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# Broadband Radio Access

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## Feature:
### Broadband Radio Access



## Status

# Guest editorial

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Broadband services have been around since the TV set was invented and broadcasting of moving pictures to the home started as a public service. We all consider this to be a natural part of everyday life, and it has been so for many years. Yet, to provide broadband communication services to the residential area is still considered a very challenging task. To provide broadband only in one direction is easy and cheap, to establish a two-way broadband service is considerably more difficult and may well become costly.

An increasing number of people and companies enjoy the benefit of fast personal computers with a mass storage for vast amounts of data as well as other equipment where high capacity transport of data is essential. Connecting them through an access network that can support broadband communication at a reasonable cost is mandatory to creating new businesses – irrespective of geographical location.

As the operator's and service provider's backbone networks already can carry a very high traffic load, the only real technical obstacle to providing the broadband services to the public is the bandwidth of the access network. In addition to TV channels such a broadband access network will open for new services and create new business opportunities.

Interactive broadband services can be supplied over cable networks, for example cable TV or standard pairs of copper wires for telephone, and through the air using radio systems. Several of the papers in this issue of *Telektronikk* argue that radio access offers cost-effective solutions for both private and business users.

A broadband radio access system is cellular with cell size varying according to population and business density and radio wave propagation conditions. The typical cell is a few kilometres in diameter and the number of terminals per radio cell may well be in the order of thousands. The local climate and demographic data are important input factors for establishing radio access systems. One of the strengths of radio is the flexibility to adopt to the local constraints. It is easily and fast established with a capacity well designed for the actual market. When the market grows the radio system can easily increase the network capacity and still provide a high quality service.

Assume that a 1 GHz bandwidth is available per basic radio cell. This is likely to be the case for the internationally adopted frequency bands (for Europe), from 40.5 to 42.5 GHz, as well as other bands above about 20 GHz. With such a bandwidth and standard robust modulation and coding techniques, the gross capacity per radio cell will be between 1 and 2 Gbit/s. Using more spectrum-efficient modulation techniques the capacity can with some limitations be increased, for example to about 10 Gbit/s. With the typical radio cell size envisaged it is readily seen that several Mbit/s capacity is available per user. The operation of the system however will not be a fixed average capacity per customer. It will vary greatly from user to user and dynamically over the day, perhaps from communication oriented traffic at busy hours to entertainment oriented traffic in the evenings. The traffic will be asymmetric seen from the individual user's point as well as from the total network. The challenging point today is to make a radio system that dynamically allocates capacity on the customer's demand at a reasonable and flexible quality and price.

The radio technology is mature and during the last years an impressive international research, equipment development and international standardisation activity have been done. This holds even at very high frequencies, above 20 GHz, where the necessary bandwidth is available for supplying broadband services to many users.

I am confident that ongoing development of broadband radio access systems will offer solutions and services most people can afford and new businesses will be established where the broadband telecommunication connections play a key role.

Terje Tjelta

# Broadband radio access for multimedia services

TERJE TJELTA, AGNE NORDBOTTEN
AND HARALD LOKTU

**Broadband services to every home at a price most people can afford is a major challenge to any operator or service provider and seems also to be requested by a growing part of the population. The services to be offered are the traditional broadcast and high capacity communication, as well as new ones such as interactive television, audio and video through the Internet, education and telemedicine. Many more will be created along with the development and deployment of broadband networks.**

**Radio offers a very interesting solution to the last kilometre access part of the network. It is interesting for several reasons: the service can be rolled out already now, it is technically advantageous over cable systems, it is environmentally friendly, and operators can invest gradually as the market grows.**

**This paper presents the current situation, discusses some technical issues for deployment of broadband radio access, and indicates future systems requirements. It focuses on the low cost aspect of the ultimate solution providing broadband services at a price most people can accept.**

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## 1 Introduction

Broadband access to every home has become a main goal for operators and users of communication, broadcast and information technology. A complete network supporting convergence of telecommunication, data and media is a must created by the developments in computer technology, the growth of interactive services represented by Internet, and the digitalisation of video services.

For the operators and the users this is observed as a need for a high capacity user friendly access network offering reliable cost effective broadband services. The need for increasing transport capacity is a consequence of the introduction of more powerful workstations, low cost high capacity data storage media, use of very demanding software which has to be downloaded puts challenging requirements on transport capacity and response. Our local data handling environment is undergoing rapid changes. The storage capacity in an ordinary PC will very soon exceed 100 GByte. The capacity of local area networks (LANs) will in a few years increase from 10 Mbit/s to several Gbit/s. The traffic structure is, as already demonstrated by electronic mail, gradually changing from a person to person connection to a person to many concept. Push delivery of large amounts of data to many is increasing fast.

The users are personal users, businesses working from home or home offices, as well as small and larger enterprises. A user may have several roles, for example a passive viewer of entertainment content or an active supplier of broadband information to smaller or larger groups of other users. Furthermore, the use of the network will vary dynamically over the day, eg. from business oriented activity during working hours to entertainment oriented activity in the evenings.

The main demands are cost-effective transport with guaranteed quality of service, perhaps at the users' choice and an on-demand capacity they are willing to pay for. The fibre based transport network already has an excess capacity, which is easily upgraded through the use of wavelength multiplexing. The bottleneck is the relatively expensive last kilometre connection – the access network. Possible solutions to this problem are sought through upgrading of existing networks and development of new technologies. Radio offers a solution where there are really no critical constraints limiting the services that can be supplied. If the right operating frequency is chosen broadband services, such as high quality video, can be supplied to a large number of users. The challenge is not being able to supply broadband services, but to develop a system that most people can afford.

## 2 Broadband in the access network

The term broadband is rarely defined precisely, and it is also used loosely in the literature. In this paper broadband indicates the capacity needed for high quality video/audio services, ie. 3–4 Mbit/s or more. Furthermore, providing broadband in the access network means to serve a large number of users. Therefore, the gross capacity of the network has to be large. Finally, a modern multimedia network must also handle different transport standards for stream and cell type traffic (ATM, IP and MPEG).

## 2.1 Current situation

Figure 1 illustrates possible solutions for broadband network connections to the home. The two main directions of development are based on increasing the capacity of the communication network (ADSL, fibre) and development of digital broadcast networks into interactive networks through the introduction of a communication type return channel. This development which partly converts the capacity of the multi-user broadcast network into an individual network, will then end up with a capacity per user depending on the total number of users. One solution to this problem is to employ a cellular architecture with a limited cell size, and developing radio based solutions like interactive satellite systems, stratospheric platforms and LMDS has also been in focus.

This paper will mainly deal with the broadband radio solutions and in particular the cellular broadband radio access network with its different phases of development starting with digital MPEG2 based broadcast which made possible the inclusion of data representing other services . The principles of this type of operation was first demonstrated in a system for analogue TV distribution in New York in 1992, based on a US patent from 1988 [1], and became an early start for the later digital systems standardised by DAVIC[1)] and DVB [2]. They have been based on the DVB-S/MPEG-2 transport multiplex for the downstream with a communication channel added to include interactivity. These early developments represented by the first generation of LMDS technology have been major steps towards convergence of broadcast, telecommunication and data. At this stage of development when the first networks are set in operation, the choice of cost effective solutions requires mass production which again requires efficient standards allowing for future development in capacity demand.

## 2.2 Broadband services delivered by radio

The classes of services such as digital broadcasting, high-speed Internet, video conferencing, data communication and telephony will live side by side on the same radio access platform. For instance, voice services may well be supplied over the Internet (voice over IP).

The converging services will not only be found attractive form the user's point of view, but also create business opportunities for communication operators or service providers in the future. Traditional operators will clearly benefit from this kind of platform being able to supply a great variety of services over a single platform, but will also face harder competition since the radio access system is easy to establish and does not require heavy investments.

## 2.3 Mobile and nomadic users

There is also a growing interest for broadband services on mobile platforms. Provided there is enough bandwidth and signal strength such services can be offered. However, it would become difficult to provide services to many users.

As indicated in figure 2 the lower frequency bands used for GSM and planned for UMTS allow no room for broadband services to many users simultaneously. At higher frequencies, ie. above about 20 GHz, there is available bandwidth, but the propagation conditions are such that services will first be developed for fixed and nomadic users. In the future it may well be possible to develop systems that can also accommodate mobility, using a high signal to interference ratios and/or smart antennas [3].

## 2.4 Experience with 42 GHz trials

After the video distribution service provided in New York at 28 GHz a growing interest has evolved in deploying millimetre radio solutions

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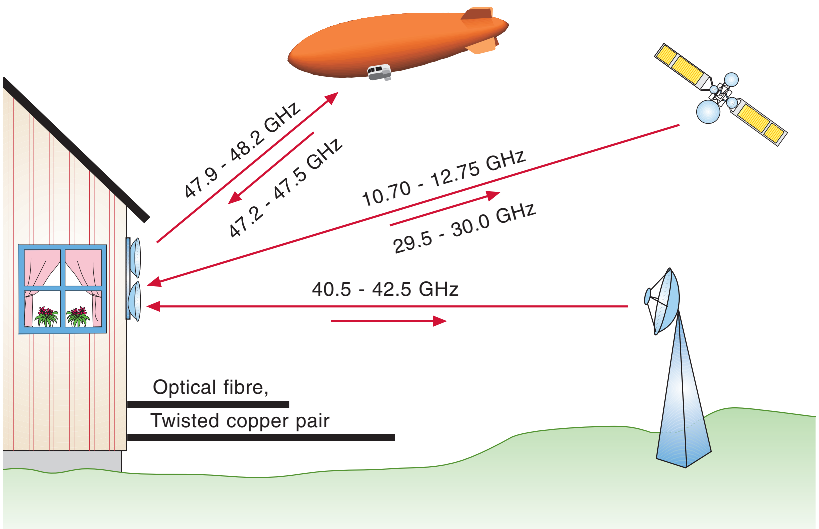


*Figure 1 Broadband multimedia connections to the home*

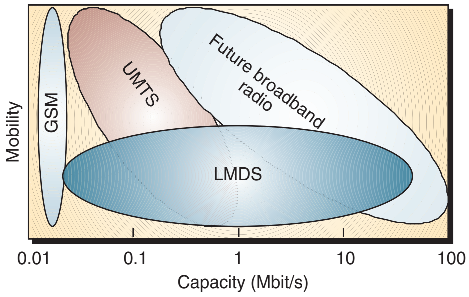


*Figure 2 Capacity versus mobility for radio access systems*

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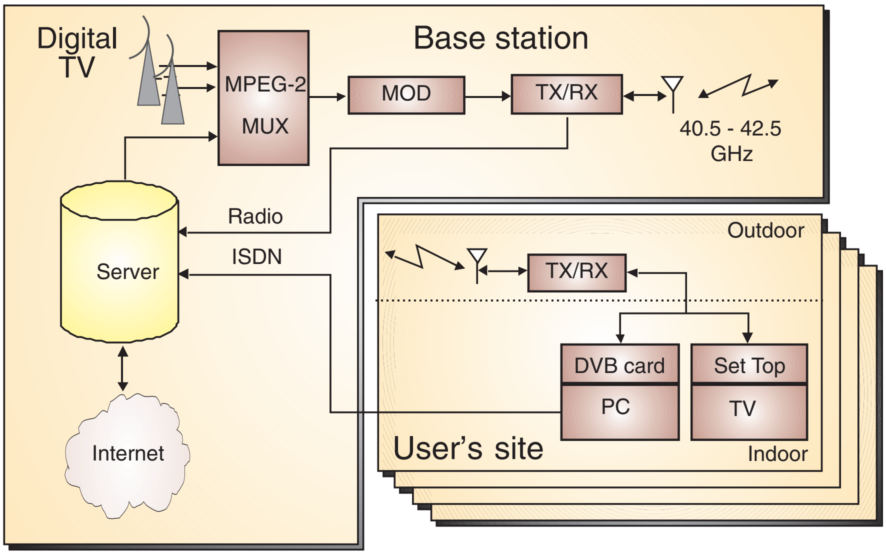
1) *Digital Audio Video Council*

*Figure 3 Broadband services delivered in a broadcast scenario*




both for television, interactive television, and broadband communication. Experimental work has been carried out at several places to demonstrate the feasibility of millimetre radio access systems and to collect information about user reactions and interests. In the European ACTS project AC215 CRABS trials were performed in several countries across Europe [4].

