dynamic effects over an area deployment, synthetic storm simulations [17] are used. A fractal based simulator has been developed at CCLRC RAL able to simulate rain fields at arbitrary scales [18]. An example of its output is shown in Figure 15.

Rain field simulators have been further developed under the COST280 activity [19] to produce dynamic channel simulators to output simultaneous attenuation time series with the correct correlation properties based on the physical link parameters.

The output synthetic attenuation time series like those shown in Figure 16, can be used for investigating the performance of the network and any mitigation techniques in use, for example automatic power control.

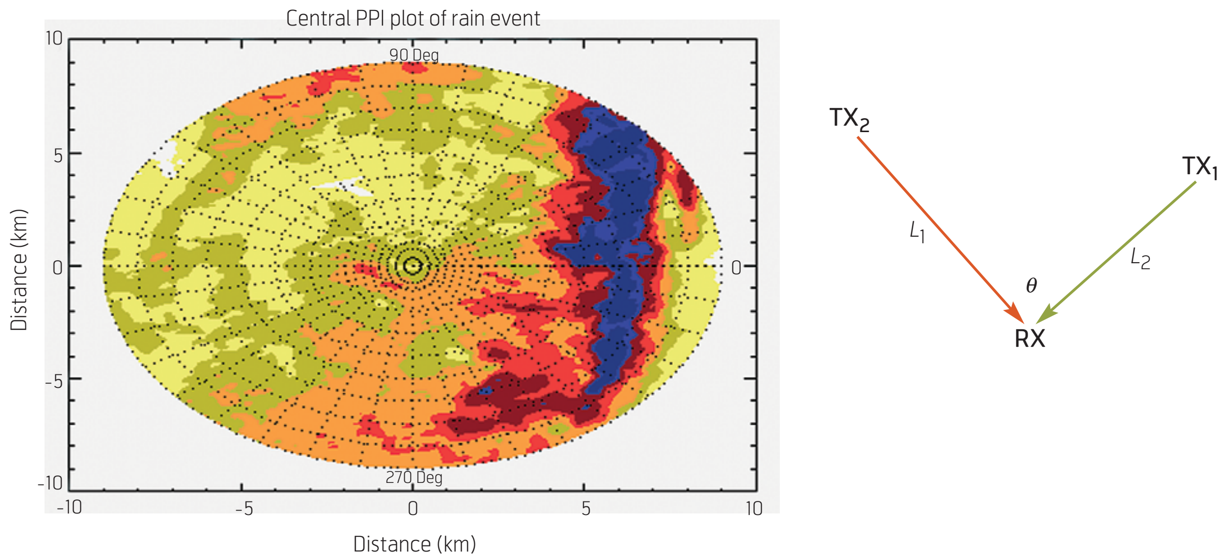

Figure 14 A rain radar image demonstrating the non-uniform nature of rainfall and the concept of path diversity

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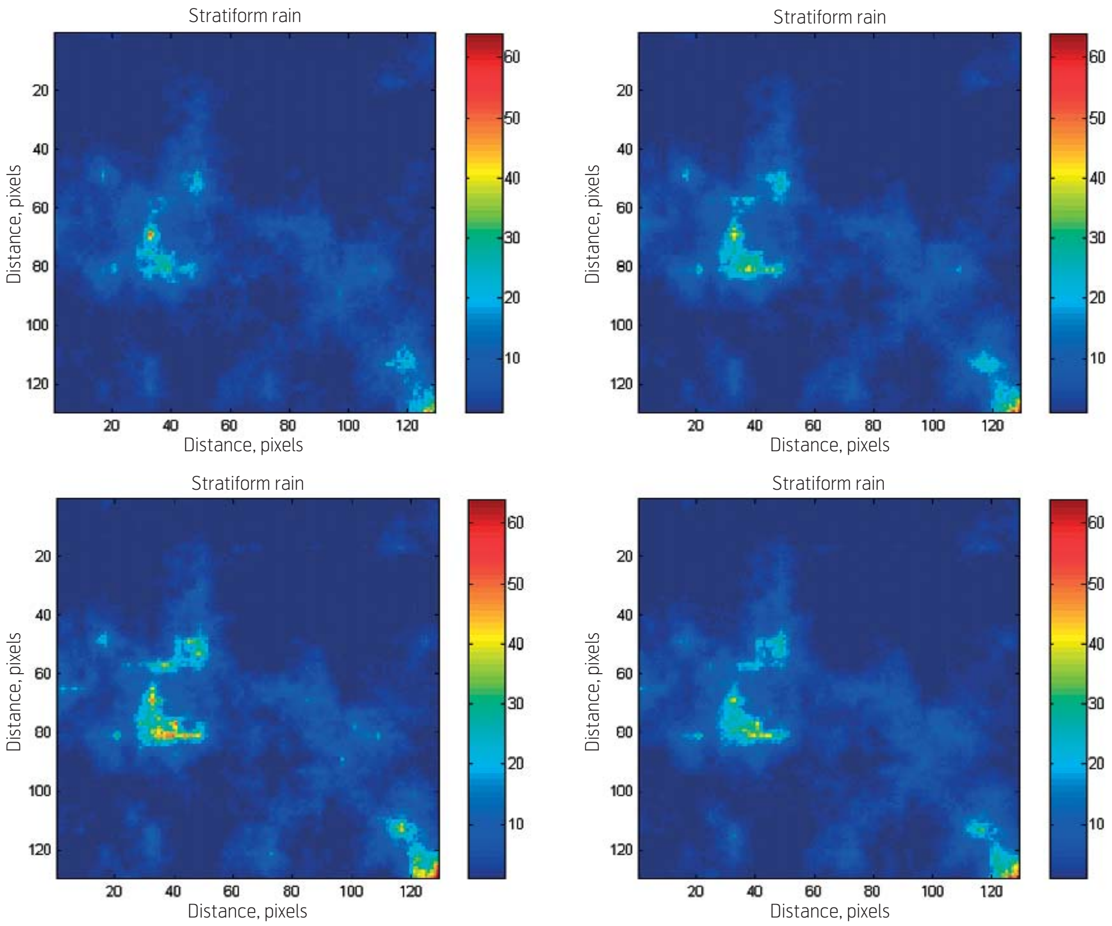

Figure 15 A synthetic storm developing

Models for Vegetation

It is sometimes necessary, especially with low height antennas in urban and rural locations to provide a service along a path that passes through vegetation.

The recommended model for vegetation attenuations is ITU-R P.833 [20], the latest version of which was recently updated to include the results of measurements made in the UK and Norway for both attenuations and to include dynamic effects caused by the movement of the vegetation in wind. The inputs to this model are vegetation type, depth location relative to the link and wind speed.

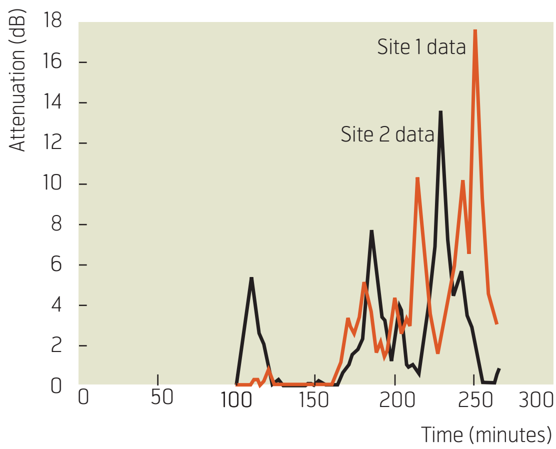

Figure 16 An example of synthetic time series data for two simulated links within the region of Figure 15

The measurements in Table 1 show that the mean loss through a single tree or bush is of the order of

Tree type		Dog-rose bush Diamter of 2 m	Apple tree Diameter of 2.8 m	Pine Diameter of 1.5 m
No wind	Mean loss (dB)	8.6	17.4	7.7
	Standard (dB)	2.0	2.8	2.2
Strong wind	Mean loss (dB)	11.7	17.8	12.1
	Standard (dB)	4.4	4.2	4.3

Table 1 Tree attenuation measurements (From ITU-R P.833)

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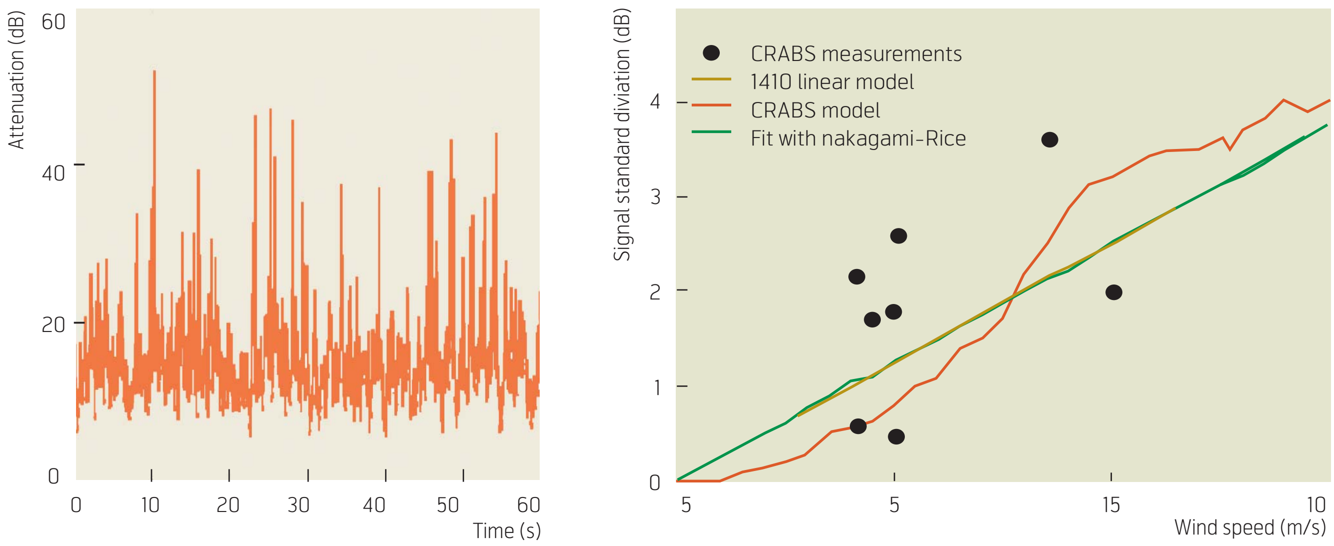

Figure 17 Measured and modelled signals through vegetation

10– 20 dB at 40 GHz. The mean loss for large blocks of vegetation can be found using the radiative energy transfer (RET) model in ITU-R P.833.

The dynamics of vegetation attenuation have been modelled through relating the standard deviation of the amplitude to the wind speed, the ratio being approximately $\sigma = v/4$ where σ is in dB and v is the wind speed in m/s. A comparison of models and measurements is shown in Figure 17.

Models for Multipath

Multipath is modelled using the techniques of the mobile industry, with the tapped delay line being used for simulations. Excess delays of up to around 0.4 µs have been measured in urban areas at around 40 GHz [21].

With information on the number, direction and relative delays of all the significant paths between transmitter and receiver a “virtual channel sounder” (see

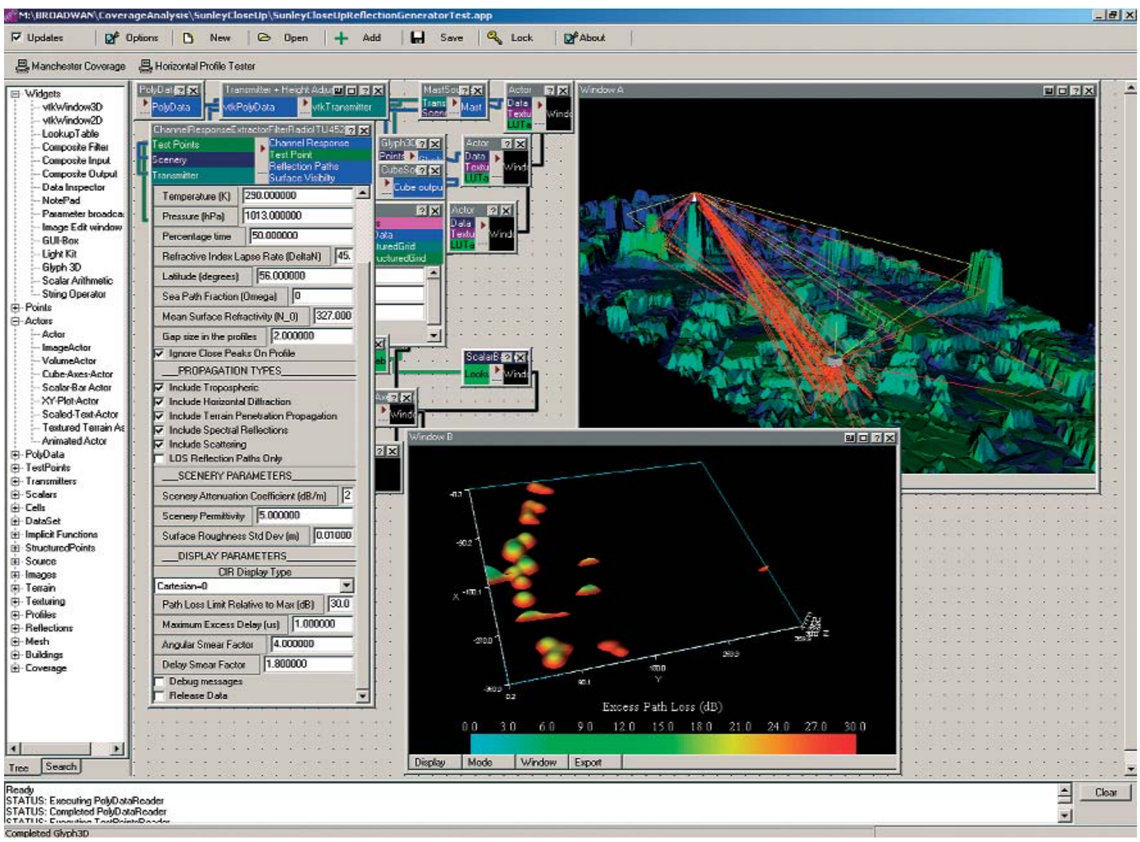

Figure 18 The virtual channel sounder developed by CCLRC Rutherford Appleton Laboratory

Figure 18) can be developed. This is able to take into account direction of arrival so that antenna patterns can be included in the simulation. The delay, amplitude and phase data can then be fed into a tapped delay line model to recover simulated time series to aid in the design of the modulation scheme.

The mechanism for multipath is usually reflection and/or the passage of the path through vegetation.

Although multipath through reflection is often considered to mainly effect systems using omnidirectional antennas and those in cluttered urban areas, Figure 19 demonstrates that multipath is not an issue that can be ignored for line of sight paths where there is a possibility of a two ray path through a spectral reflection.

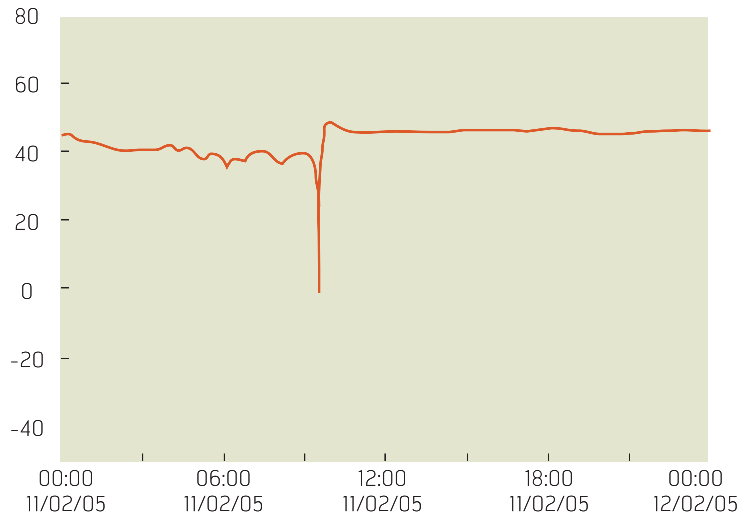

Figure 19 Multipath cancellation via ground reflection [22]

Multipath should also be considered where it is attempted to provide a service over a path which is not line of sight. The lower frequency bands are preferred for service over obstructed paths owing to the lower diffraction losses. Non line of sight capable systems are particularly important where service is to be provided in remote areas. With multiple diffraction edges, the received signal will contain significant multipath components and signal variations of around 10–20 dB are to be expected. Figure 20 shows a sample time series measurement recorded over an obstructed path at 1.5 GHz which demonstrates multipath enhancement and fading.