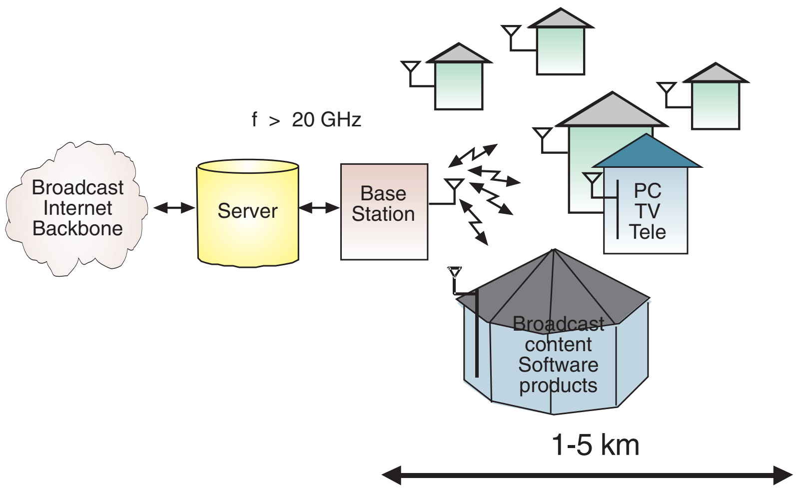
One of the CRABS trials was performed at Kjeller by Telenor R&D. The system consisted of digital broadcast services and high-speed Internet access. The actual downlink solution was based on the MPEG-2 transport stream multiplex [5], [6], [7] with a low-capacity uplink with ISDN [8] and a prototype in-band radio.

Figure 3 shows a block diagram of the basic system components at the base station and at the user's premises. At the user's premises there is an outdoor unit consisting of an antenna, filters, amplifiers and radio frequency conversion between the standardised intermediate frequency band between 950 and 2050 MHz. The units used in the trials were receivers with return by standard ISDN telephony, except for one case where an additional in-band radio provided the return. The indoor unit consists of a set-top box, as used with digital direct satellite broadcast service (similar to those used by cable services), and a PC-card. Both these devices provide much the same operations such as demodulation and unpacking of information. The set-top box delivers the TV signals and the PC-card the Internet service in the data part of the MPEG2 packets to the PC. Clearly, there would in principle be no problem delivering both services either by the set-top box or the PC-card. At the user's end both the outdoor and indoor units are small. The outdoor unit looks like a large 'old-fashioned' video camera with its 15 cm diameter horn antenna.

At the base station more equipment is obviously needed, in particular since this is a master station providing direct connection to the multiplexed MPEG 2 signals with the Internet (IP) packets embedded. However, the outdoor unit consists of a box with small horn antennas for illumination of a 90 degree sector (about 65 degrees between the 3 dB radiation patterns) and transmitters. Since this is millimetre wavelength equipment the size is also small and fits fairly easily onto any kind of wall or roof-top.

At Kjeller the users connected expressed a great interest in the high-speed Internet service [9].

*Figure 4 Schematic broadband radio access*




## 3 Technical design considerations

A schematic a broadband access network is given in figure 4. The users are homes for leisure or business, and enterprises. Many applications are foreseen including television, high speed Internet, telephony, etc. It may alternatively be called communication and broadcasting, or interactive broadcasting. The access part is the last connection from a base station to the end user.

There is a number of topics that have to be considered when a broadband radio access network is designed. These include coverage in terms of number of users that can get the service, maximum and average traffic capacity per user in both directions, quality of service, and investment and operational cost.

### 3.1 Available radio frequency bands

It is necessary to have enough radio spectrum available. Considering current internationally agreed frequency bands, the broadband applications can only by supplied to a large number of users at frequencies above some 20 GHz. At lower radio frequencies the number of users would become severely limited, or broadband would be deployed mainly in the broadcast mode. However, the broadband interactive or return channel is crucial for the development of new business opportunities. Hence, system designers have to consider frequencies above 20 GHz. The are several candidates, for example the band from 40.5 to 42.5 GHz for Europe. Table 1 lists the radio frequencies of most interest.

### 3.2 Radiowave propagation constraints

The requirement to use frequencies above about 20 GHz leads to operation on line-of-sight (LOS) paths or only partly obstructed by a single tree [12]. The coverage can be calculated by using digital maps of terrain and buildings and appropriate software tools. The latter is under development, but some estimates can be done based on three simple statistical parameters for a region: the typical building height, the ratio of the surface covered by buildings and the building density. When such a path has been established the system designer also has to take into account attenuation due to precipitation. The attenuation in rain is severe and will soon reach levels beyond practical fade margins for real systems. See [12] for in-depth discussions of the propagation constraints and [13], [14] in this issue.

Precipitation noticeably attenuates radiowaves above about 10 GHz, and is significant at 42 GHz. The specific attenuation in dB is approximately one third of the rainfall rate in mm/h. A fairly intense rainfall is perhaps 30 mm/h or more, indicating 10 dB/km or more specific attenuation. Rain intensity exceeding about 30 mm/h occurs for 0.01 % (0.9 hours) of an average year in the Kjeller region, and in southern Europe it would be considerably longer. However, the attenuation is less than 10 dB because the inhomogeneity of rainfall, and the fade margin will also be larger for actual systems. Nevertheless, rainfall must be carefully taken into account when building systems. See figures 7 or 8 of [13] in this issue for some initial path length limits and [12] for more results and calculated examples.

Another factor is the loss produced by obstructing vegetation. As a rule of thumb [12] there is about 5 dB attenuation per metre vegetation thickness. This means that service can be provided even if the user's antenna is obstructed by a single tree. However, dynamic effects from moving branches under windy conditions, might severely limit the service quality [12], and it is not recommended to operate behind trees. In the future robust systems might be developed to tolerate this kind of propagation conditions.

### 3.3 Cellular system for high coverage

In order to serve a high percentage of the houses or buildings in an area a cellular coverage has to be deployed, as done for cellular mobile phone service. The size of the cells can vary, but there will be a requirement of enough users of the system per cell. Depending on demographic data the sizes of the cells are given. There is however much flexibility in the rolling out of services, and network operators can invest as the request for service increases. Typical cell sizes in urban areas are envisaged to be in the range of 2 to 5 km in diameter [15]. For the larger cells precipitation loss may become a limiting factor, but for the smaller cells time variable propagation phenomena will have little impact on the service quality and availability.

*Table 1 Potential frequency bands of interest [10, 11]*

| Frequency range (GHz) | Bandwidth (MHz) | Comment |
|---|---|---|
| 24.5 – 26.5 | 2000 | Region 1 (Europe)<br>Sharing with other services |
| 27.5 – 29.5 | 2000 | Region 1 (Europe)<br>Sharing with other services |
| 31.0 – 31.3 | 300 | |
| 31.8 – 33.4 | 1600 | |
| 38.6 – 39.5 | 900 | Region 2 (Americas)<br>Sharing with FSS |
| 40.5 – 42.5 | 2000 | Region 1 (Europe)<br>Sharing with other services |
| 42.5 – 43.5 | 1000 | Region 1 (Europe)<br>Sharing with other services |

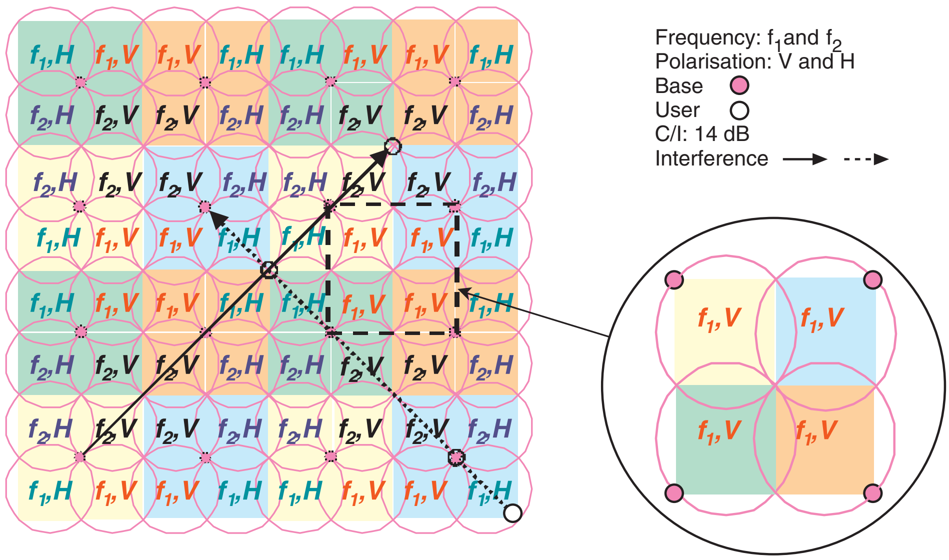



*Figure 5 Radio frequency re-use pattern showing carrier over interference relations and the four-fold freedom in selecting a base station*

In reality, terrain features along with demographic data and propagation effects determine the cellular pattern. Coverage prediction tools for cellular mobile services developed for lower frequencies within a few GHz, are not appropriate for millimetre cellular systems. The propagation effects are considerably different at higher frequencies, in particular precipitation caused by attenuation and diffraction and reflection properties. The narrow beam user's antennas makes a significant difference by discriminating against off-angle reflected or scattered signals. Also the horizontal inhomogeneity of precipitation is requiring a new approach to precipitation losses for point to area applications. New tools are under development [12] and first examples of coverage estimates are given. The coverage in suburban areas will typically be in the range 50 to 80 % with one base station. A similar coverage is also possible for regions with other building structures, for example cities with taller buildings.

By deploying a frequency re-use plan where the users can choose to be served by two or more base stations, as indicated in the next section, the coverage can be increased significantly. A coverage of 90 % or even more is possible.

### 3.4 Frequency re-use plans in an interference limited scenario

A 2 GHz bandwidth, ie. from 40.5 to 42.5 GHz, can be divided into 4 individual 1 GHz frequency blocks by utilising orthogonal polarisations. Assuming linear polarised signals in the vertical (V) and horizontal (H) direction with respect to a reference plane, the frequency re-use pattern over flat terrain can be as indicated in figure 5. This specific scheme has several very useful features: large bandwidth in a single cell, carrier-to-interference ratio (C/I) is sufficiently large for modulation schemes included in the existing DVB standards, and users can choose a base station from four directions. The latter feature increases coverage and if used dynamically significant route diversity improvement of availability under rainy conditions is achieved [12]. The enlarged part of the figure illustrates the possibility of base station selection.