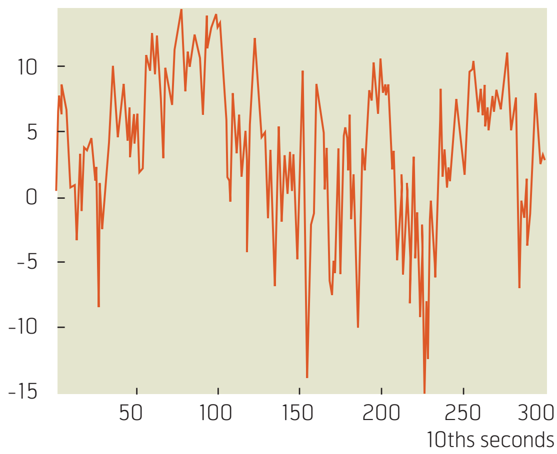

Figure 20 High resolution time series for multipath signal over an obstructed path (1.5 GHz)

Models for Interference

To make efficient use of the spectrum, the interference environment needs to be managed. Interference can be thought of as unwanted coverage, with the same models as used to predict signal levels at short ranges. The use of detailed building data and ray tracing using the model developed in BROADWAN [6] is likely to give the best results. Figure 21 shows an example of a ray trace result over a Lidar derived building height database. Interference over long ranges over ~10 km shows strong time dependency and this can be estimated using the standard ITU-R terrestrial link models, for example those recommended in ITU-R P.452 [23].

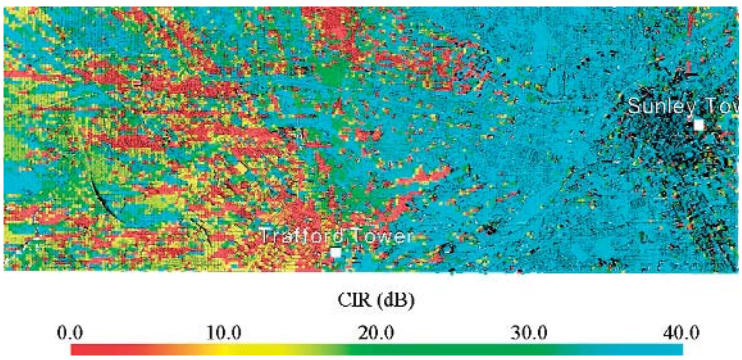

Figure 21 Detail CIR for two access base stations sharing the same frequency

At short ranges, several site general models exist for the lower frequency bands. These models are used when detailed site information is not available, or where a rough estimate is needed.

The simplest models are based on dual slope path loss, assuming the inverse square law applies to some defined distance, with a higher order law loss, e.g. 4th power of distance beyond that point. The break point and power laws are tabulated for each environment category, e.g. urban or rural. While these simple models give reasonable results at UHF they are not accurate in the higher frequency bands, where the shorter wavelengths used make it necessary to take account of local obstructions in a much more detailed

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way. Where detailed data are not available, or when execution time is an issue the models in recommendation ITU-R P.1411 can be used.

Usually, the level of interference should be well below the level of the wanted signal. There are typically many potential interferers and when evaluating interference, good estimations for paths with higher losses than would be considered for coverage is needed.

In particular, it is necessary to take account of indirect paths, for example specular reflections and scattering. An analogy demonstrating that scattering and reflection become more important as wavelength decreases; it is rarely too dark to see on a shaded street in the daytime.

Combining Models

In many simulations a model predicting the overall channel state against time is needed. A real channel will experience several propagation effects simultaneously and the model needs to combine these propagation effects in the correct way.

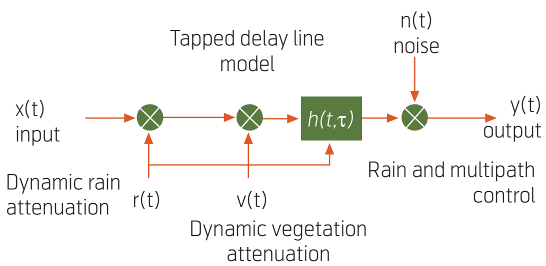

Figure 22 The BROADWAN combined propagation channel model

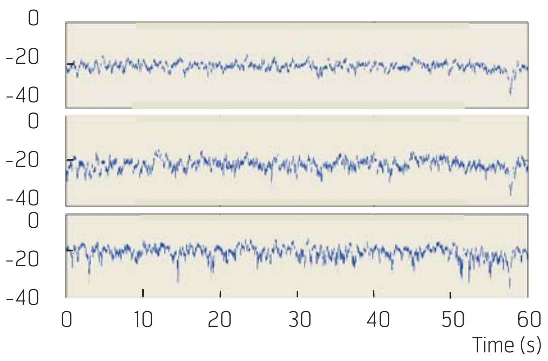

Figure 23 Sample of the dynamic simulator output (Top plot rain only, Middle plot rain + vegetation, Bottom plot rain + vegetation + multipath)

The dominant effects will typically include those of rain fading, vegetation fading, channel multipath, noise and interference.

An example of the model used by BROADWAN is presented in Figure 22.

In the combined model, the rain attenuation function $r(t)$ is derived from the synthetic rain field model or for a single link from the Maseng-Bakken model [24]. The vegetation attenuation function $v(t)$ is derived from the ITU-R P.833 vegetation model including the dynamic effects due to wind. A tapped delay line model for multipath uses a function $h(t,\tau)$ which is derived from the outputs of the virtual channel sounder. Additive white Gaussian noise is introduced at the final stage, where interference signals can also be added if necessary.

The output of the combined model, an example of which is shown in Figure 23, can be generated for each terminal within a network using appropriate and correlated individual models for each mechanism.

Conclusion

The most appropriate propagation prediction model is a compromise between the prediction accuracy and the model complexity and availability of input parameters. As a minimum, propagation environment information will be needed on

- terrain elevations or topography
- density of buildings and trees
- land use / land cover or morphology
- meteorological conditions.

Desirable additional input data:

- Locally measured climatic data (rain rate, incidence of fog, hail etc.);
- Detailed building data suitable for ray tracing;
- Detailed vegetation data for estimating vegetation attenuation.

Where appropriate detailed terrain and building data are available a ray-tracing simulator should be used for all static modeling. Ray-tracing models can potentially provide information on the relative importance of each propagation mechanism's useful design parameters including level, number, angle-of-arrival and excess delay of signals arriving at the receiver.

For simpler propagation paths that are known to be LOS, the Free space + RMD model with free-space path loss, two-ray reflection, and partial Fresnel zone obstruction loss analysis is appropriate.

Where detailed data on buildings and clutter are not available, the more general models provided by the ITU-R should be used.

Channel dynamic models should be based on the combined model presented in this paper.

Acknowledgements

This article describes some of the results of recent propagation modelling studies carried out under the EU Sixth Framework BROADWAN project.

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References

1 ITU. *Propagation data and prediction methods for the planning of short-range outdoor radio-communication systems and radio local area networks in the frequency range 300 MHz to 100 GHz*. (ITU-R Recommendation ITU-R P.1411)*)

2 ITU. *Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz*. (ITU-R Recommendation ITU-R P.1546)*)

3 *Shuttle Radar Topography Mission – Mapping the world in 3 dimensions*. July 6, 2006 [online] http://srtm.usgs.gov/

4 *Efficient Fixed Mesh Networks – Final Report*. CCLRC Rutherford Appleton Laboratory, University of Manchester, Cardiff University, Oxford Brookes University, Sinon Ltd, Satconsult Ltd, Dobbie Multimedia, April 2006. SES Project C31400/001. Available from: http://www.ofcom.org.uk/research/technology/overview/emer_tech/mesh/seshmesh.pdf

5 ITU. *Propagation data and prediction methods required for the design of terrestrial broadband millimetric radio access systems operating in a frequency range of about 20–50 GHz*. (ITU-R Recommendation ITU-R P.1410)*)

6 *Interference In and Between Wireless Access Systems*. BROADWAN Deliverable D10. July 6, 2006 [online] http://www.telenor.no/fou/prosjekter/broadwan/publ/BROADWAN_Deliverable_D10_interference.pdf

7 *Propagation Models For Dynamic Adaptive Radio*. BROADWAN Deliverable D17. October 12, 2006 [online] http://www.telenor.no/fou/prosjekter/broadwan/publ/BROADWAN_Deliverable_D17_dynamicchannel.pdf

8 *The GeoInformation® Group, Cities Revealed aerial photography*. July 6, 2006 [online] http://www.citiesrevealed.com

9 ITU. *Propagation data and prediction methods required for the design of terrestrial line-of-sight systems*. (ITU-R Recommendation ITU-R P.530)*)

10 *The Efficient Use of BFWA*. Ofcom Project AY4463, Section 4, Project final report. Available from: http://www.ofcom.org.uk/research/technology/spectrum_efficiency_scheme/ses2003-04/ay4463b/efficientuse_bfwa/

11 Allen, S M, Craig, K H, Hurley, S, Miners, W D, Taplin, R K, Willis, M J. *A Software Tool for Optimised Millimetric radio Access Cell Planning*. IST Mobile and Wireless Communications Summit, Thessaloniki, 17–19 June 2002. Available from: http://www.telenor.no/fou/prosjekter/embrace/Open_Publications/Mobile_summit_2002_software_tool.pdf

12 Biddiscombe, J. *Modelling Line of Sight Area Coverage for Millimetre-Wave Urban Radio Networks*. AP2000, Davos, Switzerland. April 2000.

13 ITU. *Specific attenuation model for rain for use in prediction methods*. (ITU-R Recommendation ITU-R P.838)*)

14 Goddard, J W F, Thurai, M. Radar-derived path reduction factors for terrestrial systems. *Antennas and Propagation, Tenth International Conference on Antennas and Propagation*, April 1997. IEE Conf 436, Vol 2, pp 218–221.

15 *The Chilbolton Advanced Meteorological Radar: CAMRa*. July 6, 2006 [online] http://www.chilbolton.rl.ac.uk/camra.htm

16 Willis, M J, Adams, C, Usman, I, Lindhom, P. *Diversity in rain*. EMBRACE Workshop: Broadband Fixed Wireless Access, Lillestrøm, Norway, 30 Sep – 1 Oct 2002. http://www.telenor.no/fou/prosjekter/embrace/Workshop/willis.pdf

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17 Callaghan, S A. *Fractal analysis and synthesis of rain fields for radio communication systems*. University of Portsmouth, June 2004. (PhD thesis.)

18 Callaghan, S A. *The Applicability Of Fractal Rain Field Models To Radio Communications System Design*. New Delhi, URSI GA, October 2005.

19 Fontan, F P, Nuñez, A, Valcarce, A, Fiebig, U C. *Converting Simulated Rain-rate Series into Attenuation Series Using the Synthetic Storm Technique*. COST280 Propagation Impairment Mitigation for Millimetre Wave Radio Systems, Final Workshop, Prague, June 2005.

20 ITU. *Attenuation in Vegetation*. (ITU-R Recommendation ITU-R P.833)*)

21 Xu, H, Rappaport, T, Boyle, R J, Schaffner, J H. Measurements and models for 38-GHz point-to-multipoint radiowave propagation. *IEEE J. Sel. Areas Comm.*, 18 (3), 310–320, 2000.

22 Willis, M J. *A long term propagation measurement campaign*. July 6, 2006 [online] http://www.ltmc.rl.ac.uk

23 ITU. *Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz.* (ITU-R Recommendation ITU-R P.452)*)

24 Maseng, T, Bakken, P. A stochastic dynamic model of rain attenuation. *IEEE Trans. Comm.*, 29, 660–669, 1988.

*) *ITU-R Recommendations are available electronically from the ITU bookshop, http://www.itu.int. The latest in force version should be used.*

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Status

Introduction

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SDL – Specification and Description Language – was standardized by ITU 30 years ago, in 1976. This issue of *Telektronikk*'s Status section presents two articles from the 12th SDL Forum, held in Grimstad, Norway, in June 2005.

Natural languages are what we speak and write. Specifications in natural languages are ambiguous with more than one interpretation. If we want unambiguous specifications, we need formal techniques, and for this purpose formal description techniques (FDTs) have been developed. A specification language is a *formal language* used in computer science. It differs from a programming language (which also is a formal language) by the fact that it does not provide directly executable code. While a programming language is used to describe *how* a problem is solved, a specification language is concerned with *what* is to be solved.

SDL has been the ITU language for description of real-time systems since 1976, and in 1980 the Standardization Sector of ITU (ITU-T) released the recommendation Z.100, *Specification and Description Language (SDL)* as a tool for specifying and describing complex telecommunication systems. The work was performed by Study Group 10, "Languages and general software aspects for telecommunication systems" until 2001, when it became part of the new Study Group 17, "Security, languages and telecommunication software". The motivation for SDL is formulated in Z.100 in the following way:

> *"The purpose of recommending SDL (Specification and Description Language) is to provide a language for unambiguous specification and description of the behaviour of telecommunication systems."*

Later, SDL has also become a tool for describing process control and real-time applications in general. SDL provides two representations, graphical as well as textual, both equivalent and complete. The underlying semantics (meaning) is defined using abstract state machines (ASM), an extension to finite state machines (FSM). Its purpose is twofold in the sense that it is used for describing both *required* behaviour (Specification) and *actual* behaviour (Description).

A biennial conference called *SDL Forum* has been held since 1983 and in this issue of the Status section we find two articles related to the SDL Forum. Professor Andreas Prinz from the Agder University College (AUC), Norway gives a report from the 12th SDL Forum held in Grimstad, Norway in June 2005. A non-profit organization called the SDL Forum Society has existed since 1990 (formally registered in 1995). Originally the aim was to act as a legal entity for the SDL Forum conferences, but it has also been closely involved in the ITU-T work. Prinz is secretary of the SDL Forum Society, and his report contains highlights from some of the speakers at the conference. For the fourth time, a "design contest" was held as part of the conference, and the second article presents one of the contributions. Merete Skjelten Tveit, a PhD student at AUC, describes how SDL can be used to both design and implement embedded systems, in this case a digital camera. In her article, several examples of SDL graphical representations are given.

Formal languages in general and SDL in particular has previously been treated comprehensively by *Telektronikk*, in a special issue on *Information Systems*, No. 2/3 in 1993 and later in several articles in the Status section.

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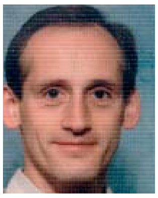
The SDL'05 conference in Grimstad

ANDREAS PRINZ



Andreas Prinz is a Professor at Agder University College

SDL (Specification and Description Language) is the ITU language for the description of real time systems since 1976. Since 1983 there is a biennial conference about theoretical and practical issues concerning SDL. The SDL conferences are supported and run by the SDL Forum Society[1)]. The 12th SDL Forum conference took place in Grimstad in June 2005[2)]. This was a very important event for everyone interested in SDL as well as in system design languages in general. The conference showed that there is considerable work going on in the areas related to SDL, but that the public awareness of the benefits of using SDL is not overwhelming.

Introduction

The 12th SDL Forum conference was held in Grimstad, organised by the Faculty of Engineering and Science of the Agder University College. Several researchers at HiA work on SDL and after the Secretary of the SDL Forum Society, Andreas Prinz, was appointed professor at HiA in 2003 the SDL community in Grimstad has been strengthened.

When the conference preparations started, the general situation was that the telecommunication industry was still short on budget and the interest in research in SDL and related technology was not that big from the industry. Universities also tended to go for other "fashionable" technologies, like the Unified Modelling Language (UML)[3)]. So the big question was how to attract enough good people for an event like this. In view of the development of SDL into the direction of UML and of UML into the direction of SDL, the decision was made to have an event that was more loosely bound to SDL and which would focus more on system design languages in general – of course with an important focus on semantically sound methods and on mathematical methods in this scope.

The papers finally accepted did also show this focus of the conference: six of them are not directly related with the ITU system design languages. This ratio was even higher for the rejected papers.

With the papers accepted, an interesting programme was set up. The day before the conference was devoted to tutorials as usual. The main conference was run three days with presentations for the selected papers and several discussion sessions. It also included the SDL Forum Society meeting and the SDL design contest. The day after the conference was devoted to workshops, which was in practice an ITU-T joint rapporteurs meeting.

Invited speakers

For the main conference two invited speakers were accepted; both would speak about code generation from high-level specifications, which incidentally is the competitive advantage SDL gives to its users. The first speaker was Andy Evans from the University of York, coming from the UML community and being speaker for the "executable UML"[4)] ideas. The second speaker was Thomas Weigert from Motorola, accounting for the use of SDL and other formal methods.

Andy Evans' talk started the conference, and it showed the primary focus of SDL'05: How is it possible to increase productivity by using high-level specifications and by automatic code generation? Andy Evans comes from the UML area with specific interest in formal specifications and automatic code generation. His vision was that in the future, fixed languages will not be as important as they are today. Instead, there will be powerful toolkits that enable the easy creation of new languages as extensions of old ones or from scratch. He showed his language handling tool called XMF which already gave a glimpse of that future in that it allows the complete generation of a language environment out of the formal description of the language.

Thomas Weigert gave a very interesting presentation on how Motorola used SDL and related technology for efficient code generation out of high-level specifications. He was able to show that the focus on high-level specifications and the complete code generation out of them brought very good productivity. This is a

1) *http://www.sdl-forum.org*

2) *http://ikt.hia.no/sdl05/*

3) *http://www.uml.org/*

4) *http://www.executableumlbook.com*

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real success story for the application of SDL and related technologies.

The presentation did not only handle the use of SDL, but how to turn high-level specifications into code. What kind of high-level specification is used varies depending on the application area. The auditorium was very impressed with this presentation, which unfortunately is not publicly available.