This scheme provides a minimum C/I of 14 dB, which is also shown in figure 5. For the downlink, where the worst case interference is shown by the solid line, there is a 5 times distance from the base station providing the service to the interfering base station. For the uplink there is also a five times distance from the edge of the cell providing transmit power control is used for users closer to the base station. The latter has to be used, but will only be done once when the system is installed. In the scheme shown the base station can have four antennas covering one quadrant each. However, it would be straightforward to split each cell into sectors and increase the network capacity. See [15] for further discussion of frequency handling in growing traffic.

### 3.5 Capacity per user

Given a 2 GHz bandwidth, as in the previous section, and a robust modulation scheme with net transmission rate of 1.5 bit/s/Hz (eg. QPSK) there will be a 3 Gbit/s gross capacity per cell. As an example assume that 25 % of the users are actively connected, ie. need transmission capacity, there is a very high capacity available per user. Figure 6 shows a calculation of capacity per user which clearly demonstrates that high capacity is available for a large number of users. For example, if 1000 users are connected to the system with the assumed 25 % activity (ie. 250 users simultaneously) they have 6 Mbit/s capacity each. In other words, an individual high-quality video channel and more than 2 Mbit/s for the return channel.

It should be noted that the numbers given above assume the modulation scheme QPSK. This is a fairly poor utilisation of the radio spectrum where 10 bit/s/Hz is obtainable. If the latter could be used the result would be a capacity 5 times that of figure 6. Furthermore, the protection coding assumed was also quite costly, ie. 25 % of the capacity, and with less spent on that the capacity per user would become larger. The simple frequency re-use pattern cannot be used directly as shown in figure 5 if the transmission efficiency is increased, but with some careful modifications taking other features into account (terrain, buildings, demographic data) it should be possible to increase capacity even beyond those given in figure 6.

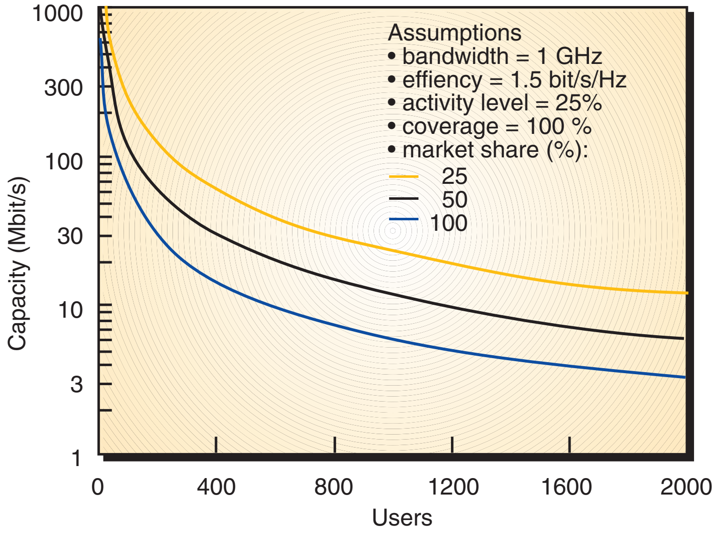



*Figure 6  Capacity per user*

## 4 Future requirements for the radio access network

### 4.1 General requirements

Any new broadband cellular network addressing the public domain has to be a cost effective full service network satisfying the following requirements:

- It has to support the services presently offered by broadcast and telecommunication networks and allow for efficient development of new broadband and interactive services. This involves the convergence of broadcast and telecommunications and leads to a requirement for flexible allocation of frequency resources between up-link and down-link.

- Coverage within the cell must be high. A coverage of 50–70 % of the cell as often quoted can not be accepted and will not in the long run lead to a strong position.

- The available capacity per user must be high with flexibility for a given user to choose capacity on demand. This implies that the cell size must be flexible. At present the area may vary by a factor of 25 allowing for some variation in user density.

- Interoperability with other networks is a must. This involves satellite networks, existing terrestrial networks and future broadband mobile networks.

- Interworking with other networks like LANs, GSM, UMTS, and DECT.

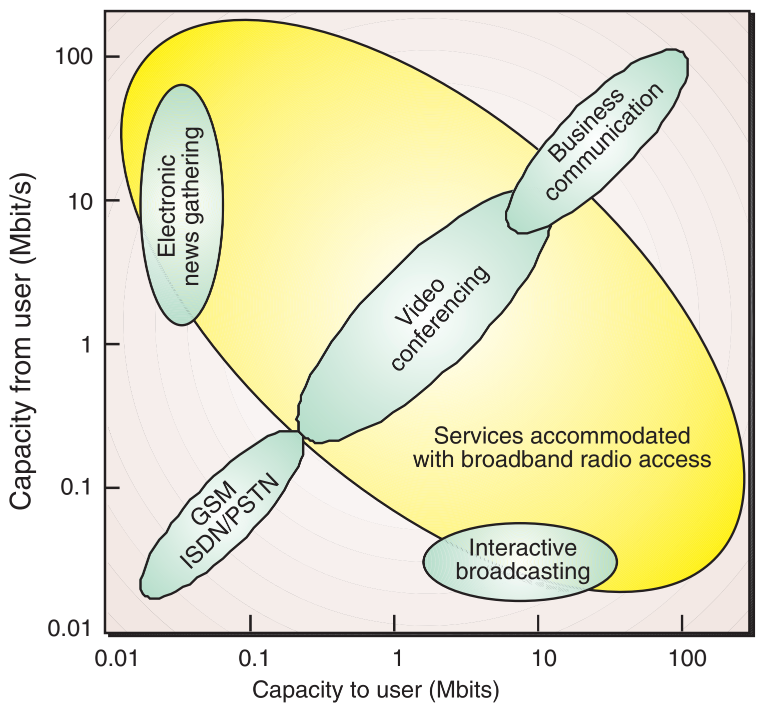
Figure 7 illustrates the capacity requirements from and towards the user for a representative range of interactive services referenced to a broadcast related development track.

It starts with the combination of digital broadcast for delivery and PSTN/ISDN for the return, and evolves to a true two-way radio based asymmetric system. In fact, both solutions can live side by side.

### 4.2 Low cost user's system

It is clear that a system for large parts of the population opens for very interesting business opportunities. The established entertainment business will be followed by a number of others making use of the broadband channels. The crucial point is the low cost system that people and small business entities can afford. Considering

*Figure 7  Capacity requirements*



the technology used it now seems clear that millimetre wave radio and electronic integration techniques have reached a level where mass production is possible. Hence, prices will become lower with the growing volume of units produced. The base band technology relevant for broadband radio access systems is not more complicated than the one used for systems such as GSM, and there is therefore no reason why it should become equally cheap. In the future scenario with software radio systems it is here seen that this part will remain cheap.

The crucial and potential high cost part is the frequency spectrum. If utilised in an inefficient manner the whole access system is bound to become costly. The key to lower costs is a capacity on-demand whereby users pay for the minimum necessary bandwidth to get the service through. The principles of such a system are well known, and further research makes them even more efficient. Equipment based on capacity on demand is also becoming available [16].

### 4.3 Quality of service

A fixed radio access system will probably be compared with existing fixed systems in many regions. The quality has to be high, both in terms of availability and performance. Availability may be around 99.99 % of an average year and the bit error ratio very low (better than $10^{-10}$).

In built-up areas with a high population density the requirement is met by the smaller cells of about 2 km in diameter. In rural areas where the cell sizes have to be larger it can be achieved by larger fade margins. It may also be realistic to have variable quality of service from region to region.

The system should be such that the users get the transmission capacity and quality of service they want and are willing to pay for. This will accommodate for a large variety of needs and markets ranging from the home to the business oriented market.

## 5 Standardisation scenarios

There are two main development paths, the digital broadcast approach basing development on the DVB-S/MPEG2 delivery system with inclusion of interactivity, and the other to start from a broadband radio link system and use it as a point-to-multipoint system with separate returns. In the latter case the number of users is then limited [17] and the systems are more for solving the communication needs of business users in a flexible way offering on-demand capacity. This should be considered as a temporary solution, which can later be integrated in a solution allowing for a mixture of high and low capacity return channels.

So far it has been widely accepted that the downlink and the uplink are kept separate in the standardisation work as they are separated by guard bands in the frequency domain. The downlink has so far been based on the DVB-S standard allowing for reuse of technology developments and in-house user equipment (set top boxes).

The uplink or interactive return channel has been an issue for separate standardisation processes in DVB, DAVIC and ETSI. Standardisation work in Europe has been undertaken by ETSI and DVB in close co-operation with DAVIC.

A separate project (DVB-I) has been established for Interactive Television, and standards suitable both for satellite broadcast interactivity and for LMDS interactive channels have been worked out. One intention of the work has been to allow DVB-I users to select the interactive return channel that best suits their needs and budget.

The DVB-I system includes:

- DVB-IP Return channel for PSTN and ISDN. This specification channel allows interactive DVB systems to operate over existing PSTN and ISDN networks.

- DVB-ID Return channel for DECT is a set of specifications implementing the use of wireless technology in a variety of systems.

- DVB-IM Return Channel for LMDS specification just being finished and finally approved by ETSI is based on the DVB-RCC (the return channel for cable systems).

In the ETSI group BRAN (Broadband Radio Access Network) the focus is more on symmetric broadband services. But that is a process originating from the communication world addressing point-to-point communication mainly, and the growing importance of point-to-multipoint and broadcast is not really recognised. Convergence of broadcast, data and telecommunication services requires such recognition.

The DVB standards are assuming non-symmetric services. The concept of interactive TV focuses on interactivity as a small addition to the broadband DVB/MPEG2 based delivery system. This is sufficient for users of Internet and retrieval of data.

## 6 Discussion and conclusions

The strength of radio access depends on the development of a broadband system at an acceptable cost. The base station is small and can easily be mounted on the rooftop or on the wall of tall buildings. Using GSM base stations even for access may well be the solution in many cases. At the user's premises the installation of a small outdoor unit is very fast. Due to the small size of the antenna it fits well into the surrounding architecture.

A radio system can also be easily re-used in other places and therefore presents both an environmentally friendly installation as well as being less critical to loss of large investments. Equipment for an entire area can easily be re-used at another site.

According to techno-economic studies [18] broadband radio access is an economical access technology, also compared to wire based solutions (fibre, coaxial cable, and copper pairs). In practice, providing broadcast services or point-to-multipoint high capacity over cable networks requires costly solutions for switches or routers, whilst radio simply makes use of a common channel over the air.

The weakness of radio depends somewhat on the operating frequency, but is mainly the problem of not reaching every user that wants the service. It should be noted that this weakness is to some extent shared with wire based systems. Some coverage predictions indicate a small maximum penetration to users in an area (eg. less than 50 %), but recent studies show that it may very well be high (more than 90 %). It depends largely on how the cellular network is built. The main problem is the requirement of line-of-sight paths between the base station and the user. In [12] it is documented that by using two base stations covering largely the same physical area the static coverage can easily be raised to above 80 % for cells with a 2 km diameter. Another factor is the attenuation due to precipitation of hydrometeors. Under rainy conditions heavy attenuation will happen, but it will not create a problem for the actual system design with cell sizes 2 km in diameter.

There has been some discussion whether a broadband radio access solution can be deployed in rural areas, due to the large number of users required (for low cost systems) and potential limiting propagation effects. It should be noted that in rural scenarios it would probably be possible to increase the system fade margin by a higher gain (narrower beam) antenna at the base station. The clustered population will also make it considerably easier to achieve required C/I and the result is an important increase in users with negligible extra cost. Furthermore, in the rural case there may not be a realistic alternative if low cost broadband return is wanted, and the users may easily accept a lower service availability.

In conclusion radio access offers a very interesting solution to providing broadband services at an acceptable cost to a large part of the population and smaller business enterprises. The technology is becoming mature where systems with low-capacity return are readily available. The evolving technology in the area will in a few years provide a low cost system tailored for a full service network with high capacity return. A low cost service is also achieved over radio through effective use of the shared resource that the radio spectrum is.

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# The development of an open interactive multimedia services delivery platform in Europe

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## 1 Introduction

"Open interactive multimedia services delivery platform" is so clumsy an expression that it is obvious that the concept does not yet exist: people would have already introduced a shorter name for it. On the other hand, it demonstrates that we have nevertheless a rather precise idea of what we want: a technical infrastructure that enables every user to access multimedia services quasi everywhere and enables every service provider to offer services to everybody. In this paper we want to show that this platform can only be a product of convergence of computer, telecommunication and broadcasting technologies and concepts. In the Image Communication project line in RACE and the Interactive Multimedia Domain of ACTS this convergence has always been part of the vision that vitalised the concertation process between the participating projects. Probably RACE and ACTS as Community Programmes and later organisations like DVB were rather unique in pushing for this convergence. The various industries and other R&D Programs had the tendency to continue to develop their own sector.

## 2 RACE and ACTS as motors of convergence

### The first wave of convergence: digitalisation of image

The prehistory of Interactive Multimedia Services starts, for our purpose, back in 1985 with the RACE (Research on Advanced Communication in Europe) program. The goal of that program was to establish commercial broadband services in Europe around 1995. A main objective was to bring together the Telecom Operators, at that moment still monopolies, and to let them learn to co-operate in research for the future. The goal was called IBC, Integrated Broadband Communications. The idea was that in the future we would have optical fibre to the home, so that telephony and television would be transported together over one and the same cable and then would also enable videophone. The question of applications was addressed by a number of application studies, mostly related to industrial processes, a little bit to video-on-demand and still less to videophone. There was also the idea that certain groups of handicapped could make very good use of video-communication. What we did was mainly to develop the digital technology for telecommunication and communication of audio-visual material. We have contributed substantially to quite a number of technologies, eg. MPEG-2, the basis for digital television. In these ten years the European Commission contributed about 1 billion ECU.

### The second wave of convergence: return channels on broadcast media

ACTS (Advanced Communication Technologies and Services), the next program, started in 1994 to apply the technology that had been developed in RACE. Besides continuing research on optical communication, mobile and service engineering ACTS made a big effort in Multimedia R&D. Domain 1, interactive digital multimedia services, constituted one third of the whole program. The second wave of convergence was characterised by the fact that now broadcasting services where whole-heartedly embraced by the RACE II and ACTS programmes, which was obvious from the projects on Digital Terrestrial TV transmission and the specification of return channels of all broadcast media.

### The third wave of convergence: incorporating the WWW

Suddenly, a convergence of interactive broadband services and the World Wide Web took place. Is it not amazing that it happened only in October 1997 at the 3rd call of ACTS? Before ACTS did not 'look at' the Internet because it was not considered broadband technology. Now we see that Internet goes Multimedia and Multimedia goes Internet.

### The convergence results of ACTS

When we look at Table 1 of ACTS Domain 1 projects we see that most projects contribute to the convergence. The projects on Multimedia Content Manipulation and Management develop tools for the content creation that can be used in all multimedia applications. The projects under Interactive Multimedia Delivery form a counter balance for the technology developed in the rest of ACTS that is nearly only concerned with broadband point-to-point communication technology. The projects in the sub-areas Presentation, Interaction and Storage and Support for Electronic Commerce & Information Access all have converging aspects in their goals. A project to single out for its particular convergence focus is the project SMASH/STORit. Its results may become crucial for the convergence between PC and Television use in the home. This project developes a storage technology and management system taking advantages of the consumer electronics related video recorder and the hard disk of a PC. They made an important contribution to the TV Anytime scenario of the DAVIC group. It is also an important element of the Multimedia Home Platform that we will see again in the context of DVB. Finally, there is a number of projects that do trials of these interactive services, like virtual museums, tele-learning, studio tools, virtual reality brokerage and indexing and entertainment.

The projects made substantial contributions to the various standardisation groups. These groups each followed a convergence path as we will see in the next section.

*Table 1 The projects of ACTS domain 1*

| | |
|---|---|
| **Multimedia Content Manipulation and Management** | |
| *Programme Production* | DVP, MIRAGE, AURORA, ATLANTIC |
| *Image Quality Evaluation and Service Monitoring* | TAPESTRIES, VISaVis, QUOVADIS, MOSQUITO |
| *MPEG 4* | MOMUSYS, EMPHASIS, VIDAS |
| *Telepresence, 3D, VR* | VANGUARD, PANORAMA, VPARK, RESOLV |
| JPEG2000 | SPEAR |
| **Interactive Multimedia Delivery** | |
| *Satellite* | ISIS, DIGISAT (TI97), CINENET (HDTV), S3M |
| *CATV* | IBCoBN, CATVDC |
| *DVB-T* | VALIDATE, INTERACT, MEMO (DAB), MOTIVATE, ITTI |
| *MMDS* | CRABS, CABSINET |
| **Presentation, Interaction & Storage** | |
| *Servers* | SICMA |
| *Open interactive multimedia terminal architecture* | SOMMIT, UNITEL, CODID |
| *IRD* | DVBIRD |
| *Storage at home* | SMASH/STORit |
| **Support for Electronic Commerce & Information Access** | |
| *Conditional access & IPR protection* | OKAPI, OCTALIS, TALISMAN, MIRADOR |
| *Client management* | SPECIAL |
| *Brokerage* | GAIA, ATMAN, MUSICIAN, GESTALT, TRADE, HYPERMEDIA |
| *User interface for electronic programme guide* | MUSIST |
| *MPEG2 & MPEG4 Services* | COMIQS, CUSTOMTV |
| *User agents* | KIMSAC, DIANE |
| **Integration and Evaluation Trials** | |
| *Trials* | AMUSE, BOURBON, TELESHOPPE, TEAM, DAM |
| *Programme integration* | EURORIM, PRIME |

## 3 Convergence in standardisation organisations

The convergence did not only happen in RACE and ACTS but also in the standardisation groups in which the projects participated, such as in MPEG (ISO/IEC Joint Committee, Motion Picture Expert Group), DVB, the European group that has standardised the digital television, and DAVIC (digital or audio-visual council).

### MPEG

The MPEG group started with the standardisation of visual and audio coding for storage on CDI (MPEG1) and Digital Television transmission (MPEG2). It incorporates 'compression' but also 'multiplexing', 'transport' and 'interaction' (DSM-CC). MPEG4 performs the steps towards an 'object/stream' approach of the AV representation of information as opposed to the 'pixel/stream' approach that characterises MPEG2. The first ideas for application were for low bitrate coding as for instance is required by mobile services, but soon possibilities for application to the Internet were discovered. With MPEG-7 for the 'Multimedia Content Description Interface' the project moves even more into Internet applications. The objective is to produce a standard description for various types of multimedia information, to enable fast and efficient searching of material that is of interest to the user.

### DVB

The DVB project was launched in order to start the specification of digital transmission standards of digital TV on the main transmission media. From the huge participation in the RACE dTTb (digital Television for Terrestrial broadcasting) project it was clear that such an organisation of the sector actors was badly needed. After the specification of DVB-S (satellite), DVB-C (Cable) and DVB-T (Terrestrial) it became urgent for the introduction of digital TV to specify also a return channel. With the help of the ACTS projects the specification is evaluated. As digital TV in the first instance is introduced by Pay TV operators and one cannot expect that the consumers will buy a set-top box for each service provider, the need for open set-top boxes is born. This has led to the MHP – the Open Interactive Multimedia Services Delivery Platform of DVB – of which we will speak in the next section.

### DAVIC

The history of DAVIC starts with the hype on Video on Demand in the world of telecom operators. Next they turned towards broadcasting channels as the need for these broadband pipes was discovered. Finally the group had to incorporate the Internet technology in order to survive. A close co-operation was established with DVB in the time that DVB developed the return channel on cable. The fact that they now concentrate on Enhanced Television Protocol, Interactive Television Protocol, Delivery systems to mobiles, TV Anytime, TV Anywhere, indicates that the days of the traditional television services soon will be over.

## 4 The need for an open service delivery platform

Although these standards are essential for a digital multimedia platform, they have so far not led to a common horizontal European market. Instead, in the current pioneering phase, several vertical markets have been established, in which a single programme/service provider or a single group of programme/service providers controls the business (value) chain. These markets are characterised by the use of proprietary APIs, eg. MediaHighway (Canal+), Open TV (TPS and others), d-box Network (Kirch Group).

The inevitable problem has arisen that applications and set-top boxes using different APIs are incompatible with each other. An end-user wanting to have access to all the multimedia services available today would have to buy several set-top boxes. This forms a considerable road block in building full confidence of consumers in the future of digital TV services. Full confidence of consumers and the final breakthrough of DVB will only be achieved in a common horizontal market with full competition enabled by clearly defined interfaces between the various layers of the business chain and with a ‘standardised’ receiver / home terminal (set-top box, integrated TV set, PC) based on a common API.

The vertical markets were important to achieve the ‘critical mass’ necessary to start the horizontal markets. In a common horizontal market, any application provided by any programme/service provider via any network can be ‘understood’ by all receivers. A horizontal market benefits also from the competition amongst the players in each layer (content providers, programme/service providers, conditional access providers, network operators, receiver manufacturers). Only a horizontal market will support and accelerate the convergence of broadcasting, computer and consumer electronics in the home.

Thus the standardisation of a multimedia home platform (mhp) is the only logical step forward. Aimed squarely at achieving full convergence, the mhp comprises the home terminal (set-top box, integrated TV set, multimedia PC), its peripherals, ie. the local cluster, and the in-home digital network. From an application point of view, advanced broadcasting with multimedia data applications arriving alongside conventional linear broadcasting, interactive services using a return channel, and Internet access will be covered.

### OPIMA

The need for an open multimedia platform that will allow end-users to access a range of multimedia services via a single platform is well understood by the Open Platform Initiative for Multimedia Access (OPIMA), a consortium currently comprising more than 40 companies and organisations, among them important content owners, and which is open to all interested parties. It agreed to use the IEC’s Industry Technical Agreement (ITA) mechanism to bring its specification to market. This first ITA was completed by September 1999.

The ITA is based on the belief that the multimedia market would see faster development if a standardised technology existed that would allow the consumer to use and pay for services, without having prior knowledge of which services would be consumed, in a simple way such as by operating a remote control device. The actual technology required to reach this goal already exists, but OPIMA believes that some aspects of it need to be standardised, thus enabling the system to work openly and efficiently. The ITA also covers security and privacy requirements, types of transactions, device types and connection types.

### The Land of Middleware

At the IST98 conference in Vienna in December a session was held called “The extended living room”. A number of technology, entertainment and education experts discussed what people would want to do in their home involving those interactive services. This was followed by a workshop called the ‘Land of Middleware’, ie. the mainly software technology that is needed to enable this vision, using the hardware of networks and platforms that have been developed till now. The Land of Middleware will be the opportunity for a myriad of service providers to be linked into value chains of many transactions and to become the servants of the millions of Kings of the Land of Middleware, ie. the end-users. In fact in the Land of Middleware everybody can change roles between King and Servant whenever he or she wishes.