The SDL Forum Society Annual General Meeting (AGM)

The SDL Forum Society runs the SDL Forum conferences officially together with the local host for the conference. Moreover, the SDL Forum Society promotes the languages SDL and MSC (Message Sequence Charts)[5].

The SDL Forum Society meeting included some formal stuff, like election of the Board and review of the Finances. Most interesting for this meeting, however, was the discussion about the future of SDL.

There are currently two ways of viewing the future of SDL: 1) it could provide a simplification of the language much in the direction of the SDL Task Force[6], or 2) it could provide an integration with UML, which in fact means an alignment and extension of the language.

The member meeting landed on the second choice. This is also the way that the ITU prefers for the future work on SDL, which is an integration of languages in a common framework where the framework is supposed to be UML. In the discussion, it was clarified that the language integration framework to be used for SDL and MSC and UML would not be UML, but rather MOF[7]. It was also clarified that the identification of a subset of SDL in terms of the simplification would also be in line with this direction.

In the meeting, there was also a discussion about the visibility of SDL. It was generally acknowledged that SDL has a big advantage over UML in that SDL has a methodology and tools to do the things that UML is still promising, but not delivering. In SDL it is possible to generate code automatically from high-level specifications. However, people do not generally know about SDL; therefore, this competitive advantage is often lost. Hence, the idea was to consider more activities to increase the visibility of SDL in the time to come.

Review of some selected papers

All in all the papers of the 2005 SDL conference have been weaker than they were for the previous conferences. This is also due to the fact that some problems are now already solved, although (see the publicity problem) not everybody knows about the solution. This led to several papers showing the application of SDL in a straightforward way, which was not new in terms of the scientific content, but still something that was missing for SDL at large. The programme committee finally decided to make up a category of short papers for those papers in order to distinguish them from “hard” research papers, but still allow them to be presented.

In general there were several papers about semantic issues, particularly two papers about MSC semantics and one about the semantics of the ‘Any()’ construct in OCL[8] (which is also related to the SDL language via the select in sets). In addition, there were several papers about code generation and some papers using Petri nets. Several papers dealt with the creation and use of new languages, e.g. an access control language.

In the following is given a short review of some of the best papers of this year’s conference. The full papers can be found in [1].

ULF-Ware: An Open Framework for Integrated Tools for ITU-T Languages

The ULF (Unified language family) initiative of ITU is trying to get a better integration between the related system description languages of ITU. The ULF-Ware article from Humboldt-University Berlin [2] presented a specific scenario that enables such integration and describes how languages have to be

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5) *The ITU standardised languages related to SDL are: 1) SDL for the description of systems, 2) MSC for the description of scenarios, 3) TTCN (Tree and Tabular Combined Notation) for the description of tests, 4) eODL for the description of components and deployment, 5) ASN.1 (Abstract Syntax Notation ONE) for data descriptions, 6) URN (User Requirements Notation) for requirements handling. Finally, UML is also used to glue together these languages.*

6) *http://www.sdl-task-force.org/*

7) *MOF (Meta Object Facility) is the OMG language for the description of metamodels. It is the language that resides on top of UML and is used for the definition of UML. For technical reasons, MOF is also part of UML. It was made clear that only the MOF part of UML would be used for the integration.*

8) *OCL (Object Constraint Language) is the OMG language for the expression of constraints. It is basically based on first order logic.*

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described in order to be successfully combined. In particular, the research group is working on an actual environment that enables the integrated use of some of the ITU languages based on an integrated language description model.

Service Discovery and Selection using Semantic Interfaces

It has long been an unsolved problem how to use more in-depth semantic information for the selection and discovery of services. The difficult part lies in what kind of abstraction can be used to formalise the interfaces apart from simple signatures. In a joint paper from the University of Ottawa and NTNU in Trondheim [3] behaviour expressions are proposed to be used combined with goals for service selection and discovery. Although appealing at first glance, several open issues remain with this approach. In particular, the use of descriptions for goals, services and features needs a common understanding to be shared between the participants. This is an area where standardisation would be needed in the future.

UCM-Driven Testing of Web Applications

This paper from the University Ottawa [4] lifts the level of abstraction of application description even higher. Starting from use case maps (UCM), test cases are developed to test web applications. This is done in two steps. Abstract test purposes are generated from a UCM model using scenario definitions and scenario extraction tools. These test purposes are then converted interactively to test cases in the FitNesse[9)] acceptance testing framework, which is popular in the Extreme Programming (XP) community[10)]. The test cases are used to validate a Web application where several typical but non-trivial bugs were planted. Challenges in the automation of the process are also discussed.

ns+SDL – The Network Simulator for SDL Systems

In order to be able to simulate SDL specification more efficiently, a paper from University Kaiserslautern [5] shows how to integrate the network simulator ns-2[11)] with SDL. The main idea is to provide an integration that will enable the use of the same code base for simulation and for production, such that the task of experimenting is not a separate activity. To this end, an extension of the network simulator ns-2 called ns+SDL was developed and tested using several protocols. The work is done using the Telelogic SDL and UML tool Telelogic Tau[12)].

Component development: MDA based transformation from eODL to CIDL

This is a very important paper, although from the title it is difficult to grasp its subject. It covers the most important area of component development within an MDA[13)] setting. eODL (extended Object Description Language) is the ITU language for specification of components; in particular their structure and interfaces. It is a high-level language developed to work together with the other ITU languages. For use in real applications it is necessary to apply a more low-level component description language such as CIDL (Component Implementation Definition Language) defined by the Object Management Group (OMG)[14)] as part of the Corba Component Model[15)]. The paper from Humboldt-University Berlin [6] shows how Java technology Meta Data Repository (MDR) is used for this transformation. The transformation is described using transformation rules which are implemented using MOF repositories as a model storage and executed using Java.

Synthesizing State machine Behaviour from UML Collaborations and Use Case Maps

Telecommunication services are provided as collaboration between components, which achieve the goal(s) of the service. UML 2.0 collaborations can be used to model services. Furthermore, they allow services to be described modularly and incrementally, since collaborations can be composed of subordinate collaborations. For such an approach to work, it is necessary to capture the exact dependencies between the subordinate collaborations. This paper from NTNU, Norway [7] presents the results of an experiment on using Use Case Maps (UCMs) for describing those dependencies, and for synthesizing the state-machine behaviour of service components from the joint information provided by the UML collaborations and the UCM diagrams.

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9) *http://fitnesse.org/*

10) *http://www.extremeprogramming.org/*

11) *ns-2 is a tool for the simulation of protocols in a network. See also http://www.isi.edu/nsnam/ns/*

12) *http://www.telelogic.com/products/tau/index.cfm*

13) *MDA (Model Driven Architecture) is the OMG way to handle generation of systems out of high-level descriptions.*

14) *http://www.omg.org/*

15) *http://www.omg.org/technology/documents/formal/components.htm*

Consistency Checking of Concurrent Models for Scenario-Based Specifications

Scenario-based specifications such as message sequence charts (MSC) offer an intuitive and visual way of describing design requirements. On the other hand, Petri nets can model concurrency constraints in a natural way, and are often used in modelling system specifications and designs. Since there are gaps between MSC models and Petri net models, keeping consistency between these two kinds of models is important for the success of software development. This paper from Nanjing University, China [8] considers the problem of checking Petri nets as models of concurrent systems against scenario-based specifications expressed by message sequence charts. It provides algorithms to solve the existential mandatory consistency-checking problems.

Associated Events

Tutorials

Four tutorials were presented on the tutorial day. These were selected according to the focus of the conference and with the idea to attract people. This was quite successful, because several people attended the tutorial day only without taking the conference.

Bran Selic from IBM Rational Software gave an overview of UML2.0 which was very much appreciated by the audience. Ina Schieferdecker and her team at GMD Fokus in Berlin presented an overview of MDA technologies in the scope of testing. Iulian Ober from Verimag Grenoble presented their verification tool called 'IF'[16) and its validation capabilities for real-time models. Finally, Eckhardt Holz from Hasso-Plattner-Institut Potsdam, Germany handled the transformation and integration of languages, again using SDL and UML as examples.

Workshops

In order to keep the conference short, it was decided to include discussion sessions into the programme rather than having an extra workshop day. The first discussion session was about MDA and the conclusion here was that ITU languages are far better in MDA than the UML group of languages.

The next discussion was about the use of SDL for the internet in terms of the Daidalos EU project [9]. There was not much discussion following this session, although the presentation was interesting. Another session was devoted to SDL education, and here it turned out again that there was not enough good teaching material for SDL available. Finally, there was a panel discussion about the future of SDL, which was continued in the SDL Society AGM (see there).

The SDL design contest

Since 2002 there has been an SDL design contest co-located with the SDL conference. This year's contest was sponsored by Safire SDL[17). The topic of the contest was the design of a digital camera according to a given requirements specification. Four entries have been delivered to the contest, and all of them have been very impressive. They all showed how an SDL specification was derived from the informal requirements and how this specification was enough to produce real executing code, including the connection to a real camera.

Tool presentations

During the course of the conference, tool builders presented their tools. Two of the tools were real SDL tools (Cinderella SDL[18) and Telelogic Tau[19)), while the other tools were tools related to UML or other languages.

ITU-T joint rapporteurs meeting

The conference was followed by an ITU-T joint rapporteurs meeting, a practical arrangement, because the people attending the conference could just proceed to the language standardisation issues related to SDL. This included several open issues with the standards that have to be finished before the next ITU meeting in Geneva in September 2005.

Summary

The SDL Forum 2005 conference has brought together theoreticians, users and tool builders of SDL. It was a fruitful event. The publicity of SDL has to be increased in order to get across the message that SDL is already one language of choice for automatic code generation.

16) *http://www-verimag.imag.fr/~async/IF/IFx.html*

17) *http://www.safire-sdl.com/*

18) *http://www.cinderella.dk/*

19) *http://www.telelogic.com/products/tau/index.cfm*

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References

1 Prinz, A, Reed, R, Reed, J (eds). SDL 2005: Model Driven. *Proceedings of the 12th International SDL Forum*, Norway. Lecture Notes in Computer Science, LNCS 3530, Springer, 2005.

2 Fischer, J, Kunert, A, Piefel, M, Scheidgen, M. ULF-Ware – An Open Framework for Integrated Tools for ITU-T Languages. In: *Proceedings of the 12th International SDL Forum*, Norway. Lecture Notes in Computer Science, LNCS 3530, Springer, 2005.

3 Sanders, R T, Bræk, R, von Bochmann, G, Amyot, D. Service Discovery and Component Reuse with Semantic Interfaces. In: *Proceedings of the 12th International SDL Forum*, Norway. Lecture Notes in Computer Science, LNCS 3530, Springer, 2005.

4 Amyot, D, Roy, J-F, Weiss, M. UCM-Driven Testing of Web Applications. In: *Proceedings of the 12th International SDL Forum*, Norway. Lecture Notes in Computer Science, LNCS 3530, Springer, 2005.

5 Kuhn, T, Geraldy, A, Gotzhein, R, Rothländer, F. ns+SDL – The Network Simulator for SDL Systems. In: *Proceedings of the 12th International SDL Forum*, Norway. Lecture Notes in Computer Science, LNCS 3530, Springer, 2005.

6 Böhme, H, Schütze, G, Voigt, K. Component Development: MDA Based Transformation from eODL to CIDL. In: *Proceedings of the 12th International SDL Forum*, Norway. Lecture Notes in Computer Science, LNCS 3530, Springer, 2005.

7 Humberto Nicolás Castejón Martínez. Synthesizing State-Machine Behaviour from UML Collaborations and Use Case Maps. In: *Proceedings of the 12th International SDL Forum*, Norway. Lecture Notes in Computer Science, LNCS 3530, Springer, 2005.

8 Li, X, Hu, J, Bu, L, Zhao, J, Zheng, G. Consistency Checking of Concurrent Models for Scenario-Based Specifications. In: *Proceedings of the 12th International SDL Forum*, Norway. Lecture Notes in Computer Science, LNCS 3530, Springer, 2005.

9 *Designing Advanced Interfaces for the Delivery and Administration of Location independent Optimised personal Services (DAIDALOS)*. Integrated Project in EU's 6th Framework Programme, Information Society Technologies (IST). Project no IST-2002-506997. June 15, 2006 [online] http://www.ist-daidalos.org/

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A Cinderella-based prototype of a digital camera – a contribution to the SDL'05 Design Contest

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SDL is a formal language which has its origin in telecommunications, but it is also a language applicable to specifying and implementing distributed systems in general. This paper will show how an SDL specification is a formal description of both the architecture and the behaviour of a system, in this case a digital camera. The possibility to provide a user-friendly and realistic view of an SDL system by means of an implemented GUI is also discussed.

1 Introduction

The purpose of this paper is to show how SDL is used to design and implement embedded systems.

The SDL design contest was arranged for the fourth time at the 12th SDL Forum in Grimstad, Norway in June 2005 [1]. The challenge was to create and test a software prototype of a digital camera. The system had to be implemented in SDL and should follow a given requirements specification. The deliverable for the contest should include a simulated environment with a user interface and also an automated test environment with SDL scenarios for taking pictures, changing camera settings and editing pictures.

There were four contributions to the SDL design contest, and they were all presented and defended in a session at the SDL Forum. The design solutions were then judged by the audience in accordance with ten evaluation guidelines given by the contest sponsors, SAFIRE. Two of the contestants were using the SAFIRE development environment for SDL, one was using Telelogic Tau, while I was using Cinderella SDL Version 1.3 [2] for both implementation and tests.

This SDL specification is based on SDL-2000, but most of the concepts used are from the SDL'88 standard. The main focuses during the implementation were simplicity in design and maximum use of simple language elements, in accordance with the evaluation guidelines. This is one of the main reasons the new features of SDL-2000 were not necessary. In this way, this paper also shows that it is not necessary to use the additional advanced mechanisms of SDL-2000 and still be in accordance with the standard. When features from SDL-2000 are used, this will be emphasized.

This article is structured as follows: In chapter 2, I will give an overview of the requirements given for the camera prototype. Chapter 3 deals with the architectural design, while chapter 4 gives an introduction to the behaviour of the implemented system. In chapter 5, the tests and the testing environment are presented. Finally, I will conclude in chapter 6.

2 Requirements

The camera prototype had the following minimum design requirements, cf. requirement specification in [3]:

- A trigger button that sends press and release signals;
- A light sensor that when required returns a signal declaring the current brightness;
- Two exposure modes:
  - Manual (user defined duration)
  - Automatic (automatically-defined duration, based on light sensor value)

Active Mode

- Three buttons are enabled: Flash, Timer and Edit
- Image current view can be displayed on the screen
- User can toggle the flash settings: auto-flash, no-flash and flash-on
- User can toggle the timer settings: timer on and timer off
- Push trigger to take photo
- The light sensor returns bright or dark
- The exposure is short or long
- When memory is full, there should be a warning

Figure 1 Requirements in active mode

Editing Mode

- Four buttons are enabled: Back, Forward, Delete, Exit
- Display number of current photo and the total number of photos
- Possibility to navigate through saved photos
- Exit returns to active mode
- Deleting photos from memory

Figure 2 Requirements in editing mode

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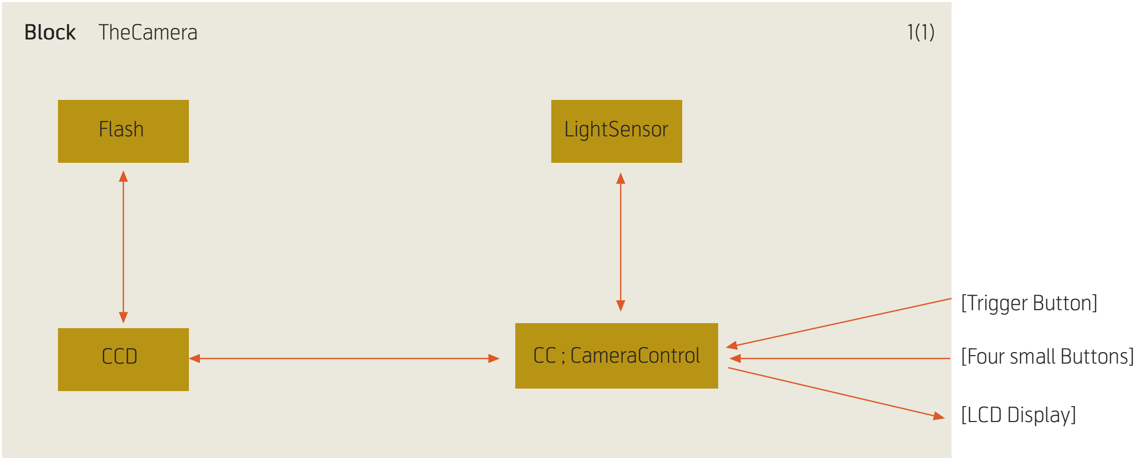

Figure 3 The camera system

- A simple user interface:
  - Toggle the exposure mode
  - Set the manual exposure time
  - Save or delete the last picture

These requirements were supplied by a number of additional requirements which are shown in Figures 1 and 2.

3 Architecture

When designing this software prototype, a main focus was on simplicity. In this section I will give an overview of the architectural solution of the digital camera.

According to the requirements, the camera should have a trigger button, four small buttons and an LCD display. The user interacts with the system by pushing the trigger button or one of the four small buttons.

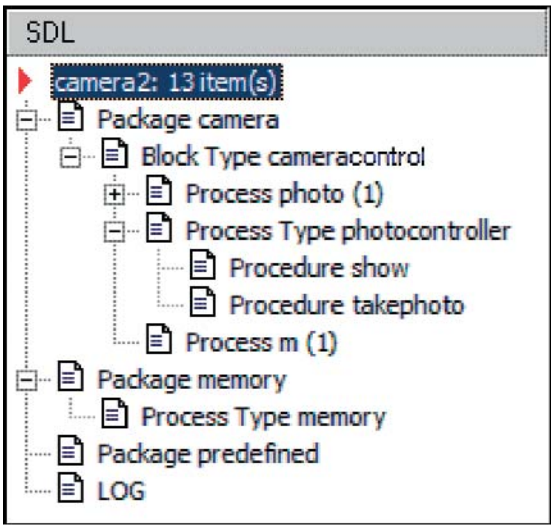

Figure 4 Hierarchical structure

The LCD display gives output to the user by photos or text messages.

The camera consists of four different units: the `CameraControl`, which handles all the interaction from the environment, a `LightSensor`, a `CCD` and a `Flash`.

The light sensor communicates with the camera control, and gives the current brightness. The flash is set based on the user's settings and the brightness returned from the light sensor. The CCD is responsible for the actual photographing. This is all illustrated in the block `TheCamera` in Figure 3.

3.1 Hierarchical structure of the camera system

The camera is modelled like an open system with extensive use of types on all possible levels. As we can see from Cinderella's explorer view (Figure 4) the system has a hierarchical structure of three levels; block type, process type and procedure. Use of block types provides the possibility of putting the system into packages, which in turn encourages reuse. The memory is modelled separately as a process type within a separate package, and is then used inside the camera package. Package is a concept from SDL'92.

3.2 The design

The hierarchical structure shows that an instance of the block type `CameraControl` is the top level description of the camera. There is also an instance `Photo` of process type `PhotoController` which handles all the communication with the environment. `Photo` is in turn connected to a local instance of the process type `memory (m: memory)`, which handles all the saved photos.

The process instance `Photo` is connected to the environment through three channels: `user_interac-`

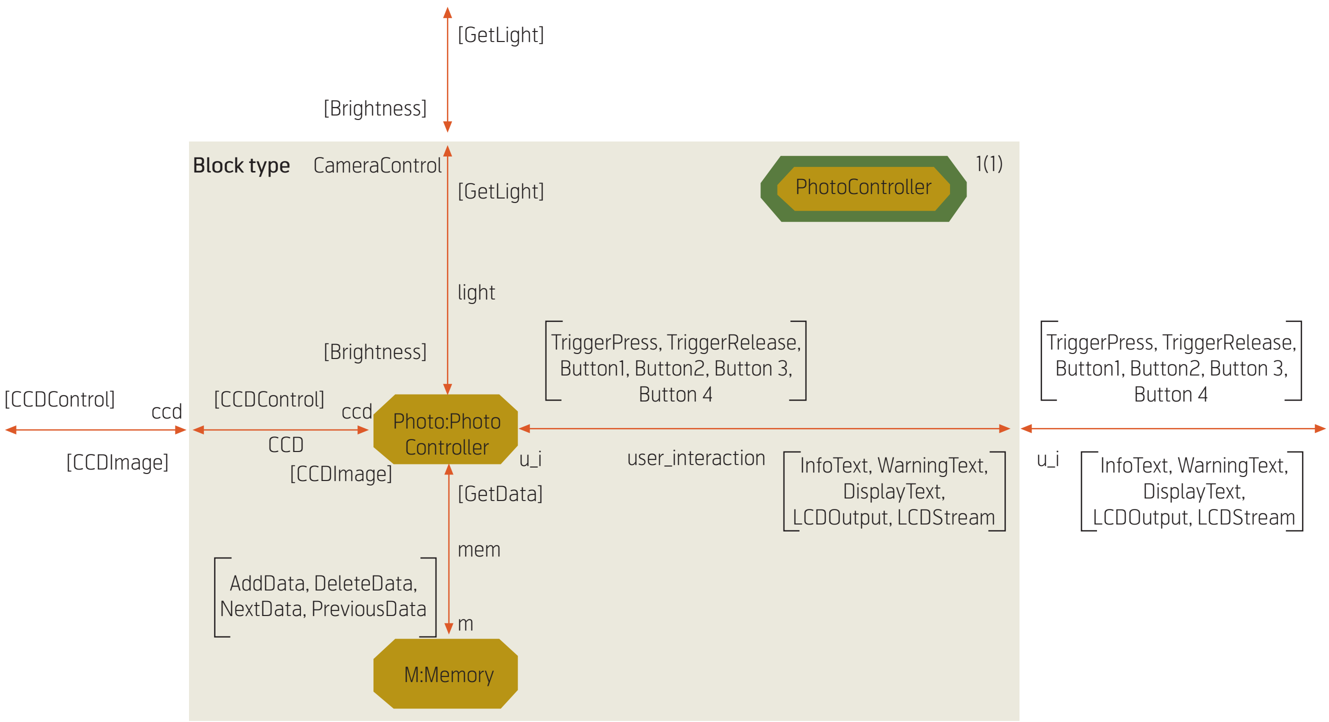

Figure 5 The top level design

tion, light and CCD (cf. Figure 3). The signals passed in incoming direction over the channel user_interaction are the user's interaction with the camera, while the outgoing signals are the camera's output to the user. When a photo is to be shot there will be a request to the light sensor about the brightness. The signals passed over the channel light are the camera control's interaction with the light sensor, and CCD contains signals for actually taking the photo.

The connection to the memory is through the channel mem and includes signals for saving and deleting photos, and also navigating through the saved photos.

3.3 Runtime Environment

The camera system is a stand-alone system and is completely run and simulated in Cinderella. It is modelled as an open SDL system; this means that there are channels which connect the system to the environment. In this case we have three channels which all go through Cinderella.

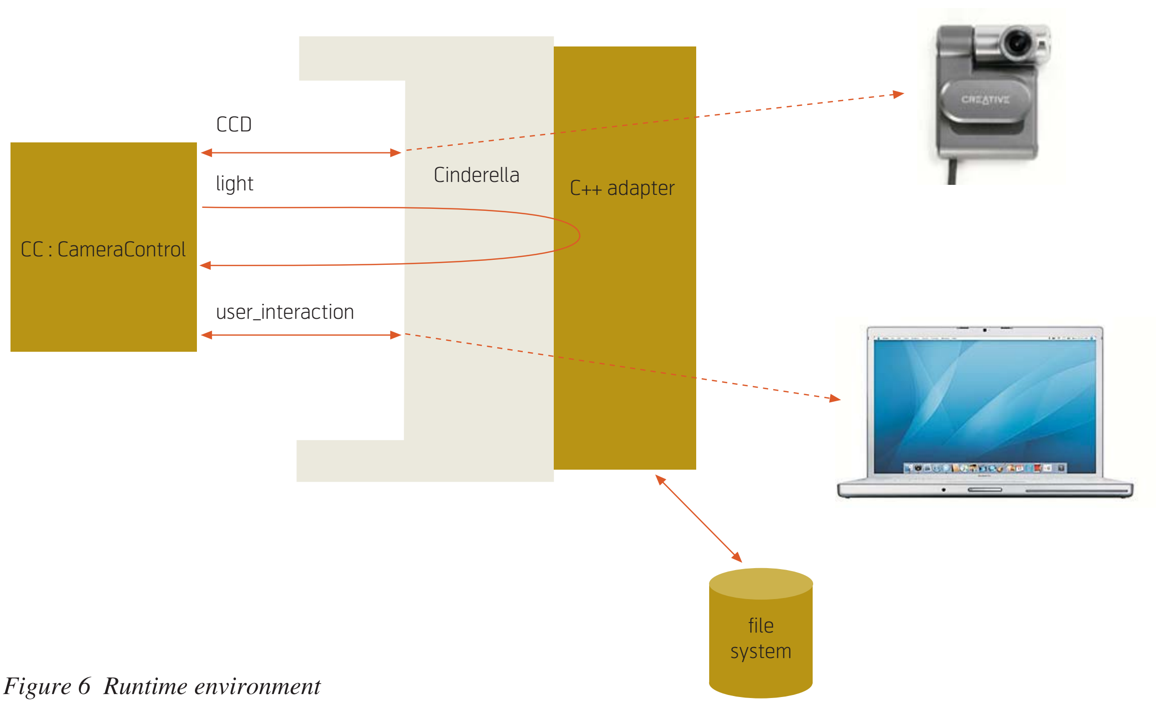

Figure 6 Runtime environment

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To provide a more user-friendly and realistic view of the SDL camera system and the environment, a graphical user interface was implemented. Cinderella provides the possibility to include source in the form of a Visual Studio C++ project, and the concepts in the GUI are assigned to the signals in the SDL system. This is illustrated as the C++ adapter in Figure 6.

As mentioned in 3.2 there are three different channels (see Figure 3) which connect the camera to the environment. Figure 6 illustrates how these channels communicate with the runtime environment. The user can give input, like take a photo or change settings, to the camera system using a terminal. The output from the camera, such as text messages or taken photos, will also be shown within the GUI which runs on the terminal. The `CCD` communicates with a real web camera. We also have the communication with the light sensor, which is a recurrent channel.

The photos taken are saved in the file system, while the memory inside the camera handles the file names.

Figure 7 User interface

```
signal

/* user input */
TriggerPress,             /* pressing the trigger button */
TriggerRelease,           /* releasing the trigger button */
Button1,                  /* pressing button 1 */
Button2,                  /* pressing button 2 */
Button3,                  /* pressing button 3 */
Button4,                  /* pressing button 4 */

/* output to user */
LCDOutput(Image),         /* showing one image */
DisplayText(Charstring, Charstring, Charstring, Charstring),
                          /* Displaying text for the four buttons */
InfoText(Charstring),     /* Displaying text in the status line */

/* light sensor */
GetLight,                 /* request light sensor value */
Brightness(BValue),       /* light sensor result */

/* taking photo */
CCDControl(Flash,TValue), /* request to take image */
CCDImage(Image),          /* image taken */
```

Figure 8 Signal list

3.4 User Interface

Figure 7 shows a screenshot of the user interface when the camera is in active mode. The signal list in Figure 8 shows the signals which are relevant to this camera mode.

We have a trigger button which is assigned to the signals `TriggerPress` and `TriggerRelease`. We also have four small buttons below the screen. Each of these buttons is assigned to one of the four signals: `Button1`, `Button2`, `Button3` and `Button4`. The buttons are implemented as four different incoming signals because they represent four physical different units and we need to distinguish which of the buttons is being pushed. The four small buttons are labelled with text, and these signals are independent of the label settings. The text labels are represented by the outgoing signal `DisplayText`. On top of the LCD screen we have a text line giving us information about the memory usage and number of photos remaining. `InfoText` takes care of this. The `LCDOutput` signal gives us the current picture on the screen.

When a photo is shot, a request is sent to the light sensor. This is represented by the signal `GetLight`. The light sensor, which is placed in front of the camera, returns the `Brightness`. The outgoing signal `CCDControl` is a request to take an image. A separate flash signal is not implemented, as both this and the exposure time are represented as parameters in the signal `CCDControl` (cf. Figure 8). The actual taken photo is returned in the signal `CCDImage`.

4 The behaviour of the system

The camera has two modes; an active mode which provides everything necessary for taking pictures (see requirements Figure 1), and an editing mode where the user has the possibility to navigate through saved photos and also delete them (see Figure 2).

4.1 State transitions

The process type camera (Figure 9) is a high level abstraction of the behaviour in the camera system. The diagram only shows States and Input, except from the Start symbol. The purpose is to show the different states in the camera and the triggers that lead to changes of state. The behaviour in the transitions between the states is omitted.

When the camera is turned on, we are in Active Mode, State Active. We can then take photos by pressing the trigger. The camera then goes into the state `TakePhoto`. `TakePhoto` is a composite state and its internal structure is described in Figure 10. Composite state is a new concept of SDL-2000, and is a means to hierarchically structure the state machines.

After the trigger is pressed and released, the light sensor is queried about the current brightness. The photo is taken and we wait for the data (the photo) to be written out on the LCD Display. After the photo is taken, there will be a recovery while the taken picture is written to the memory. During the recovery, all the buttons on the camera are disabled. When the recovery time has expired, the camera returns to active mode.

When taking a picture, it is possible to use a timer. The timer may be set in the Active Mode, and when the trigger is pressed, the camera will be in the state `TimerRunning`. The camera will wait here for the timer to expire before entering the procedure `TakePhoto`. When the timer is running, no input is allowed, except for `Button4` which at this time is labelled Cancel. Cancel will abort the timer and the camera will return to Active Mode.

From Active Mode the user can change to Edit Mode, `StateEdit`, by pushing the edit button (`Button4`). In `StateEdit` we have the possibility to navigate through the saved photos by the buttons labelled Back and Forward. After pushing the buttons, the camera will be in the state `WaitForMemory` until the picture is captured from the memory by `getData`.

When the memory is full, there will be a warning to the user. The state diagram shows that after the camera has left the `TakePhoto` state, there will be a test whether the memory is full or not. If there is enough free space in memory the camera continues in `StateActive`. On the other hand, if the memory is full, the camera enters the state `MemoryFull`. There

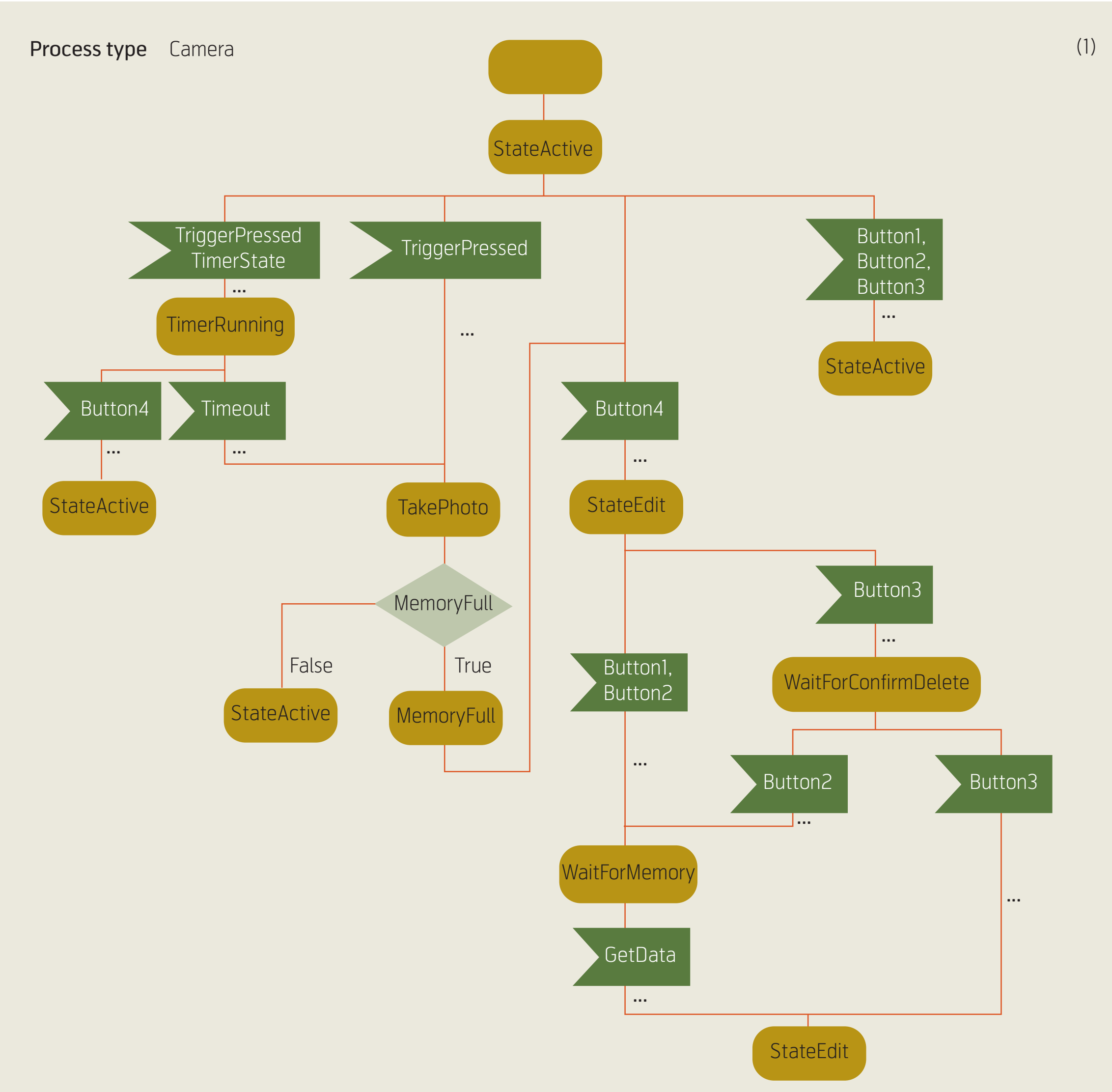

Figure 9 State diagram

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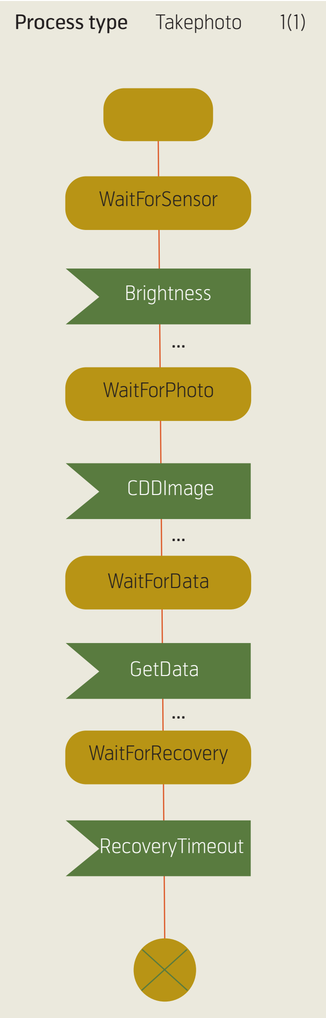