## 5 Requirement and opportunities for an open multimedia platform

The following is a selection of key elements from the basic requirements list.

**Interoperability** – In order to prevent lock-in to any proprietary format or single vendor etc. and to allow cost-effective products to be produced using technologies from freely competing vendors the specification including the API shall support a full range of services and low to high functionality implementations and shall be network and hardware platform independent.

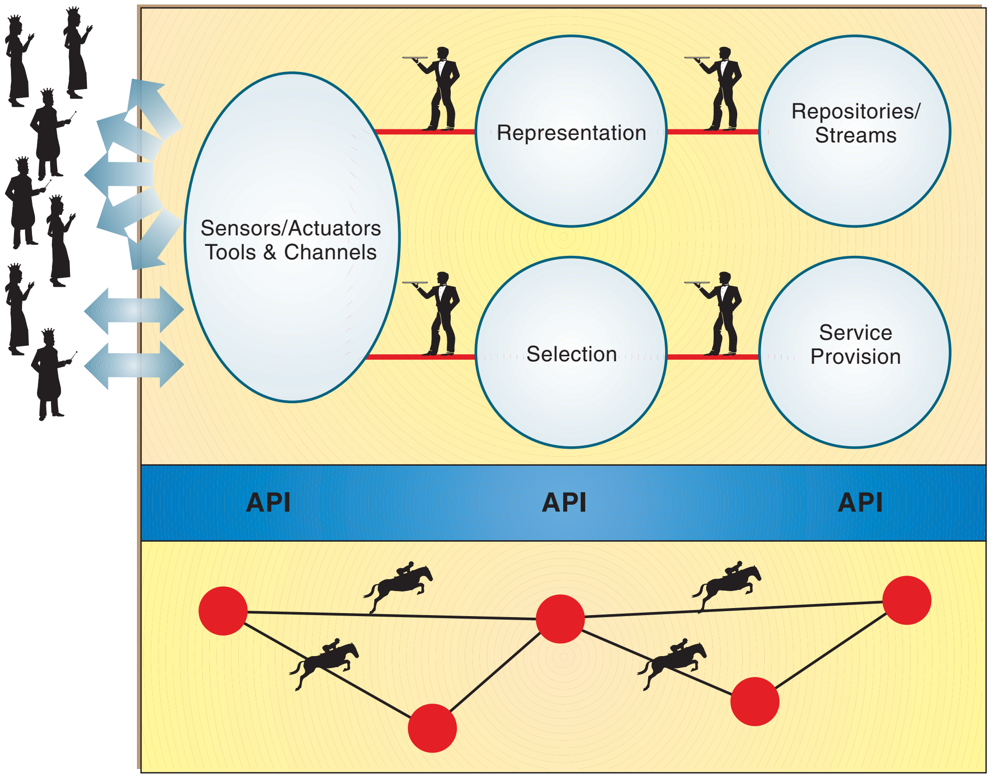


*Figure 1 The Land of Middleware (© Carlos Pires)*

**Predictability** – Each application that is developed will need to comply sufficiently with the reference model to ensure interoperability in a competitive environment. This should result in host platforms where the integrity of the application is protected, and its behaviour is stable and predictable (thus resulting in a high quality of service and Intellectual Property Right Management Friendly). The reference model must also define modes for data delivery, memory handling, object handling and instruction execution.

**Evolution, scalability, extensibility and backwards compatibility** – The platform shall be designed to be extensible towards future functionality. Scalability and backwards compatibility shall be maintained. Scalability means enabling low-end and high-end terminal devices (eg. simple set-top boxes and PC theatres) as well as the whole platform to serve low- and high-end user requirements, respectively. Enhancements to future products in terms of hardware and software capabilities shall be backwards-compatible with previous generation solutions, so that future applications do not crash older platforms and that older platforms are able to provide some level of user experience of the broadcast applications. Existing applications must be able to run on new generation devices. The level of the user experience shall be scaled down according to the hardware capability. Capabilities shall be provided by the API. The evolution of the system over time shall be maintained by consensus through industry-wide bodies (eg. under the control of both service providers and manufacturers).

**Modularity** – Allows a number of distinct product levels offering trade-offs between the scope of services enabled by the functionality and the complexity (cost) associated with the implementation.

**Stability** – Consumers shall have confidence in the market-place and the perceived longevity of products. The basic solution shall be stable over time, with well defined extension procedures for future enhancements.

**Migration** – A possible migration path shall be defined to evolve from the current situation based on proprietary systems towards the future common platform environment, including the API.

**Based on open standards** – The system shall be based on existing standards, if available. Existing solutions available on the market, or any other solution that may seem appropriate should also be considered under the condition that each solution feature is disclosed and properly documented. The system shall be fully published and accessible through a recognised standards body.

**Upgradability / Downloadability** – The definition of the system shall not prevent firmware upgrades. The platform shall be able to be upgraded through the network in an environment where several receiver implementations co-exist.

**Simplified and cost-controlled operation** – Applications and data shall be transmitted in a bandwidth-efficient format that allows applications to be transmitted only once, therefore avoiding unnecessary simulcasting. In order to do this, solutions shall be based on the separation of data from the applications. This shall enable different applications to use the same data. For an EPG as a typical application, this means use of the DVB service information (SI) data to the largest extent possible without the need to transmit this information as part of the EPG application.

**Generic API** – A single generic API shall be the target to be used in parallel with existing proprietary APIs. It shall allow support of real-time streaming applications, downloaded and locally stored applications, allow any broadcaster or any application provider to write and supply applications, allow the look and feel of all applications to be under the control of the broadcaster and/or application provider, provide access to the DVB-SI data, allow any manufacturer to implement the API in his own way.

### Opportunities

A new set of advanced revolutionary multimedia applications is to emerge. This ranges from distributed simulations, interactive remote visualisation, electronic cinema, distributed multiparty games, large-scale shared virtual environments and complex system modelling. Those new applications would have to be supported by advanced end-to-end services with stringent requirements and would have to be accessible to all kind of users through new multisensorial-multimodal interfaces.

The capacity of the networks to provide higher QoS will allow advanced applications in the field of real-time simulation and large scale and shared virtual environments. Those applications will interact strongly with the network. The design and implementation of related software will be needed to achieve exchange between application and infrastructure.

Thanks to enabling coding and representation technology we are now moving from a text-based world (the largest part of the WWW today) to a world of visual and increasingly multimodal information. Navigation, access and exchange of information will in the future be largely based on visual components and visual appreciation. Image-intensive networked virtual, augmented and mixed environments are the essence of future communication services. They are providing the essential requirements for future representation, coding and delivery systems and standards.

Interfaces to information and communication devices will be approached in a similar manner. It will be possible to communicate with these systems in a natural, intuitive way not only via a keyboard but also via speech and gestures. The system will help us to perform the right interactions with the environment by presenting the environment in a simulated way if this is helpful. Sensors and displays will be very adaptable to the environment.

## 6 IST programme as the motor for user friendly services

The convergence of information and communication technologies has urged the organisation of the 5th Framework Programme to tackle the problems in an integrated way. The Basic Technologies and Infrastructure part of IST (Key Action IV) has the following parts:

- Simulation, Visualisation, Interfaces
- Systems software
- Networks
- Subsystems
- Microelectronics.

The highest layer is the part that is the continuation of the work in ACTS Multimedia Domain. Compared with ACTS this layer will comprise less R&D on transport, more on simulation and advanced human system interaction. However, the work will certainly produce the requirements for the advanced multimedia Applications and use the advantages of modern networks. The relevant action lines are the following:

**IV - 4.1 – Real time simulation and visualisation technologies**
*Objective*: To develop and demonstrate large-scale and/or real-time distributed simulation and visualisation systems for design, to support control and business processes, for training and general-interest applications. The work covers basic modules and tools, as well as integrated environments and bridging technologies. Support to multi-scale multi-physics simulations, interoperability and re-usability of software components on heterogeneous distributed systems, and support for collaborative work, are particular priorities. In addition to demonstrations and assessments, complementary work is expected to include both first-user and best-practice actions.

**IV - 4.2 – Large-scale shared virtual and augmented environments**
*Objective*: To develop and demonstrate models, languages and technologies for shared virtual and augmented environments and to explore human interaction in them, for both professional and consumer uses. The scope includes multi-sensory interaction within both reality-based and non-real virtual and augmented environments and their seamless integration with audio-visual representation and coding techniques. It covers new and improved virtual-reality modelling languages,

virtual-presence concepts such as telepresence, avatars and autonomous agents, scalability and interoperability over distributed heterogeneous platforms and networks, and reducing the cost of access. The technological work should be complemented by large-scale demonstrators of new applications and by social and psychological research addressing both novice and experienced users.

**IV - 6.1 – Multisensorial-Multimodal Interfaces**
*Objective*: Development and demonstration of integrated multi-transducer subsystems using advanced sensor, actuator and display technologies including image and auditory scene processing. The scope includes the development of new interaction paradigms and intermediation technologies supporting intelligent multi-modal, multi-sensorial user interfaces for portable and/or wearable information appliances and systems. The approach should aim at affordability, ease of use and accessibility and be targeted to both consumer and professional electronics, individual and group, users. The scope also includes the development and demonstration of technologies for advanced displays, including, as appropriate, integrated driver, image processing, touch-sensing and control electronics, aiming at low-cost, mass-market applications. The work is to be complemented by take-up actions.

From the proposals offered in the recent 1st call of IST it is clear that much work will be devoted to the open service platform and the applications that will run on it. As is clear from the action line text this work will be followed by a take-up action.

The aim of the *Open Advanced Interfaces Initiative* is to stimulate the take-up of integrated access and interface technologies for providing services on both professional and consumer platforms. The initiative comprises trials and best practice actions. *Trials* use recent, innovative, open standards and technologies – such as convergent multimedia APIs and MPEG 4 and 7 – for content-level and service-level interaction with audio-visual media and 3D on home appliances and platforms. *Best practice actions* perform reliability, conformance and assurance testing of professional and consumer service platforms, with a view to improving open user access to audio-visual services.

## 7 Conclusions

The work that has been conducted in the R&D Programmes of the European Union has contributed to the realisation of the Open Interactive Multimedia Services Delivery Platform that seems now at the brink of breaking into the market. Industry led specification groups such as MPEG, DVB and OPIMA are specifying products that can be introduced to the market by many equipment manufacturers and can be operated by many different content providers and network operators.

Once such a platform will be available and indeed has been introduced into many households, it will be a platform on which many new advanced representation and interaction models can be delivered to the public. Models that go far beyond the possibilities of present-day TV technology and on-line services.

Also in the 5th Framework Programme the European Union will stimulate the R&D contribution towards this basic platform. As the transmission problems have been largely solved the focus will be now on the tuning of the interfaces between the user and the terminal, the service and the representation and between the applications and the networks.

A point to consider carefully is that in this process of transformation from vertical to horizontal markets the vertical capturing is not replaced by a horizontal capturing but that an open situation is created with competition at all levels.

## 8 Further reading

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*Disclaimer*: The contents of this article represent the position of the author and do not necessarily represent the position of the European Commission.