Figure 10 Internal structure of TakePhoto

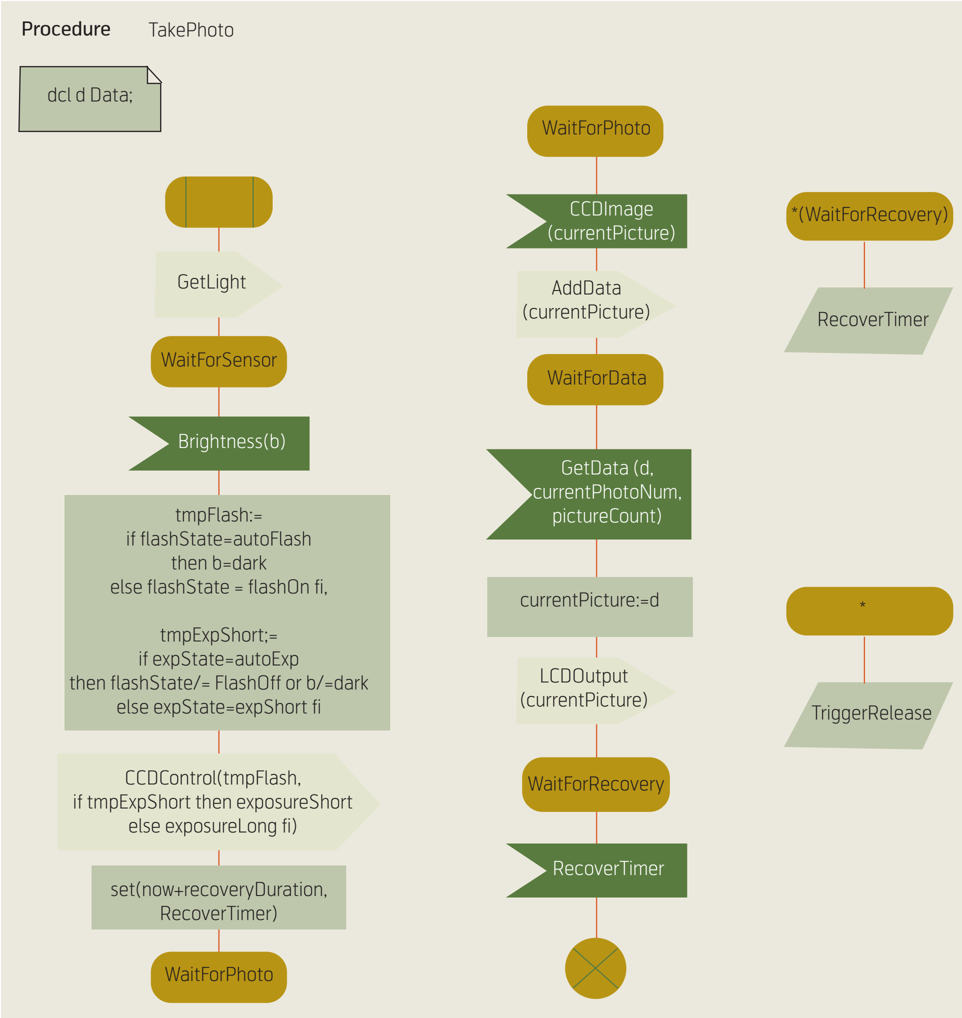

Figure 11 Procedure TakePhoto

is no possibility to take more photos when the camera is in this state. The user will then have the possibility to change to Edit Mode by pushing `Button4`, and then delete a number of photos (`Button3`). The deleting has to be confirmed by `Button3`, or cancelled by `Button2`.

4.2 Implementation of TakePhoto

Even though section 4.1 shows `TakePhoto` as a composite state, the actual implementation shown in Figure 11 is a procedure. The reason for this is that the Cinderella SDL version 1.3 does not support the concept of composite state from SDL-2000.

As we could see from the state diagram, the camera enters this procedure when the trigger button is pressed and released. After a request to the light sensor, we get the Brightness in return. Based on the value from the light sensor and the user's settings, the flash and exposure are set in the two variables `tmpFlash` and `tmpExpShort`. We then have the signal `CCDControl` containing the parameters for flash and exposure, as an outgoing request to take a photo. Next step is the `RecoverTimer` to be set. The `RecoverTimer` is then saved because as we will see in the following, there are parallel ongoing events when taking photos.

Meanwhile the `RecoveryTimer` is running, the taken picture is returned as a parameter in the signal `CCDImage` and is then added to the memory by `AddData`. `GetData` gets the current picture from the memory together with the number of this picture and total number of pictures. The actual picture is then written out on the LCD display by the signal `LCDOutput`. The top-level design in Figure 5 shows the communication between the processes `Cam` and `Memory`, and the signals `AddData` and `GetData`.

Finally, the `RecoverTimer` expires. In the diagram this is represented as an input signal of the same name.

The variable `Image` which is a parameter in the signals `CCDImage`, `AddData` and `LCDOutput`, is not implemented according to a special type of image.

Whether the current image is of type jpg, bmp or gif makes no difference. The data type of the variable could then be changed in the declaration whenever needed, without any problems. This is already done once, when the data type was changed from integer to char string in an early step of the implementation.

4.3 Use of save

Save is a concept in SDL which is widely discussed, and there are lots of different opinions on the subject.

In the procedure `TakePhoto` in Figure 11, save is used to handle the `RecoverTimer`. The `RecoveryTimer` is running while the taken photo is written to the memory and out on the LCD display. Since we do not know how long this will take, save is appropriate to use. If the `RecoverTimer` expires before the photo is written to the memory, this is simply ignored (saved) until all the actions between the timer is set and the `WaitForRecovery` in Figure 11 are done. If, on the other hand the photo is written to the memory and out on the LCD display before the timer has expired, the camera will stay in the `WaitForRecoveryState` as usual until the timer times out.

Figure 12 shows the same procedure `TakePhoto`, but with an alternative solution without the use of

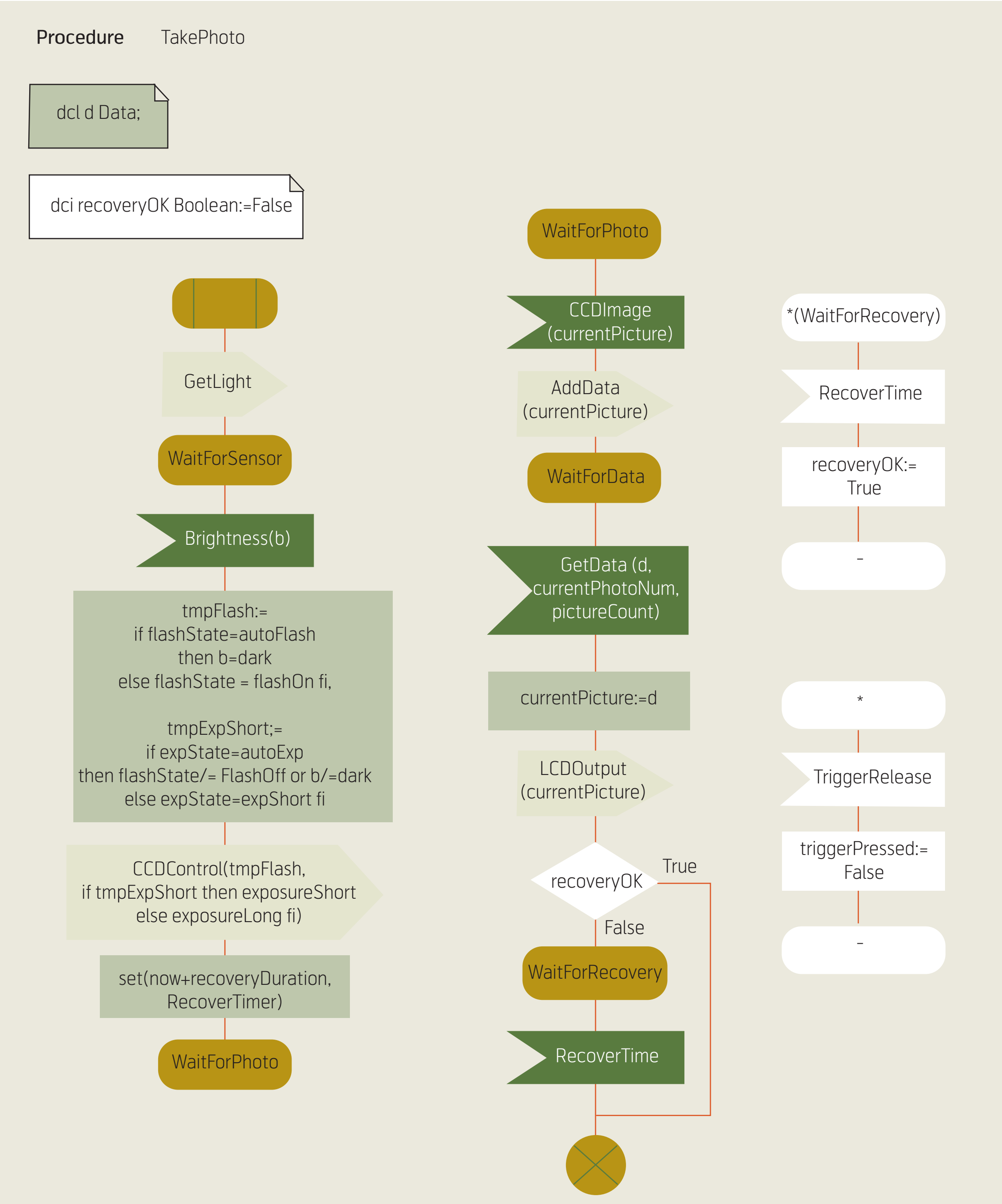

Figure 12 TakePhoto without save

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save. A Boolean variable recoveryOK is declared in the process and when the RecoverTimer expires, the recoveryOK is set to true. A decision is used to branch according to the value of the Boolean variable.

By comparing Figures 11 and 12 it is easy to see the benefits that save gives when it comes to simplicity in the design, in contrast to use of the local variable recoveryOK in Figure 12. Another benefit save gives in this example relates to the trigger-Pressed. Without the use of save, this variable has to be set to false inside the TakePhoto procedure. This conflicts with what is illustrated in the state diagram (Figure 9), namely that everything about pressing the trigger is handled outside the TakePhoto procedure. This is an important aspect of encapsulation.

5 Tests

SDL is quite suitable to use as a simple test description language. The SDL task force discusses testing in their document on SDL+[4] and they identify some problems with tests in SDL. Organization of tests and forming a conclusion from tests are not supported in SDL, while checking responses from tests is only partly supported. The following section will give an overview of how the test part is solved in relation to the camera system.

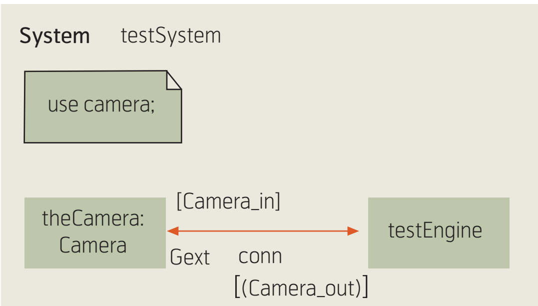

Figure 13 testSystem

5.1 Test Harness design

We have implemented an SDL system called Test-System (Figure 13) to take care of the tests. This system contains the block testEngine. All the signals and type descriptions are available by using the camera package and the testEngine is connected to an instance of the camera.

Inside the testEngine (Figure 14) we have two processes: TestManager and testProcess. The testProcess gives a message to the TestManager that a test is ready to be run. The TestManager will then respond with the signal Start-TestCase. The test case is run, and hopefully the testProcess returns the signal TestCase-Success (Figure 15).

5.2 Test cases

The camera system is implemented following the principles from test driven development. We have taken the requirements one by one and written a test that fails. We have then written an implementation that makes the test succeed. This leads to all the requirements being covered by tests and all tests being 100 % successful.

Figure 16 shows one of the implemented test cases, TestCase1. This is a test case of what should happen when pushing the trigger to take a photo. This test corresponds to the procedure TakePhoto as we have seen earlier (Figure 11). Figure 17 shows the same testcase, but as an MSC diagram from when the test is running. This includes the communication between a test process and photo. Photo is also here an instance of the process type PhotoController, cf. section 3.2, and Figures 4 and 5.

The block TestEngine (Figure 14) shows a process testProcess which receives all the signals going out from the camera as input and has all the input signals to the camera as output. This is illus-

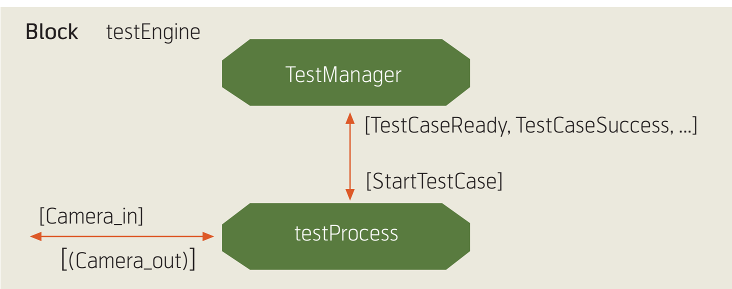

Figure 14 testEngine

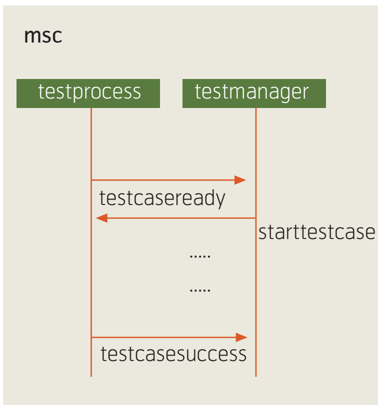

Figure 15 testCommunication

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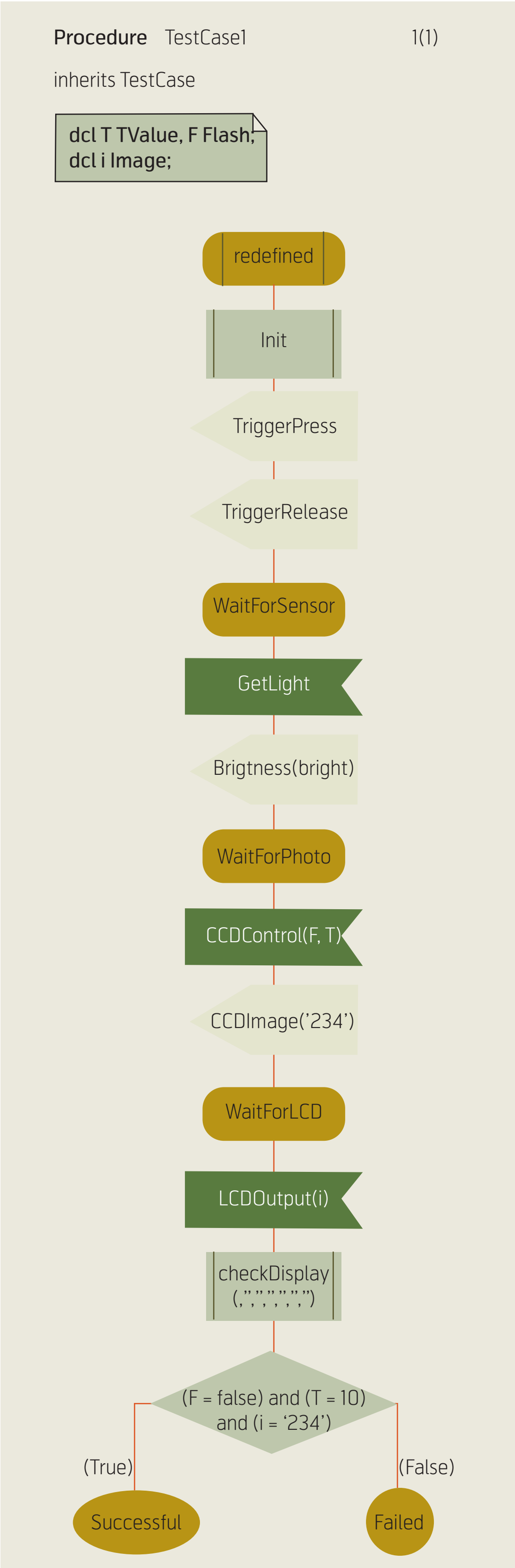