# Towards the next generation LMDS systems architecture

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## 1 Introduction and history of MVDS and LMDS

Both the rapid changes in technology and the convergence of the communications and broadcast industries have influenced the future perceived use of the 40.5 – 42.5 GHz bands for LMDS services over the last few years. In the first half of the 1990s the concept of Multipoint Video Distribution Services (MVDS) for TV traffic was being discussed actively in Europe. The CEPT organisation identified a band at 40.5 to 42.5 GHz (as well as lower frequency bands) for such services, which were largely then considered to be for analogue TV distribution systems, with the possibility of a limited element of interactivity for services such as video on demand (VoD), game shows and home shopping, etc. The specification in the UK for such services (MPT 1550) [1] emerged in 1993.

However the rapid progress of digital TV under the twin activities of Digital Video broadcasting (DVB) [2] combined with MPEG coding for video pictures [3] rendered these earlier analogue TV approaches to LMDS almost obsolete before the ink was dry on the documents. Some analogue MVDS systems have been deployed in Europe and elsewhere, as neither the digital technology for transmission of MPEG coded TV pictures nor the consumer set top boxes were available commercially until quite recently.

### 1.1 Digital TV and LMDS

The convergence of both telecommunications and broadcasting systems has also been greatly facilitated through digital broadcasting. Although the initial services considered for the 40.5 – 42.5 GHz band were broadcast, strong pressure from the communications community has encouraged a combination of these two activities through the concept of broadband local multipoint distribution services (LMDS). In this concept, both services are carried by the same overall system. These changes have occurred relatively rapidly. It has been difficult until recently to consolidate on one system solution, as the requirements for both operators and users have been constantly changing. Initially the major traffic was expected to be provided on the downlink, where several tens of channels operating at 34 Mbit/s would carry a combination of broadcast and video services. Limited interactivity would be required to control the selection of TV services, select VOD and participate in home shopping, etc. In the UK, the MPT 1560 specification [4] proposed a system with 96 TV channels occupying 1.9 GHz of spectrum with interactive services confined to two 50 MHz bands at either end of the frequency slot. Many channels of TV and video traffic would be provided through 34 Mbit/s MPEG coded transmission. (About 2 Mbit/s is considered sufficient for video quality and 8 Mbit/s for high quality TV transmissions.) Set top boxes to decode the MPEG transmissions, which have recently become available at consumer electronics prices, operate in conjunction with conventional TV sets. These services would be provided in a franchise area through a cellular structure, serviced through a number of base stations. Individual cell sizes would be between 2 and 5 km in diameter.

During this evolutionary period the use of Internet by both professional and domestic users has grown dramatically both in North America and certain parts of Europe. The volume of Internet traffic on conventional telephone systems has already caused congestion problems in the US and Norway. These emerging LMDS services are now seen as a cost effective and timely technology to satisfy this growth of demand for much higher capacities and data rates than can be carried on conventional telephone systems. Although direct to home satellite services might, in principle, offer similar data rates (but only on the down link), LMDS have much greater capacities on the downlink and could also provide several megabits/s on the uplink.

### 1.2 Classes of user

In general the three categories of user have been identified (figure 1). These are:

- TV users who require a fairly low data rate (32 kbit/s) on the interactive path for programme selection, video on demand (VoD), participation in games shows, TV shopping, etc.;
- Telephony services (ISDN) and basic Internet for domestic users ($n$ x 64 kbit/s);
- Connections to small and medium-sized enterprises (SMEs) which would require their local Ethernet and telephony based traffic to be connected to the main networks with data rates >2 Mbit/s.

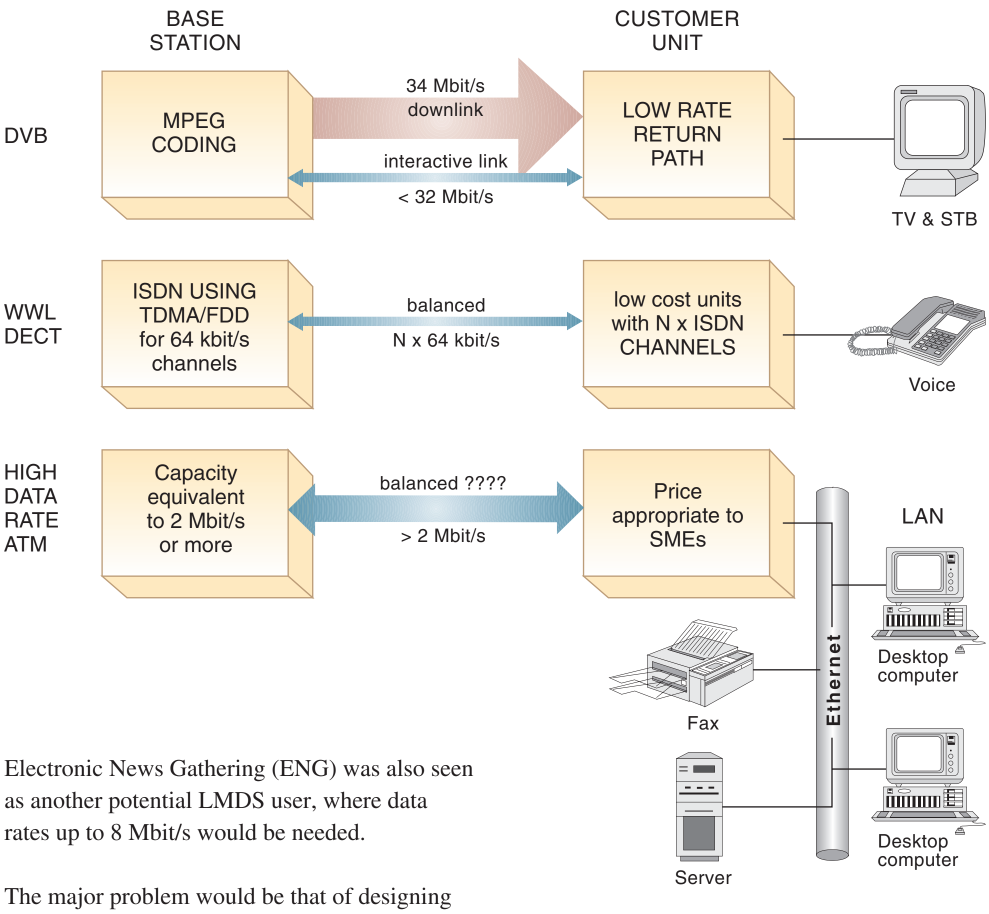



*Figure 1 Classes of users for LMDS services*

Electronic News Gathering (ENG) was also seen as another potential LMDS user, where data rates up to 8 Mbit/s would be needed.

The major problem would be that of designing an LMDS systems architecture which could accommodate this wide variation of requirements, without imposing a costly solution on the domestic users, who might require only limited data rates on their interactive channels.

## 2 Systems architecture for LMDS systems

### 2.1 The LMDS concept at 42 GHz

Millimetre wave systems have two main features: very large available bandwidths and the small physical size of high gain antennas. This advantage is however qualified by the very limited range (a few kilometres) over which such systems can provide an effective service, due to propagation effects and blockage considerations. This second restriction confines the system design to either a cellular or a mesh approach. This paper considers only cellular systems as the mesh systems, although applicable to high data rate interactive traffic, have difficulty in accommodating multi-channel digital TV traffic. A typical 'franchise area' (see figure 2) of about 1000 square kilometres might be serviced by many individual cells. The local base stations could be connected by either a fibre/coax or a radio links infrastructure to a main co-ordination centre for the franchise.

The broadband highways provide services to the particular LMDS franchise through terrestrial and satellite telecommunication and broadcast systems.

The connection of individual users is simpler than that of a mobile system, provided a good line-of-sight exists between base station and user. As the user is stationary, the concept of hand-off between cells is not necessary and the use of high gain antennas combined with terrain and building blockage severely limits the occurrence of adjacent cell interference.

### 2.2 System requirements and data rates

The wide range of services provided and the service availabilities demanded pose a serious problem for the system architecture. Table 1 shows a typical range of services, together with their respective availability, which might be carried by an LMDS system. (This list of possible traffic types evolved through discussions in the CRABS project [5].)

Telephone services, although only requiring low data rates, have traditionally been regulated so that they conform to the very high availabilities associated with emergency services. For a wired network, this imposes a requirement on the quality of operational services, but does not produce a technological difficulty. However for millimetre wave systems, the last 0.005 % of availability can only be provided through a very large systems margin, due to rain outage.

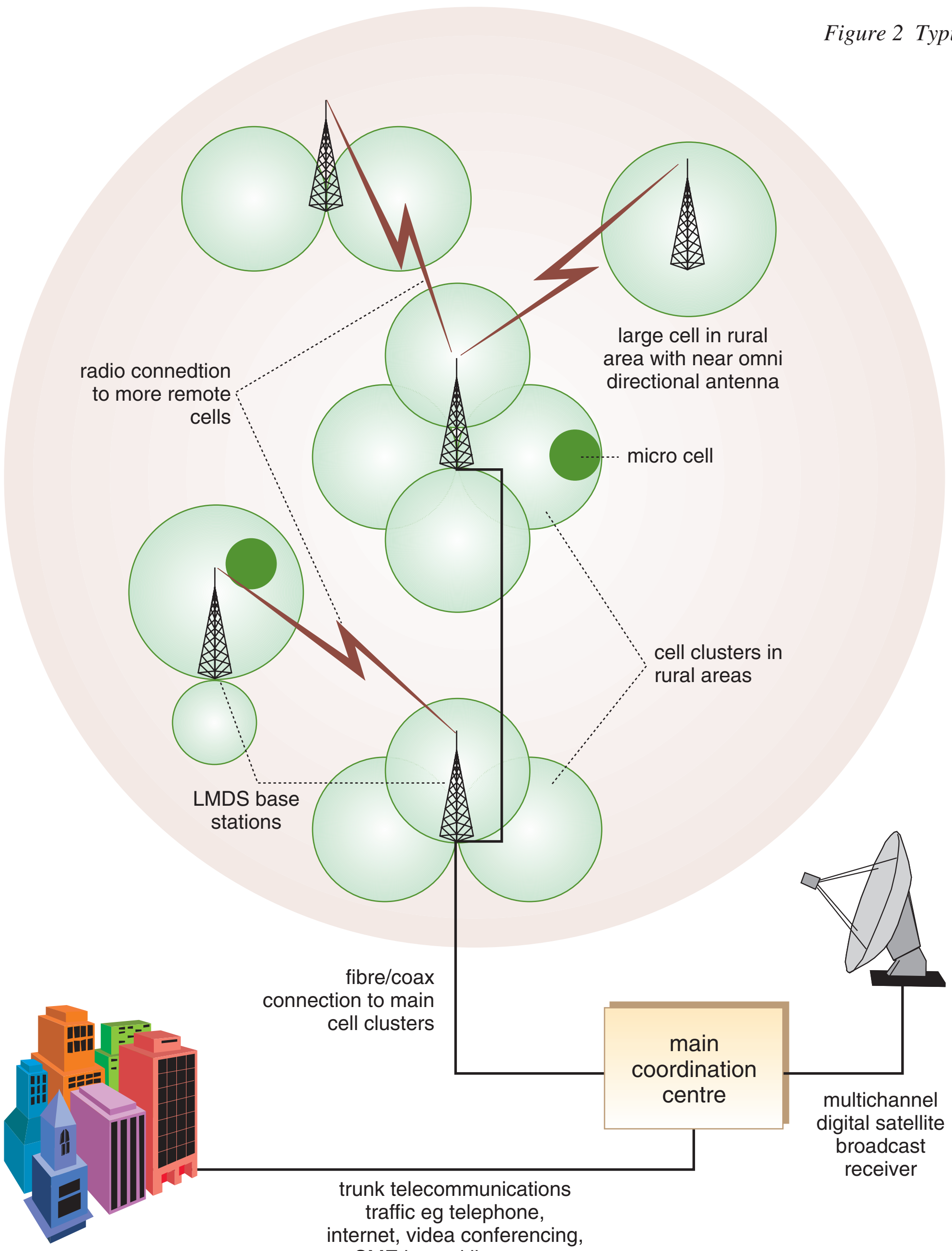



*Figure 2 Typical LMDS franchise configuration*

Other services might well be acceptable at lower availabilities. For instance any Internet service, which is likely to be restricted by the peak traffic demands, does not need the very high availabilities associated with telephony. The higher data rate services for SMEs and video conferencing might also be acceptable at a lower availability, especially as very high availability might impose a serious cost penalty. SMEs dominate the traffic capacity requirements.