Figure 16 TestCase1 in SDL

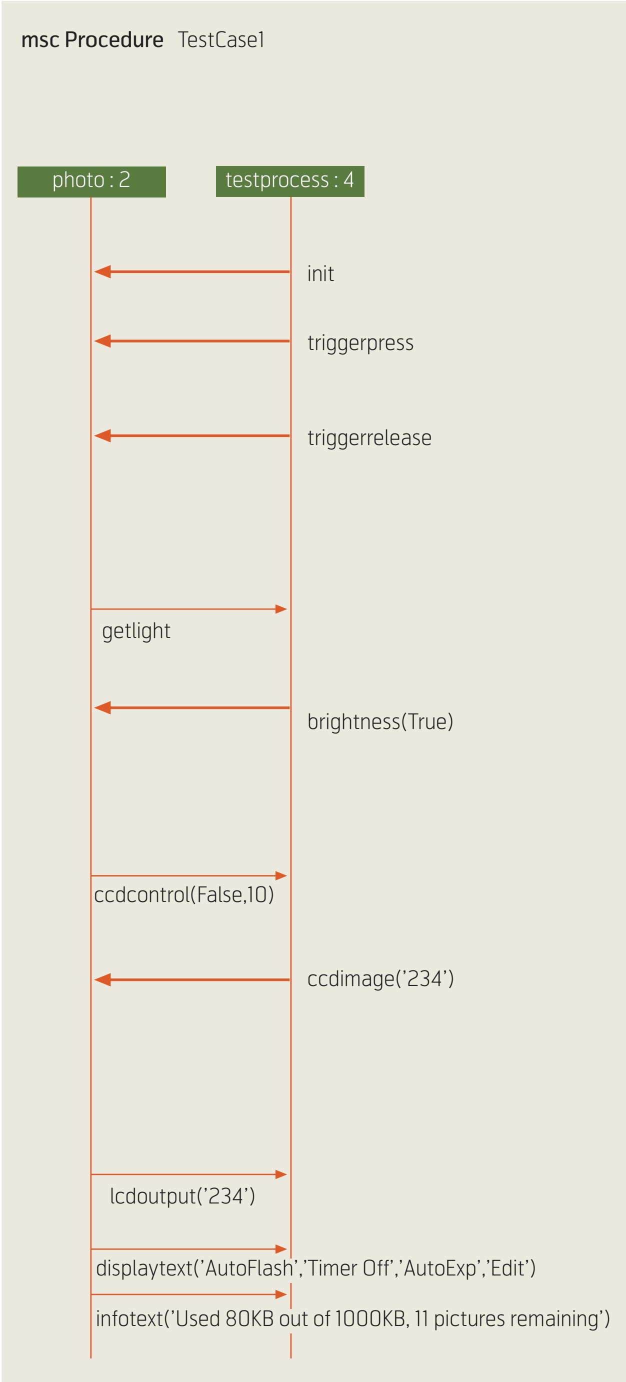

Figure 17 TestCase1 in MSC

trated by the two signal lists `camera_in` and `camera_out`. A signal list contains a number of different signals, and these two lists contain all the same signals as in the implementation of the camera system. This is possible because the test environment is also within the SDL, and is a good example of reuse.

5.3 Test Environment

This `TestCase` procedure is implemented as part of the test environment and is also used as a template for the other test cases that we have implemented. As an example we can see `TestCase1` (Figure 16) which is inherited from this `TestCase` procedure.

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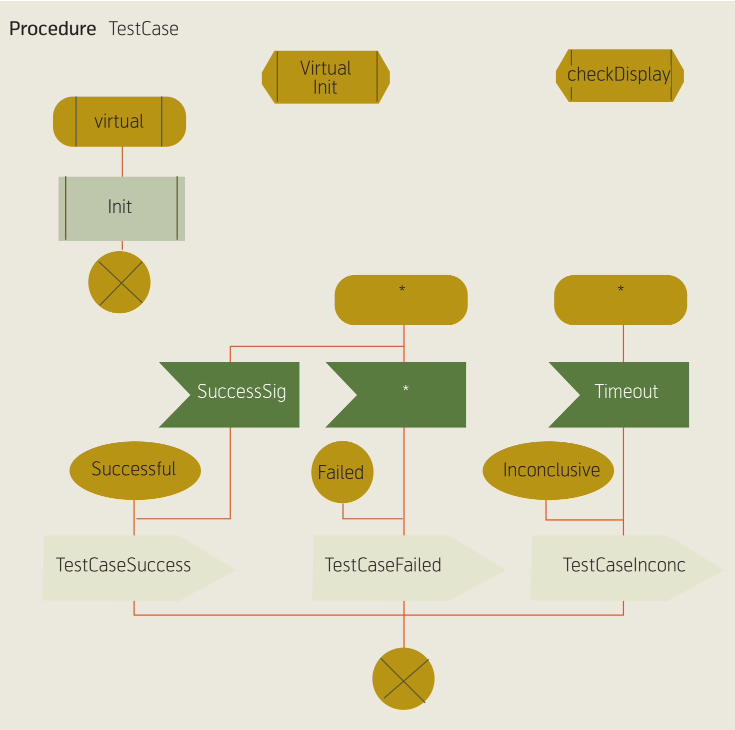

Figure 18 TestCase

This template procedure also defines three test verdicts: `Successful`, `Failed` and `Inconclusive`. By means of the three related signals it is easy to state that a test is finished and also what the conclusion is.

6 Conclusion

The purpose of this article was to show how SDL could be used to design and implement embedded systems. This is done based on my contribution to the SDL Design Contest, which is a specification of a digital camera.

An SDL specification is a formal description of both the architecture and the behaviour of the system. When starting to specify and design an SDL system, it is natural to start with some sort of a high level picture of the architecture of the system. This high level picture shows the different units the system consists of, and the connection between the units and the environment. It is natural also to do the same thing when it comes to the behaviour. We will then move stepwise from just sketches of the system into a formal system description and SDL can be used on all levels of abstraction.

References

1 *12th SDL Forum*, Grimstad, Norway, June 2005. June 19, 2006 – [online]. http://ikt.hia.no/sdl05/

2 *Cinderella*. Cinderella SDL Version 1.3. 2002. June 19, 2006 – [online]. http://www.cinderella.dk.

3 *SAFIRE Team*. SDL'05 Design Contest. June 19, 2006 – [online]. http://www.safire-sdl.com/contest/sdl_05.htm.

4 *SDL Task Force*. SDL+ Version 1.3. 2003. June 19, 2006 – [online]. http://www.sdltaskforce.org

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Terms and acronyms in Ubiquitous Broadband Access

Acronym/ Term	English	English	Web resources
16-QAM	16-level Quadrature Amplitude Modulation	A modulation method in which the amplitude of two quadrature waves is changed in order to represent the data signal. A constellation diagram is often used to represent this kind of modulation. In QAM the constellation points are usually arranged in a square grid with equal horizontal and vertical spacing, although other configurations are possible. The number of points in the grid is usually a power of 2 (2, 4, 8 etc.), and since QAM usually is square, the most common forms are 4-QAM (or QPSK), 16-QAM, 64-QAM, 128-QAM and 256-QAM. QPSK and 16-QAM are e.g. used in current and future mobile radio systems like 3G/HSDPA and WiMax/IEEE 802.16, while 64-QAM and 256-QAM are often used in digital cable television and cable modems.	
2G	Second Generation mobile technology	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 technology	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 2Mb/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 of producing 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
3GPP2	Third Generation Partnership Project 2	A collaborative third generation (3G) telecommunications specifications-setting project comprising North American and Asian interests developing global specifications for ANSI/TIA/EIA-41 Cellular Radiotelecommunication Intersystem Operations network evolution to 3G and global specifications for the radio transmission technologies (RTTs) supported by ANSI/TIA/EIA-41. 3GPP2 was initiated as a result of the International Telecommunication Union's (ITU) International Mobile Telecommunications IMT-2000 initiative, covering high speed, broadband, and Internet Protocol (IP)-based mobile systems featuring network-to-network interconnection, feature/service transparency, global roaming and seamless services independent of location. 3GPP2 is a collaborative effort between five officially recognized Standards Development organisations (SDO): ARIB – Association of Radio Industries and Businesses (Japan), CCSA – China Communications Standards Association (China), TIA – Telecommunications Industry Association (North America), TTA – Telecommunications Technology Association (Korea) and TTC – Telecommunications Technology Committee (Japan)	http://www.3gpp2.org
AAA	Authentication, Authorization and Accounting	Key functions to intelligently control access, enforce policies, audit usage, and provide the information necessary to do billing for services available on the Internet.	
AAL	ATM Adaption Layer	The use of Asynchronous Transfer Mode (ATM) technology and services creates a need for an adaptation layer in order to support information transfer protocols, which are not based on ATM. This adaptation layer defines how to segment and reassemble higher-layer packets into ATM cells, and how to handle various transmission aspects in the ATM layer. Examples of services that need adaptations are Gigabit Ethernet, IP, Frame Relay, SONET/SDH, UMT/Wireless, etc. The main services provided by AAL are: Segmentation and reassembly, handling of transmission errors, handling of lost and misinserted cell conditions and timing and flow control.	http://www.itu.int
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.	

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Acronym/ Term	English	English	Web resources
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.	
AP	Access Point	A point where users access the system/network, e.g. a base station in a wireless network.	
API	Application Programming Interface	The specific method prescribed by a computer operating system or by an application program by which a programmer writing an application program can make requests of the operating system or another application. 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.	
AS	Application Server		
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 a 2.5 Gb/s. Standardised by ITU-T.	
AU	Authentication Header		
BAR	Backbone Attaching Router		
BFWA	Broadband Fixed Wireless Access	BFWA 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 and suburban areas.	
BGCF	Breakout Gateway Control Function		
BRAN	Broadband Radio Access Network	A standardization project in ETSI for Broadband Radio Access Networks (BRAN). It was established in 1997 as the successor of the former Sub-Technical Committee RES10, which developed the HIPERLAN/1 specifications. The project prepares standards for equipment providing broadband (25 Mbit/s or more) wireless access to wire-based networks in both private and public environments, operating in either licensed or license exempt spectrum. These systems address both business and residential applications. Close relationships have been established with the ATM Forum, the HiperLAN2 Global Forum, the IEEE Wireless LAN Committees P 802.11a and IEEE 802.16, the Internet Engineering Task Force, the MMAC-PC High Speed Wireless Access Systems Group, the International Telecommunication Union Radio sector (ITU-R) and a number of internal ETSI Technical Bodies. ETSI BRAN currently produces specifications for three major Standard Areas: 1) HiperLAN2, a mobile broadband short-range access network, 2) HIPERACCESS, a fixed wireless broadband access network, and 3) HIPERMAN, a fixed wireless access network which operates below 11 GHz.	http://portal.etsi.org/bran
BROADWAN	Broadband Services for Everyone over Fixed Wireless Access Networks	European research project funded by the 6th framework Programme IST (Information Society Technologies). The project ran from 2004 to 2006 with 25 partners. The major goals of the project were to 1) Develop an economically realistic network architecture to provide true broadband services for all citizen in Europe; 2) Bring European industry in the lead for next generation wireless solutions; 3) Motivate advanced utilisation of broadband services at all levels of the society by performing wireless demonstrations and trials in rural areas.	http://www.telenor.no /broadwan/, http://cordis.europa.eu /ist/projects/projects.htm
BS	Base Station		
BWA	Broadband Wireless Access	A technology aimed at providing high-speed wireless access over a wide area from devices such as personal computers to data networks. Most widely used technologies are LMDS and MMDS and IEEE 802.16, also known as WiMAX.	
C/I	Carrier to Interference Ratio	Also called SIR – Signal to inteference ratio. The power ratio between the useful signal level (C) and interfering signals (I). Often expressed in dB.	
CAC	Call Admission Control	A method used to prevent congestion in Voice Traffic. It is a preventive Congestion Control Procedure used in the Call Setup phase. CAC can be used to prevent congestion in connection-oriented protocols such as ATM. There are several CAC schemes available. It prevents oversubscription of VoIP networks. CAC mechanisms extend the capabilities of QoS tools to protect voice traffic from the negative effects of other voice traffic and to keep excess voice traffic off the network.	
CAPEX	Capital expenditure	Expenditures used by a company to acquire or upgrade physical assets such as equipment, property, industrial buildings. In accounting, a capital expenditure is added to an asset account (i.e. capitalized), thus increasing the asset's basis.	

Acronym/ Term	English	English	Web resources
CDMA2000	Code Division Multiple Access 2000	A family of third-generation (3G) mobile telecommunications standards that use CDMA, a multiple access scheme for digital radio, to send voice, data, and signalling data (such as a dialled telephone number) between mobile phones and cell sites. It is the second generation of CDMA digital cellular. The CDMA2000 standards CDMA2000 1x, CDMA2000 1xEV-DO, and CDMA2000 1xEV-DV are approved radio interfaces for the ITU's IMT-2000 standard and a direct successor to 2G CDMA, IS-95 (cdmaOne). CDMA2000 is standardized by 3GPP2. CDMA2000 is a registered trademark of the Telecommunications Industry Association (TIA-USA) in the United States, not a generic term like CDMA.	http://www.3gpp2.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 more often used than CLEC.	
COST	European Cooperation in the Field of Scientific and Technical Research	COST is an intergovernmental network with nine scientific COST Domain Committees formed by scientists of the European scientific community. The scientific quality control is the main responsibility of the COST scientific Domain Committees which follow evaluation procedures established by the COST Committee of Senior Officials (CSO) involving the mandatory use of external peer reviewers. It was established in 1971 at a ministerial conference of 19 European countries as a response to the American challenge. It now (2006) has 35 member countries. From 2003, the European Science Foundation (ESF) acts as the legal entity for COST. There are currently more than 500 running actions (projects).	http://www.cost.esf.org/
CPE	Customer Premises Equipment	Any terminal and associated equipment and inside wiring located at a subscriber's premises and connected with a carrier's telecommunication channel(s) at the demarcation point ("demarc"). The demarc is a point established in a building or complex to separate customer equipment from telephone company equipment. CPE generally refers to telephones, DSL modems or cable modems, or purchased set-top boxes for use with communication service providers' services. Also included are key phone systems and most private branch exchanges.	
CRABS	Cellular Radio Access for Broadband Services	European research project in the ACTS programme (Project AC215). The main objective was to develop and demonstrate a cellular radio system to provide broadband interactive digital television and multi-media services through several user and service trials in five areas in Europe. The project involved detailed studies of the systems architecture necessary for implementation and the development of standards vital for future commercial products. The project had 14 partners and ran from 1996 to 1999.	http://www.telenor.no/fou/prosjekter/crabs/crabs.html, http://cordis.europa.eu/infowin/acts/rus/projects/ac215.htm
CSCF	Call/Session Control Function	Several roles of SIP servers or proxies used to process SIP signalling packets in the IP Multimedia Subsystem (IMS).	
CWDM	Coarse Wavelength Division Multiplexing	A relatively low-cost WDM technology that uses wide spacing (about 10 – 20 nm) between wavelengths and un-cooled optics. CWDM is standardised by ITU-T G.694.1.	http://www.itu.int
DAB	Digital Audio Broadcast	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
dB	Decibel	One tenth of a Bel, where 'Bel' refers to Alexander Graham Bell. A unit of measure of signal strength, usually the relation between a transmitted signal and a standard signal source. Decibel was invented by the Bell System to express gain or loss in telephone transmission systems. Decibel is a logarithmic unit which defines the level of gain or loss in signal strength in a circuit or link, or device compared to a reference value. $[dB] = 10\log_{10}(p/p_{ref})$, where p denotes the actual power level, and p_{ref} denotes the reference power.	
DECT	Digital Enhanced Cordless Telecommunication	Formerly called Digital European Cordless Telephone. An ETSI standard for digital portable phones, commonly used for domestic or corporate purposes. DECT is a cellular system with cell radii of 25 to 100 metres. DECT uses a net bit rate of 32 kbit/s. It operates in the frequency band from 1880 to 1900 MHz. The band is divided into 10 carriers, each with 2 x 12 timeslots. It can serve a traffic density of approx. 10,000 Erlang/km^2 The DECT physical layer is a combined frequency division multiple access (FDMA)/time division multiple access (TDMA) system using time division duplex (TDD) to separate traffic in the two directions.	http://www.etsi.org
DiffServ	Differentiated Services	A method of trying to guarantee quality of service on large networks such as the Internet.	http://www.ietf.org
DL	Downlink		
DMB	Digital Media Broadcast	Wireless Broadband technology based on the DAB (Digital Audio Broadcast) system.	

Acronym/ Term	English	English	Web resources
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, however, were not enthusiastic about it, 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) reduce 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.	
DTT	Digital Terrestrial Television network	A network for transport of digital TV channels. The network can also be used for broadband communication.	
DVB	Digital Video Broadcasting	An international digital broadcast standard for TV, audio and data. DVB can be broadcast via satellite, cable or terrestrial systems. It has initially been used in Europe and the Far East.	http://www.dvb.org/
DVB-C	Digital Video Broadcast – Cable		
DVB-H	Digital Video Broadcasting – Handheld		
DVB-RCS	Digital Video Broadcasting, Return Channel via Satellite		
DVB-S	Digital Video Broadcast – Satellite		
DVB-T	Digital Video Broadcast – Terrestrial		
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
ESA	European Space Agency	The European Space Agency's mission is to shape the development of Europe's space capability. ESA has 17 Member States. ESA's job is to draw up the European space programme and carry it through. The Agency's projects are designed to find out more about the Earth, its immediate space environment, the solar system and the Universe, as well as to develop satellite-based technologies and services, and to promote European industries. ESA also works closely with space organisations outside Europe.	http://www.esa.int/esaCP/index.html
ESP	Encapsulating Security Payload	A part of the IPsec frameworrk for Internet security. The ESP extension header provides origin authenticity, integrity, and confidentiality of a packet.	http://www.ietf.org
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

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Acronym/ Term	English	English	Web resources
FDD	Frequency Division Duplex	A duplex communication system is one where signals can flow in both directions between connected parties. FDD is the application of frequency-division multiple access to separate outward and return signals.	
FEC	Forward Error Correction	A technique of error detection and correction in which a transmitting host computer includes a number of redundant bits in the payload (data field) of a block or frame of data. The receiving device uses the extra bits to detect, isolate and correct any errors created in transmission.	
FSO	Free Space Optics	A telecommunication technology that uses light propagating in free space to transmit data between two points. The technology is useful where the physical connection of the transmit and receive locations is difficult, for example in cities where the laying of fibre optic cables is expensive. Free Space Optics is also used to communicate between spacecraft, since outside of the atmosphere there is little to distort the signal. The optical links usually use infrared laser light, although low-data-rate communication over short distances is possible using LEDs. IrDA is a very simple form of free-space optical communications. Distances up to the order of 10 km are possible, but the distance and data rate of connection is highly dependent on atmospheric conditions.	
FTTC	Fibre To The Cabinet	Also known as FTTN (Fibre to the Neighbourhood). A Hybrid Fibre Coax (HFC) network architecture involving an optical fibre which terminates in either a street side or neighbourhood cabinet, which converts the signal from optical to electrical. The subscriber connection is either over twisted pair cable or coaxial cable.	
FTTH	Fibre To The Home	The installation of optical fibre from directly into the subscriber's home. FTTH is also referred to as fibre-to-the-building (FTTB), which includes optical fibre that is installed directly into a home or enterprise.	
FTTN	Fibre To The Node/ Neighbourhood	A Hybrid Fibre Coax (HFC) network architecture involving an optical fibre which terminates in either a street side or neighbourhood cabinet, which converts the signal from optical to electrical . The subscriber connection is either over twisted pair cable or coaxial cable.	
FTTO	Fibre To The Office		
FTTP	Fibre To The Premises		
FTTx	Fibre To The "x"	FTTx refers to several different forms of optical Fibre architectures including Fibre-to-the-Node/Neighbourhood (FTTN), Fibre-to-the-Exchange (FTTEx), Fibre-to-the-Cabinet (FTTCab), Fibre-to-the-Curb (FTTC), Fibre-to-the-Building (FTTB), Fibre-to-the-Home (FTTH) and Fibre-to-the-Premises (FTTP).	
FWA	Fixed Wireless Access	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 and suburban areas.	
GBE	Gigabit Ethernet	A term describing various technologies for implementing Ethernet networking at a nominal speed of 1 Gb/s. Gigabit Ethernet is supported over both optical fibre and twisted pair cable. Physical layer standards include 1000BASE-T, 1 Gb/s over cat-5e copper cabling and 1000BASE-SX for short to medium distances over optic fibre. While it is currently deployed in high-capacity backbone network links its speed is largely not yet required for small network installations. Gigabit Ethernet begun to penetrate the desktop as of 2000.	
GPON	Gigabit PON	A PON (Passive Optical Network) which extends the BPON (Broadband PON) to support bitrates in excess of 1 Gb/s. It is specified by ITU-T G.984.	http://www.ponforum.org http://www.itu.int
GPRS	General Packet Radio Service	An enhancement to the 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 to 48 kb/s.	http://www.etsi.org http://www.3gpp.org
GSM	Global System for Mobile communications	A digital cellular phone technology system that is the predominant system in Europe, but is 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. GSM defines the entire cellular system, from the air interface to the network nodes and protocols. As of January 2005, there were more than 1.2 billion GSM users in more than 200 countries worldwide. The ubiquity of the GSM standard makes international roaming very common between mobile phone operators which enable phone users to access their services in many other parts of the world as well as their own country. GSM differs significantly from its predecessors in that both signalling and speech channels are digital, which means that it is seen as a second generation (2G) mobile phone system. This fact has also meant that data communication was built into the system from very early on. GSM is an open standard which is currently developed by the 3GPP.	http://www.gsmworld.com/ http://www.etsi.org http://www.3gpp.org

Acronym/ Term	English	English	Web resources
HDTV	High Definition Television	Broadcast of television signals with a higher resolution than traditional formats (NTSC, SECAM, PAL) allow. Except for an early analogue 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.	
HF-BWA	High Frequency Broadband Wireless Access	BWA-systems operating at frequencies above 20 GHz.	
HIPER-ACCESS	High Performance Radio Access	A Point-to-MultiPoint (PMP) network architecture intended for high speed (up to 120 Mb/s) and high-QoS fixed wireless access. Applications include broadband access for residential and small business users to a wide variety of networks as a flexible and competitive alternative to wired access networks, however HiperACCESS is not an LMDS-type system. HiperACCESS standardization focuses on solutions optimized for frequency bands above 11 GHz (e.g, 26, 28, 32, 42 GHz) with high spectral efficiency under LOS (Line Of Sight) conditions. For bandwidths of 28 MHz, both FDD and TDD channel arrangements as well as H-FDD terminals are supported. HiperACCESS is an interoperable standard, allowing for PMP systems with base station and terminal stations from different manufacturers. The HiperACCESS (HA) specifications are being developed by TC (Technical Commitee) BRAN.	http://www.etsi.org
HIPERLAN	High Performance Radio Local Area Network	A short-range variant of a broadband radio access network intended as a complementary access mechanism for UMTS systems as well as for private use as a wireless LAN type system. HiperLAN offers high speed (up to 54 Mb/s) access to a variety of networks including the UMTS core networks, ATM networks and IP based networks. Basic applications include data, voice and video, with specific Quality of Service parameters taken into account. HiperLAN/2 systems can be deployed in offices, classrooms, homes, factories, hot spot areas such as exhibition halls and, more generally, where radio transmission is an efficient alternative or complements wired technology. The HiperLAN/2 specifications are being developed by ETSI Project BRAN.	http://www.etsi.org
HIPERMAN	High Performance Radio Metropolitan Network	A standard created by the European Telecommunications Standards Institute (ETSI) Broadband Radio Access Networks (BRAN) group to provide a wireless network communication in the 2 – 11 GHz bands across Europe and other countries which follow the ETSI standard. HIPERMAN is a European alternative to WiMAX (or the IEEE 802.16 standard) and the Korean technology WiBro.	http://www.etsi.org
HMIPv6	Hierarchical Mobile Internet Protocol Version 6	An enhancement to the Mobile IP technique being developed to improve mobile communications in certain circumstances by making the processes more secure and more efficient.	http://www.ietf.org
HSDPA	High-Speed Downlink Packet Access	Enhancement of the 3G standard UMTS in order to provide higher bit rates on the downlink. The theoretical data rate can reach 14.4 Mb/s.	http://www.3gpp.org
HSS	Home Subscriber Service		
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.	
IEEE	The Institute of Electrical and Electronics Engineers	USA based organisation open to engineers and researchers in the fields of electricity, electronics, computer science and telecommunications. Established in 1884. The aim is to promote research through journals and conferences and to produce standards in telecommunications and computer science. IEEE has produced more than 900 active standards and has more than 700 standards under development. Divided into different branches, or 'Societies'. Has daughter organisations, or 'chapters' in more than 175 countries worldwide. Headquarters in Piscataway, New Jersey, USA.	http://www.ieee.org

Acronym/ Term	English	English	Web resources
IEEE 802.11	The IEEE 802 LAN/MAN Standards Committee Working Group for WLAN	Refers to a family of specifications developed by the IEEE for wireless local area networks. It also refers to the "Wireless LAN working group" of the IEEE 802 project. 802.11 specifies an over-the-air interface between a wireless client and a base station or between two wireless clients. The IEEE accepted the specification in 1997. There are several specifications in the 802.11 family, including i) 802.11 – provides 1 or 2 Mbit/s transmission in the 2.4 GHz band; ii) 802.11a – an extension that provides up to 54 Mbit/s in the 5 GHz band. It uses an orthogonal frequency division multiplexing encoding scheme rather than FHSS or DSSS; iii) 802.11b provides 11 Mbit/s transmission in the 2.4 GHz band and was ratified in 1999 allowing wireless functionality comparable to Ethernet; iv) 802.11g provides 20+ Mbit/s in the 2.4 GHz band; v) 802.11z is a method for transporting an authentication protocol between the client and access point, and the Transport Layer Security (TLS) protocol. More variants are also under preparation, including support of 100 Mbit/s traffic flows.	http://www.ieee802.org/11/
IEEE 802.16	The IEEE 802 LAN/MAN Standards Committee Working Group on Broadband Wireless Access Standards	A specification for fixed broadband wireless metropolitan access networks (MANs) that use a point-to-multipoint architecture. Published on 8 April 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/
IEEE 802.3	The IEEE 802 LAN/MAN Standards Committe Working Group on CSMA/CD (Ethernet)	The permanent CSMA/CD (Ethernet) working group of the IEEE 802 project.	http://www.ieee802.org/3/
IETF	Internet Engineering Task Force	A large open international community of network designers, operators, vendors, and researchers concerned with the evolution of the Internet architecture and the smooth operation of the Internet. It is open to any interested individual. The technical work of the IETF is done in its working groups, which are organized by topic into several areas (e.g. routing, transport, security, etc.). Much of the work is handled via mailing lists. The IETF holds meetings three times per year. The IETF working groups are grouped into areas and managed by Area Directors (AD). The ADs are members of the Internet Engineering Steering Group (IESG). Providing architectural oversight is the Internet Architecture Board, (IAB). The IAB also adjudicates appeals when someone complains that the IESG has failed. The IAB and IESG are chartered by the Internet Society (ISOC) for these purposes. The General Area Director also serves as the chair of the IESG and of the IETF, and is an ex-officio member of the IAB. The Internet Assigned Numbers Authority (IANA) is the central coordinator for the assignment of unique parameter values for Internet protocols. The IANA is chartered by the Internet Society (ISOC) to act as the clearinghouse to assign and coordinate the use of numerous Internet protocol parameters.	http://www.ietf.org/rfc /rfc3935.txt
IMS	IP Multimedia Subsystem	IMS is a standardised Next Generation Networking (NGN) architecture for telecom operators that want to provide mobile and fixed multimedia services. It uses a Voice-over-IP (VoIP) implementation based on a 3GPP standardised implementation of SIP, and runs over the standard Internet Protocol (IP). Existing phone systems (both packet-switched and circuit-switched) are supported. IMS was originally defined by an industry forum called 3G.IP (www.3gip.org) formed in 1999. 3G.IP developed the initial IMS architecture, which was brought to 3GPP for industry standardization as part of their standardization work for 3G mobile phone systems in UMTS networks. It first appeared in release 5 (evolution from 2G to 3G networks), when SIP-based multimedia was added. Support for the older GSM and GPRS networks was also provided. "Early IMS" was defined to allow for IMS implementations that do not yet support all "Full IMS" requirements. 3GPP2 (a different organisation) based their CDMA2000 Multimedia Domain (MMD) on 3GPP IMS, adding support for CDMA2000.	http://www.3gpp.org http://www.ietf.org
IntServ	Integrated Services	A computer network architecture that specifies the elements to guarantee quality of service (QoS) on networks. IntServ can for example be used to allow video and sound to reach the receiver without interruption. IntServ specifies a fine-grained QoS system. The idea of IntServ is that every router in the system implements IntServ, and every application that requires some kind of guarantee has to make an individual reservation. "Flow Specs" describe what the reservation is for, while the Resource Reservation Protocol (RSVP) is the underlying mechanism to signal it across the network.	http://tools.ietf.org /html/rfc1633
IP	Internet Protocol	A protocol for communication between computers, used as a standard for transmitting data over networks and as the basis for standard Internet protocols.	http://www.ietf.org
IPSec	IP Security	Securiy protocol for the internet.	http://www.ietf.org
IPTV	Internet Protocol Television	A system where a digital television service is delivered using the Internet Protocol over a network infrastructure, which may include delivery by a broadband connection.	

Acronym/ Term	English	English	Web resources
IPv4	Internet Protocol version 4	IPv4 is version 4 of the Internet Protocol (IP) and the first version of the Internet Protocol to be widely deployed. IPv4 is the dominant network layer protocol on the Internet. It is described in IETF RFC 791 (September 1981) which obsoleted RFC 760 (January 1980). IPv4 is a data-oriented protocol to be used on a packet switched internetwork (e.g. Ethernet). It is a best effort protocol in that it doesn't guarantee delivery. It doesn't make any guarantees on the correctness of the data; it may result in duplicated packets and/or packets out-of-order. All of these things are addressed by an upper layer protocol (e.g. TCP, UDP). See also IP and Ipv6.	http://www.ietf.org
IPv6	Internet Protocol version 6	Ipv6 is version 6 of the Internet Protocol (IP). A network layer standard used by electronic devices to exchange data across a packet-switched internetwork. It follows IPv4 as the second version of the IP to be formally adopted for general use. IPv6 is intended to provide more addresses for networked devices, allowing, for example, each cell phone and mobile electronic device to have its own address. IPv4 supports 4.3 billion addresses, which is inadequate to give one (or more if they possess more than one device) to every living person. IPv6 supports 3.4 × 10e38 addresses, or 5 × 10e28 (50 octillion) for each of the roughly 6.5 billion people alive today. Invented by Steve Deering and Craig Mudge at Xerox PARC, IPv6 was adopted by the Internet Engineering Task Force in 1994, when it was called "IP Next Generation" (IPng). As of December 2005, IPv6 accounts for a tiny percentage of the live addresses in the publicly-accessible Internet, which is still dominated by IPv4. The adoption of IPv6 has been slowed by the introduction of network address translation (NAT), which partially alleviates address exhaustion.	http://www.ietf.org
IRR	Internal Rate of Return	A capital budgeting method used by firms to decide whether they should make long term investments. The IRR is defined as any discount rate that results in a net present value of zero, and is usually interpreted as the expected return generated by the investment.	
ISDN	Integrated Services Digital Network	A digital telecommunications 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
ISP	Internet Service Provider	A vendor who provides access for customers to the Internet and the World Wide Web. The ISP also typically provides a core group of internet utilities and services like e-mail and news group readers.	
IST	Information Society Technologies	Thematic Programmes of the 5th and 6th Framework Research Programmes funded by the European Union. The first IST programme ran from 2000 to 2004, the IST programme of the 6th Framework Research Programme started in 2003 and runs to 2006.	http://www.cordis.lu/ist/
ISUP	ISDN User Part	Part of ITU's Signalling System #7 which is used to set up telephone calls in Public Switched Telephone Networks. It is specified by the ITU-T as part of the Q.7xx series.	http://www.itu.int
ITU	International Telecommu-nication Union	On 17 May 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
ITU-R	International Telecommu-nication Union Radiocommu-nication Sector	A sector of the ITU whose mission it is, inter alia, to ensure rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including those using satellite orbits, and to carry out studies and adopt recommendations on radiocommunication matters. It was created on 1 March 1993, replacing the former International Radio Consultative Committee (CCIR).	http://www.itu.int/ITU-R
ITU-T	International Telecommu-nication Union – Standardi-zation Sector	A sector of the ITU, whose mission it is to ensure an efficient and on-time production of standards (Recommendations) covering all fields of telecommunications. It was created on 1 March 1993, replacing the former International Telegraph and Telephone Consultative Committee (CCITT).	http://www.itu.int/ITU-T/
LAN	Local Area Network	A network shared by communicating devices, usually in a small geographical area. A system that links together electronic office equipment, such as computers and word processors, and forms a network within an office or building.	
LF-BWA	Low Frequency Broadband Wireless Access	BWA systems operating at frequencies below 20 GHz.	
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 Multi-point Distribu-tion System	System for Wireless Local Loop applications which can replace cable based access to private and corporate customers. Operates typically in millimetre wave band. Can provide bandwidth of several Mb/s to the end customer.	
LOS	Line of Sight	This term is often associated with radio transmission systems indicating there is a clear path between the transmitter and receiver.	