| Service | No. of users per cell | Bit rate kbit/s | Availability % | No. of users operational in busy hour | Megabit/s required each way |
|---|---|---|---|---|---|
| Telephones | 200/400 | 32 | 99.996 | 50 | 1.6 |
| Internet | 100 | 128 | 99.9 | 100 | 12.8 |
| Video conference | 10 | 384 | 99.9 | 10 | 3.8 |
| SMEs | 10/30 | 2000 | >99.9 | 30 | 60 |
| ENG | 1/2 | 8000 | 99.9 | 1 | 8 |
| Total traffic required Mbit/s | | | | | 86.2 |

*Table 1 System requirements and availability*

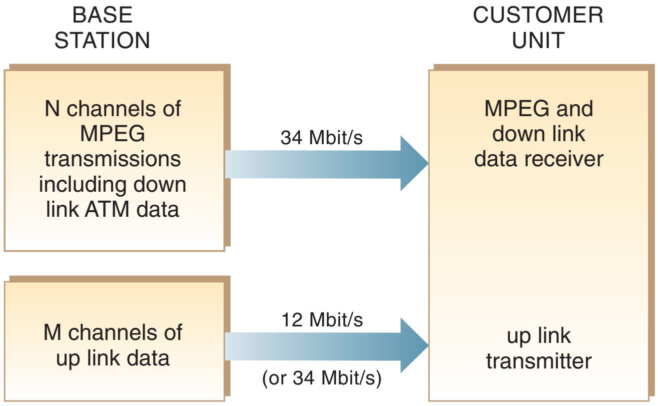



*Figure 3 Up- and downlink data rates for next generation LMDS*

Table 1 shows the traffic expected in a cell with a population of 2000 and penetration of 20 % to 25 %. It also indicates the bit rates and availabilities appropriate for these differing services. An attempt has been made to estimate the traffic capacity requirements in the 'busy hour' (last column). Whereas the telephony traffic increases to one in ten customers, it has been assumed that Internet, video conferencing and SMEs services run at near full capacity in the busy hour. A total traffic capacity of nearly 100 Mbit/s might be generated in each cell.

## 2.3 Data rates on up- and downlinks

The data rates to be carried on the up- and downlinks are shown in figure 3. On the downlink the base station transmits *N* channels of 34 Mbit/s MPEG coded traffic which would also include ATM traffic embedded in the MPEG cell format of 188 bytes. This basic data rate has been largely determined by the DVB and MPEG system designs, where low cost set top boxes, which can decode these MPEG-2 transmissions at 34 Mbit/s, are available. The options for the uplink are not so 'set in concrete', and basic RF power constraints, phase noise and frequency stability of low cost domestic users' systems are probably the greatest restriction. A traffic rate of at least 12 Mbit/s is achievable although it would be desirable to increase this rate to 34 Mbit/s (data rate of 25 Mbit/s when coding is added), to make it entirely compatible with 25 Mbit/s ATM systems.

## 2.4 Cell size, system parameters and propagation constraints

### 2.4.1 Propagation effects

#### 2.4.1.1 Rain effects

The first major constraint on cell size is determined by rain attenuation effects. Figure 4 indicates the additional margin needed for a point-to-point system to overcome rain effects with an availability of 99.99 %, as a function of cell size, for the seven climatic regions in Europe. These predictions [6] are based on the ITU-R Recommendation P.530, which sub-divides the world into climatic zones starting with A (lowest rainfall) and up to P – tropical. Most of Europe is categorised at or below climate region K with only the regions in North Italy and Southern Greece at Climate L.

For a 2 km range a 9 dB margin would be adequate for 99.9 % availability. This increases to about 25 dB an for availability of 99.99 %. Larger margins, which are common on point-to-point systems where trunk traffic is carried, seem inappropriate for LMDS systems, where the connection is only between one user and the base station. Due to the limited geographic extent of heavy rain, not all the customers in any one cell would be affected simultaneously, and figure 4 gives a rather pessimistic view of the rain effects as far as area coverage is concerned.

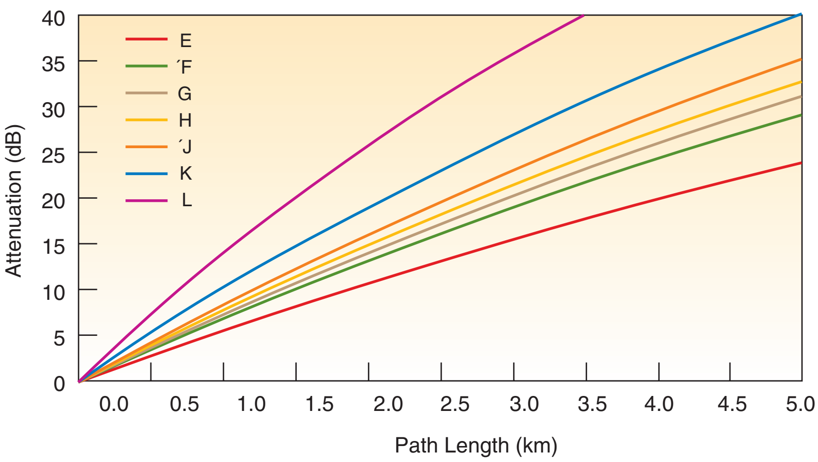
A fade margin of 20 dB on a 2 km link is proposed for operational LMDS systems, as this would provide 99.99 % availability for most of Europe for the LMDS system specification (ie. about 1 hour per year outage). In very high rainfall climates a slightly smaller cell size of 1.5 km would achieve the same 99.99 % availability.

Again in rural areas with low population densities, larger cells might be the only economic solution, resulting in lower service availabilities. At 5 km range, a 20 dB margin is more than sufficient to provide a 99.9 % service in all of Europe (ie. 8 hours loss of service per year).

#### 2.4.1.2 Building, terrain and vegetation blockage

The other propagation constraints which limit service are those of building, terrain and vegetation blockage. As the range increases beyond about 1 km, the number of roof tops which can be seen from the base station with a direct line-of-sight, falls off rapidly. Again a realistic size of 2 km seems a good compromise for most situ-

*Figure 4 Rain attenuation for 99.99 % availability*



ations, especially as those users at the cell extremities could be in range of adjacent base stations, which could provide an alternative transmitter.

Vegetation (trees) also significantly affect the number of users in suburban and rural situations, where a single tree [7] can produce a variable attenuation of ~ 20 dBs. The channel distortions produced by trees also exhibit multipath features, unlike the flat (across the band) fading caused by rain and building blockage.

When blockage is taken into account, simulation studies [8] indicate that base stations might only be able to service between 50 % and 60 % of the users within the nominal cell area at 2 km range with base station antennas at 20 to 30 m height. The option to access more than one base station would improve this penetration.

Multipath caused through reflections from buildings and terrain, which is normally present in lower frequency wireless access systems, is significantly reduced as a result of the narrow beam of user's antennas and the low reflection coefficients (average –10 dB) of typical objects [9] at frequencies near 40 GHz.

### 2.4.2 Traffic density constraints

Traffic density is the final constraint on cell size. In urban areas with more than 5000 houses/square kilometre, cells larger than 2 km could well become saturated very quickly, if the service take-up is anything near existing predictions. Although it is difficult to predict the total traffic requirement for new services, perhaps 200 active users per square kilometre might each require simultaneous services of more than one Mbit/s. Then the base station would need at least 200 Mbit/s capacity/km$^2$. Even with 2 GHz bandwidth available to be allocated to the entire system, such demands would restrict the cell size to a few square kilometres.

### 2.4.3 LMDS cell parameters

The effects discussed above will constrain the cell specification to:

| | |
|---|---|
| Cell size | 2 km |
| Margin | 20 dB |
| Penetration | 60 % |
| Availability | 99.99 % |

## 2.5 Important LMDS parameters

The parameters for LMDS systems are determined by both the predicted performance of low cost technology in the next few years and environmental considerations. Table 2 lists these main parameters.

| | |
|---|---|
| Cell size | 2 – 5 km |
| Base station antenna height | 20 – 40 m |

| Antennas | |
|---|---|
| User unit | 35 dB |
| Base station | 15 – 20 dB |
| Trunk | 45 dB |

| Downlink | |
|---|---|
| RF power (Transmitter) | 20 to 27 dBm |
| Bandwidth of amplifier | 500 MHz to 1.5 GHz |
| Coding | 7/8 or 3/4 rate Viterbi with RS |
| Modulation | QPSK (16 QAM) |
| Receiver noise figure LNA | 7 to 6 dB |
| Data rate MPEG-2/ATM 25 | 34/25.2 Mbit/s |
| Channel spacing | 39 MHz |
| Back off for multiple channel operation | 0.5 dB |
| Out of band radiation | –40 dB at 500 MHz |

| Uplink | next generation | future upgrade |
|---|---|---|
| Transmitter RF power | 14 dBm | 17 dBm |
| Uplink transmission data rate | 12.6 | 34 Mbit/s |
| Modulation | GMSK | DQPSK |
| Coding | RS (188,204) | |
| Uplink noise figure (base station Rx) | 5 dB | |
| C/I | >12 dB | >14 dB with power control |

*Table 2 LMDS parameters*

Base station antenna heights in the 20 m to 40 m range seem possible. Although it would be desirable to have higher masts, it is unlikely that they would be acceptable on environmental grounds. Various designs of base station antenna have been studied in this project and elsewhere (MPT 1560), where typical gains for a 90° sector antenna at 42 GHz fall in the region of 15 to 20 dB. The user antenna, typically a 15 cm diameter horn with a phase correcting lens, gives a gain near 35 dB. Although even larger gains are possible, pointing and stability problems become an issue for low cost domestic installations. However the higher gain antennas might be useful to improve the availabilities for users in rural areas, where cells larger than 2 km are necessary. Antennas connecting base stations for trunk traffic could easily be ~ 45 dB gain (comparable with those employed in the l-o-s systems which interconnect the GSM mobile infrastructure at 38 GHz).

The RF power levels of the base station transmitter amplifier for single chip devices are typical ~ 25 to 27 dBm with bandwidth of at least 500 MHz. The downlink data rate (34 Mbit/s) and modulation schemes (QPSK) are largely fixed, if the DVB-S MPEG specifications are accepted for LMDS systems. Simulations [10] of the downlink channel have indicated that only a 0.5 dB back-off is needed to reduce inter-modulation to a desirable level, when up to 12 channels are transmitted through one such power amplifier.