Acronym/ Term	English	English	Web resources
MAC	Medium Access Control	The lower of the two sub layers of the Data Link Layer. In general terms, MAC handles access to a shared medium, and can be found within many different technologies. For example, MAC methodologies are employed within Ethernet, GPRS, and UMTS.	
MAN	Metropolitan Area Network	Large computer networks usually spanning a campus or a city using wireless infrastructure or optical fibre connections to link their sites. Some technologies used for this purpose are Asynchronous Transfer Mode (ATM), Fibre Distributed Data Interface (FDDI) and Switched Multimegabit Data Service (SMDS). These older technologies are in the process of being displaced by Ethernet-based MANs in most areas. MAN links between LANs have been built without cables using either microwave, radio, or infra-red free-space optical communication links.	
MAP	Mobility Anchor Point		
MBMS	Multimedia Broadcast 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 target 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
MGCF	Media Gateway Control Function	The functions of a Media Gateway Controller.	
MGW	Media Gateway	Converts media provided in one type of network to the format required in another type of network.	http://webapp.etsi.org /Teddi/
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.	
MIP	Mobile IP	A communication protocol that allows a device to move between different networks while maintaining a permanent IP address. The Mobile IP protocol is defined in RFC 3344.	http://www.ietf.org
MIPv6	Mobile IP version 6	A communication protocol which allows nodes to remain reachable while moving around in the IPv6 Internet. It allows a mobile node to move from one link to another without changing the mobile node's IP address. It is defined in IETF RFC 3775. Security mechanisms (IPsec) for MIPv6 are defined in RFC 3776.	http://www.ietf.org http://tools.ietf.org/html /rfc3775, http://tools.ietf.org/html /rfc3776
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
MPEG	Moving Picture Expert Group	MPEG is a working group of ISO/IEC (ISO/IEC JTC/SC29 WG 11) in charge of the development of standards for coded representation of digital audio and video. The working group has developed three sets of standards defining coding and transmission of audio and video; MPEG-1, MPEG-2 and MPEG-4. Another standard developed is MPEG-7, the standard for description and search of audio and visual content. MPEG-21 is a standard defining Multimedia Framework.	http://www.chiariglione .org/mpeg/
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. It is specified in IETF RFC 2702.	http://www.ietf.org
MRF	Multimedia Resource Function		
MWS	Multimedia Wireless Services		

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Acronym/ Term	English	English	Web resources
NAT	Network Address Translation	In computer networking, the process of network address translation (NAT, also known as network masquerading or IP-masquerading) involves re-writing the source and/or destination addresses of IP packets as they pass through a router or firewall. Most systems using NAT do so in order to enable multiple hosts on a private network to access the Internet using a single public IP address. According to specifications, routers should not act in this way, but many network administrators find NAT a convenient technique and use it widely. Nonetheless, NAT can introduce complications in communication between hosts. NAT first became popular as a way to deal with the IPv4 address shortage and to avoid the difficulty of reserving IP addresses. Use of NAT has proven particularly popular in countries other than the United States, which (for historical reasons) have fewer address-blocks allocated per capita. It has become a standard feature in routers for home and small-office Internet connections, where the price of extra IP addresses would often outweigh the benefits. In a typical configuration, a local network uses one of the designated "private" IP address subnets (such as 192.168.x.x or 10.x.x.x), and a router on that network has a private address (such as 192.168.0.1) in that address space. The router is also connected to the Internet with a single "public" address (known as "overloaded" NAT) or multiple "public" addresses assigned by an ISP. As traffic passes from the local network to the Internet, the source address on the packets are translated on the fly from the private addresses to the public address(es). The router tracks basic data about each active connection (particularly the destination address and port). When a reply returns to the router, it uses the connection tracking data it stored during the outbound phase to determine where on the internal network to forward the reply; the TCP or UDP client port numbers are used to demultiplex the packets in the case of overloaded NAT, or IP address and port number when multiple public addresses are available, on packet return. To a system on the Internet, the router itself appears to be the source/destination for this traffic. The use of NAT creates problems for applications where the source and destination addressses and port numbers are used in the protocols, such as voice over IP.	
NGN	Next Generation Network	A network concept that aims at providing a framework to encompass the large variety of existing and emerging protocols and services, facilitate a further evolution of these, decouple the evolution from the underlying network infrastructure and facilitate the interfacing of a plethora of available media. The rationale behind NGN lies founded in paradigm shifts that have been taking place within the technological solutions and the business models in the telecom industry as a whole. The concept is based on IP-technology and is being specified by ITU-T.	http://www.itu.int
NPV	Net Present Value	Term used when evaluating a business case about the present net value of future investments.	
NWA	Nomadic Wireless Access		
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.	http://www.oecd.org
OFDM	Orthogonal Frequency Division Multiplexing	A spread spectrum technique that distributes the data over a large number of carriers spaced apart at precise frequencies. This spacing provides the "orthogonality" in this technique, which prevents the demodulators from seeing frequencies other than their own. The benefits of OFDM are high spectral efficiency, resiliency to RF interference, and lower multi-path distortion. This is useful because in a typical terrestrial wireless scenario there are multipath-channels (i.e. the transmitted signal arrives at the receiver using various paths of different lengths). Since multiple versions of the signal interfere with each other (inter symbol interference (ISI)) it becomes very hard to extract the original information. OFDM is sometimes called multi-carrier or discrete multi-tone modulation. It is the modulation technique used for digital TV in Europe, Japan and Australia. It is used in DAB, ADSL and WLAN 802.11a and g and WMAN 802.16 standards.	
OMA	Open Mobile Alliance	A standards body which develops open standards for the mobile industry. The OMA was created in June 2002 as an answer to the proliferation of industry forums each dealing with a few application protocols: the WAP Forum (focused on browsing and device provisioning protocols), the Wireless Village (focused on instant messaging and presence), the SyncML Consortium (focused on data synchronization), the Location Interoperability Forum, the Mobile Games Interoperability Forum and the Mobile Wireless Internet Forum. Each of these forums had its bylaws, its decision-making procedures, its release schedules, and in some instances there was some overlap in the specifications, causing duplication of work. The OMA was created to gather these initiatives under a single umbrella. Members include traditional wireless industry players such as equipment and mobile systems manufacturers and mobile operators, but also software vendors.	http://www.openmobile-alliance.org/

Acronym/ Term	English	English	Web resources
OPEX	Operations Expenditure	A company's operational cost in contrast to CAPEX – Capital Expenditure, which is the company's investment cost.	
P-CSCF	Proxy CSCF	A SIP proxy that is the first point of contact for an IP Multimedia Subsystem (IMS) terminal. It can be located either in the visited network (in full IMS networks) or in the home network (when the visited network is not yet IMS compliant).	http://www.3gpp.org http://www.ietf.org
PLC	Power Line Communi-cation	A system for transmitting broadband signals through the power lines directly to the customer premises.	
PMP	Point-to-Multipoint		
PPP	Point-to-Point Protocol	A commmunications protocol commonly used to establish a direct connection between two nodes. It can connect computers using serial cable, phone line, trunk line, cellular telephone, specialized radio links, or fibre optic links. Most internet service providers use PPP for customers' dial-up access to the Internet. An encapsulated form of PPP, called PPP over Ethernet, or PPPoE, is commonly used in a similar role with Digital Subscriber Line Internet service. PPP is commonly used to act as a layer 2 (the "Data Link" layer of the OSI model) protocol for connection over synchronous and asynchronous circuits, where it has largely superseded an older non-standard protocol (known as SLIP), and telephone company mandated standards (such as X.25). PPP was designed to work with numerous layer 3 network layer protocols, including IP, Novell's IPX, and AppleTalk. PPP is specified by IETF RFC 1661.	http://tools.ietf.org/html/rfc1661
PSTN	Public Service Telephone Network	Common notation for the conventional analogue telephone network.	
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
QPSK	Quadrature Phase Shift Keying	A digital modulation scheme that conveys data by changing, or modulating, the phase of a reference signal (the carrier wave) using four levels.	
RRM	Radio Resource Management		
RSU	Remote Switching Unit	A remote part of a digital exchange.	
RTCP	Real-Time Control Protocol	RTCP is defined in the same RFC as RTP. The header is similar to the RTP header. It defines the periodic transmission of control packets to all participants in the session, using the same distribution mechanism as the data packets. It is specified that the RTCP protocol should use an odd port number that is one higher than the corresponding RTP port number.	http://www.ietf.org
RTP	Real-Time Transport Protocol	The Internet standard protocol for the transport of real-time data, including audio and video. RTP is used in virtually all voice-over-IP architectures, for video-conferencing, media-on-demand, and other applications. A thin protocol, it supports content identification, timing reconstruction, and detection of lost packets. The protocol is defined in RFC 3550. RTP should use a dynamically allocated even port number. The actual media coding payload is defined in separate RFCs. RTP combines its data transport with a control protocol (RTCP), which makes it possible to monitor data delivery for large multicast networks, see also RTCP.	http://www.ietf.org
RTP	Reception Test Point	A location in three-dimensional spatial coordinates at which the signal strength from all cells can be evaluated. Used in technical evaluation of a cell plan.	
SA	Security Associations		
S-CSCF	Serving CSCF	The central node of the signalling plane of the IP Multimedia Subsystem (IMS). It is a SIP server, but performs session control as well. It is always located in the home network. The S-CSCF uses DIAMETER Cx and Dx interfaces to the HSS to download and upload user profiles – it has no local storage of the user.	http://www.3gpp.org http://www.ietf.org
SDH	Synchronous Digital Hierarchy	SDH is a standard technology for synchronous data transmission on optical media. It is the international equivalent of North American SONET (Synchronous Optical Network). Both technologies provide faster and less expensive network interconnection than traditional PDH (Plesiochronous Digital Hierarchy) equipment. It is a method of transmitting digital information where the data is packed in containers that are synchronized in time enabling relatively simple modulation and demodulation at the transmitting and receiving ends. The technique is used to carry high capacity information over long distances. 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). SDH is specified by ITU-T G.707.	http://www.itu.int

Acronym/ Term	English	English	Web resources
SDTV	Standard Definition TV		
SIIT	Stateless IP/ICMP Translation Algorithm	An Internet standards track protocol. A transition mechanism algorithm which translates between IPv4 and IPv6 packet headers (including ICMP headers) in separate translator "boxes" in the network without requiring any per-connection state in those "boxes". This new algorithm can be used as part of a solution that allows IPv6 hosts which do not have a permanently assigned IPv4 address to communicate with IPv4-only hosts. It is specified by IETF RFC 2765.	http://tools.ietf.org/html /rfc2765
SIP	Session Initiation Protocol	An IETF Protocol used to set up voice calls over an IP network. Also the name of the IETF WG developing the protocol.	http://www.ietf.org
SOHO	Small Office, Home Office		
SRTM	Shuttle Radar Topography Mission	SRTM is a joint project between the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). The objective of this project is to produce digital topographic data for 80 % of the Earth's land surface (all land areas between 60° north and 56° south latitude), with data points located every 1-arc second (approximately 30 metres) on a latitude/longitude grid. The absolute vertical accuracy of the elevation data will be 16 metres (at 90 % confidence).	http://srtm.usgs.gov/
SSL	Secure Sockets Layer	A cryptographic protocol which provides secure communications on the Internet for such things as web browsing, e-mail, Internet faxing, and other data transfers. SSL provides endpoint authentication and communications privacy over the Internet using cryptography. In typical use, only the server is authenticated (i.e. its identity is ensured) while the client remains unauthenticated; mutual authentication requires public key infrastructure (PKI) deployment to clients. The protocols allow client/server applications to communicate in a way designed to prevent eavesdropping, tampering, and message forgery. SSL was developed by Netscape. SSL version 3.0 was released in 1996 and later served as the basis for TLS version 1.0, an IETF standard protocol first defined in RFC 2246.	http://tools.ietf.org/html /rfc2246
STB	Set Top Box	A device that connects to a television and some external source of signal, and turns the signal into content then displayed on the screen. The signal source might be an ethernet cable (see triple play), a satellite dish, a coaxial cable (see cable television), a telephone line (including DSL connections), or even an ordinary VHF or UHF antenna. Content, in this context, could mean any or all of video, audio, Internet webpages, interactive games, or other possibilities.	
TDD	Time Division Duplex	A duplex communication system is one where signal can flow in both directions between connected parties. TDD is the application of time-division multiple access to separate outward and return signals. Time division duplex has a strong advantage in the case where the asymmetry of the uplink and downlink data speed is variable.	
TDMA	Time Division Multiple Access	A technology for shared medium (usually radio) networks. It allows several users to share the same frequency by dividing it into different time slots. The users transmit in rapid succession, one after the other, each using their own timeslot. This allows multiple users to share the same transmission medium (e.g. radio frequency) whilst using only the part of its bandwidth they require. Used in the GSM, PDC and iDEN digital cellular standards, among others. TDMA is also used extensively in satellite systems, local area networks, physical security systems, and combat-net radio systems.	
TISPAN	Telecommunication and Internet converged Services and Protocols for Advanced Networking	The ETSI core competence centre for fixed networks and for migration from switched circuit networks to packet-based networks with an architecture that can serve in both. TISPAN is responsible for all aspects of standardisation for present and future converged networks including the NGN (Next Generation Network) and including service aspects, architectural aspects, protocol aspects, QoS studies, security related studies, mobility aspects within fixed networks, using existing and emerging technologies. TISPAN is structured as a single technical committee with core competencies, under which there are Working Groups and Project Teams.	http://www.etsi.org http://portal.etsi.org/tispan
TLS	Transport Layer Security	Transport Layer Security (TLS) is a protocol that ensures privacy between communicating applications and their users on the Internet. When a server and a client communicate, TLS ensures that no third party may eavesdrop or tamper with any message. TLS is the successor to the Secure Sockets Layer (SSL).	
TVHE	TV Head End		
UCR	User Connecting Router		
UHF	Ultra-High Frequencies	Notation used to denote the frequency band from 300 to 3,000 MHz.	
UL	Uplink		

Acronym/ Term	English	English	Web resources
ULE	Ultra-Light Encapsulation		
UMTS	Universal Mobile Telecommunications 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 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/
UNESCO	United Nations Educational, Scientific and Cultural Organization	A specialized agency of the United Nations established in 1945. Its stated purpose is to contribute to peace and security by promoting international collaboration through education, science, and culture in order to further universal respect for justice, the rule of law, and the human rights and fundamental freedoms proclaimed in the UN Charter.	http://portal.unesco .org/en/
URSI	Union Radio-Scientifique Internationale (International Union of Radio Scientists)	A non-governmental and non-profit organisation under the International Council for Science, responsible for stimulating and co-ordinating, on an international basis, studies, research, applications, scientific exchange, and communication in the fields of radio science. It was established in 1922. The URSI secretariat is located at Ghent University in Belgium.	http://www.ursi.org
UWB	Ultra Wideband	A technology for transmitting information spread over a large bandwidth that should, in theory and under the right circumstances, be able to share spectrum with other users. The FCC and ITU-R define UWB in terms of a transmission from an antenna for which the emitted signal bandwidth exceeds the lesser of 500 MHz or 20 % bandwidth. Thus, pulse-based systems, wherein each transmitted pulse instantaneously occupies a UWB bandwidth, or an aggregation of at least 500 MHz worth of narrow band carriers, for example in orthogonal frequency-division multiplexing (OFDM) fashion can be regarded as UWB systems.	
VDSL	Very High Speed Digital Subscriber Line	VDSL transmits data up to 26 Mb/s over short distances of twisted pair copper wire. The shorter the distance, the faster the connection rate. Specified by ITU-T G.993.1. Second generation, VDSL2, supports up to 100 Mb/s data rate either symmetric or asymmetric in the range 1 – 3 km. Specified in ITU-T G.993.2.	http://www.itu.int
VHF	Very High Frequency	Notation used to denote the frequency band from 30 to 300 MHz.	
VoIP	Voice over Internet Protocol	Voice over Internet Protocol (also called VoIP, IP Telephony, Internet telephony, and Digital Phone) is the routing of voice conversations over the Internet or any other IP-based network. The voice data flows over a general-purpose packet-switched network, instead of traditional dedicated, circuit-switched voice transmission lines.	
WCDMA	Wideband Code Division Multiple Access	Modulation and multiple Access Technique employed by the 3G standard UMTS.	
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	Worldwide Interoperability for Microwave Access	A specification for fixed broadband wireless metropolitan access networks (MANs) that use a point-to-multipoint architecture. Based on the IEEE 802.16 WMAN. Published on 8 April 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/
WIPAS	Wireless IP Access System	A point-to-multipoint fixed wireless access system that provides broadband IP services for home and business users. A system dveloped by NTT (Japan) for the 26 GHz band.	http://www.ntt.co.jp
WLAN	Wireless Local Area Network	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 the Internet.	
WLL	Wireless Local Loop	The use of a wireless communications link as the "last mile / first mile" connection for delivering telephony service and broadband Internet to telecommunications customers. Various types of WLL systems and technologies exist.	

Acronym/ Term	English	English	Web resources
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 8 April 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/
WRAN	Wireless Regional Access Network	A generic term covering different technologies to provide wide area wireless networks. Also the name of the IEEE 802.22 standards committee on Wireless Regional Access Networks. The charter of IEEE 802.22 is to develop a standard for a cognitive radio-based PHY/MAC/air interface for use by license-exempt devices on a non-interfering basis in a spectrum that is allocated to the TV Broadcast Service.	http://www.ieee802.org/22/
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.	http://www.dslforum.org

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