On the uplink the parameters are largely determined by cost. Modulation schemes could be either GMSK (more tolerant to phase noise and frequency drift), or more spectrally efficient DQPSK or even QPSK. Transmitter powers for domestic units of 14 dBm and data rates of 12.6 Mbit/s using either GMSK or DQPSK modulation are considered as reasonable base-line assumptions for the next generation systems. However, a desirable goal might be to design a system which could have an uplink data rate of at least 25 Mbit/s for ATM interoperability. DQPSK modulation might be preferred with its increased spectral efficiency and lower Eb/No requirement over GMSK. However the controller in the consumer unit might need to increase its clock rate by a factor of three to keep up with the increased data rate. A good compromise at this stage would be to opt for the lower spectral efficiency and the greater robustness of GMSK at 12.6 Mbit/s. However the system design should be kept entirely compatible with upgrading to 34 Mbit/s DQPSK some time in the future.

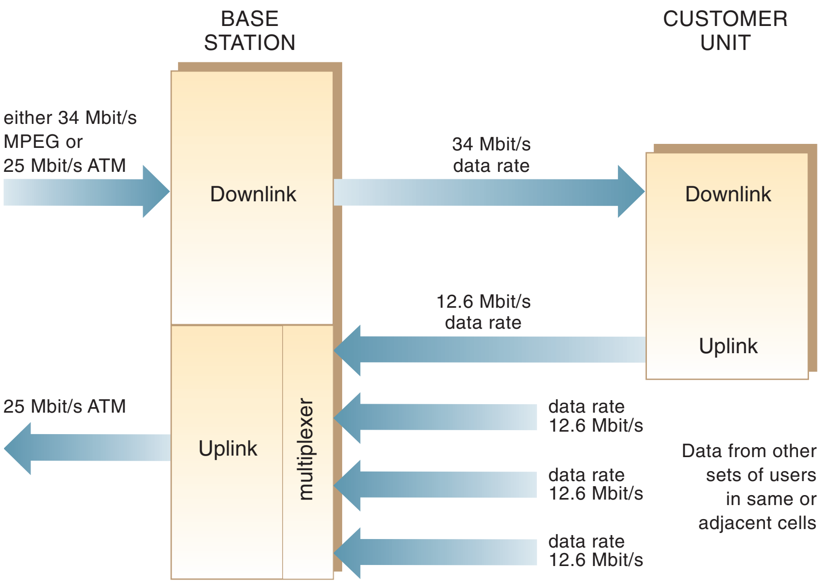
Antenna gains greater than 35 dB require higher precision mountings (for stability reasons) and alignment techniques than are desirable for domestic applications. Noise figures for receivers at the base station in the 5 to 7 dB range are again practical figures, obtainable with current technology.

### 2.6 Transmission rates on the up- and downlinks

The output transmission from the base station can be either MPEG coded or ATM traffic embedded in the MPEG frame format. Actual data rates will be lower than transmission rates due to coding and overhead consideration. Basic transmission rates of ~ 50 Mbit/s with both convolution encoded at 7/8 (or even 3/4 rate) and concatenated with Reed Solomon (RS) block codes would give a final data rate of 34 Mbit/s on the downlink. This coding scheme would improve a basic bit error ratio (BER) of $10^{-3}$ to $10^{-10}$, which in effect achieves an error free channel. However on the uplink the 12.6 Mbit/s transmissions with only RS (188,204) coding would require a larger Eb/No to achieve the same error free channel. Convolution coding on the uplink is not considered viable in a next generation implementation, due to the bursty nature of the traffic. At the base station, two separate uplink streams would be multiplexed at the base station to provide an overall standard 25 Mbit/s ATM transmission on the backbone (see figure 5a).

The 53 byte ATM cells are embedded in the 188 byte MPEG cell on the basis that three ATM cells can always be contained in a single MPEG cell. The 3 ATM cells transmitted at 25 Mbit/s would take 51 µs whereas the single MPEG cell at 34 Mbit/s takes the significantly less time of 46 µs. When operating even at full capacity, the MPEG packet structure can always keep up with

*Figure 5a ATM traffic flow between base station and users*



the ATM data and sometimes only 2 ATM cells would be embedded in a single MPEG packet.

The preferred access scheme on the uplink would be multi-frequency (MF)-TDMA [11]. The protocol selects a particular channel for each user, depending on their individual traffic requirements, so that the optimum packing is achieved on the available channels. One feature of this scheme is that of a variable frame structure, which allows a number of ATM cells to be transmitted together without a guard band - between each cell. This longer packet structure reduces the overhead associated with the preamble required for convolution coding.

Currently the power constraints of the consumer unit RF system and the ability of the controller to cope with data rates >15 Mbit/s limit the uplink clock rate to 12.6 Mbit/s. However as more powerful RF chips and fast clock rate processors become available, the system should be able to accommodate uplink data rates of 34 Mbit/s, thus by-passing the multiplexer interface which combines the two 12.6 Mbit/s data channels, to achieve the goal of a seamless ATM 25 Mbit/s interface to each user.

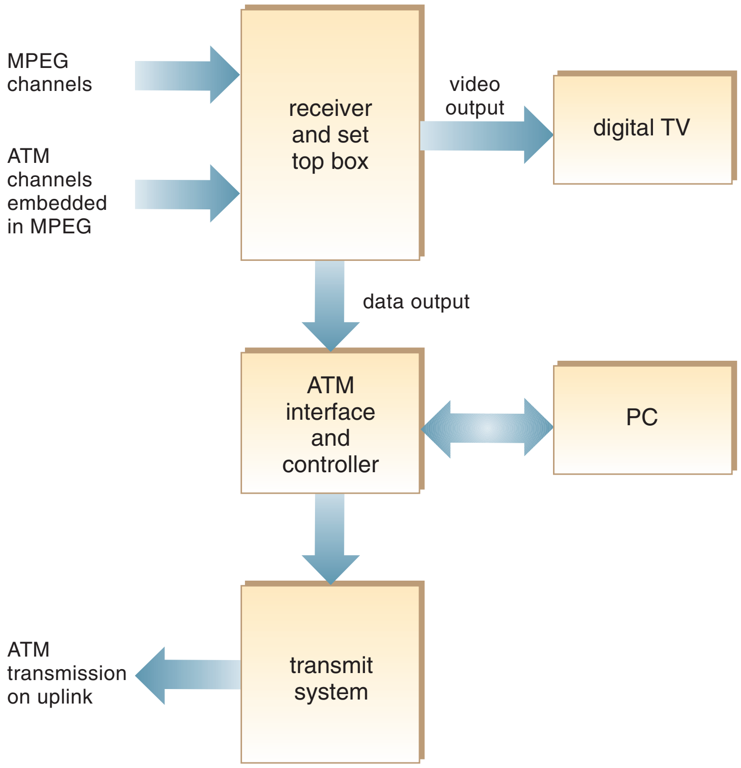



*Figure 5b Consumer unit*

### 2.6.1 Consumer unit

The individual user units receive two types of data streams: either MPEG coded or ATM embedded in MPEG frame format. These downlink streams are demodulated by the set top box (figure 5b) and then split before decoding as either an MPEG TV channel or as an ATM channel. The uplink ATM based traffic is controlled through the PC.

## 2.7 Link budgets

The link budgets (which use the parameter in table 2 and the cell constraints summarised in section 2.4.3) are shown for both down- and uplinks in tables 3 and 4. Both are calculated for the scenarios of QPSK and GMSK/QPSK modulation schemes on the down- and uplinks, respectively and that of the base station having a gain of 19 dB at the extremity of the cell.

| | | |
|---|---|---|
| transmitter power | dBm | 27 |
| base station antenna | dB | 19 |
| gain | | |
| feed loss | dB | 2 |
| transmitted power/channel | dB | –13.8 (12 channels/) power amplifier |
| cell size | km | 2 |
| free space loss | dB | –130.6 |
| receiver noise figure | dB | 7 |
| receiver antenna gain | dB | 34.2 |
| received power | dBm | –66.2 |
| C/T | $dBWK^{-1}$ | –127.2 |
| bandwidth (34 MHz) | dBHz | 75.3 |
| Boltzman's constant | $dBWHz^{-1}K^{-1}$ | –228.4 |
| total margin | dB | 25.9 |
| margin @ BER 1 in $10^3$ | dB | 19.1 (QPSK 6.8 dB margin) |

*Table 3 LMDS downlink budget*

Table 4 LMDS uplink budget

| | | Next generation | Future upgrade |
|---|---|---|---|
| transmitter power | dBm | 14 | 17 |
| consumer unit antenna gain | dB | 34 | |
| feed loss | dB | 2 | |
| cell size | km | 2 | |
| free space loss | dB | –130.6 | |
| receiver noise figure base station | dB | 5 | |
| receiver antenna gain | dB | 19 | |
| received power | dBm | –65.6 | |
| C/T | $dBWK^{-1}$ | –124.6 | |
| bandwidth (8.5/34 MHz) | dBHz | 69.2 | 75.2 |
| Boltzman's constant | $dBWHz^{-1}K^{-1}$ | –228.4 | |
| total margin | dB | 34.6 | |
| margin @ BER 1 in $10^3$ | dB | 22.6 dB | ~ 22 |

On the downlink, the power from one 27 dBm amplifier is split between 12 channels (each operating at 34 Mbit/s). This produces a margin near 20 dB (19.1 dB) to accommodate rain fading at the 2 km extremity of the cell.

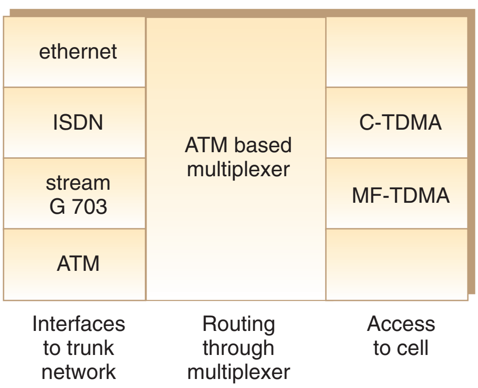
For the next generation system, the up-link data rate (using DQPSK) of 12.6 Mbit/s and a 14 dBm RF power amplifier is sufficient to return a margin > 22 dB at the cell edge. (This would remain above ~ 20 dB for the upgrade system with a 17 dBm transmitter and DQPSK modulation at 34 Mbit/s.)

### 2.7.1 Adjacent cell interference

These link budget calculations have been made under the assumption that the carrier to interference ratios (C/I) are much higher than the carrier to noise ratios (C/N), at least in rain fading conditions. Thus in the first order link budget calculations the C/Is can be neglected. This will be true for isolated deployments of LMDS systems but not so if an operator installs a system with several base stations some of which re-use the same frequencies in near-adjacent cells. A novel dual-frequency dual-polarisation re-use pattern was developed in the CRABS project [5], which always achieved C/I > 14 dB on both up- and downlinks, providing some limited power adjustment was undertaken at user sites during installation. In practice, because of terrain, vegetation and building blockage much greater C/I values would be experienced, making the isolated link budget calculations above achievable in most cases, even in a fairly large LMDS deployment

## 2.8 Basic design of switch and protocol

The basic design of the system, which follows the modified LISSY concepts [11] is shown schematically in figure 6, where the full range of interfaces and outputs are shown. The standard interface to the network would generally be ATM at 25 Mbit/s. However the system has the capability of accepting ISDN, Ethernet and G703 interfaces. This configuration (figure 6) represents the arrangement for the base station. However the user units would be a sub-set of the same overall design concept. Thus users wishing, for instance, a local Ethernet connection or an ISDN interface will have that feature built into their system design.



(MF-TDMA: Frequency Multiplex TDMA)

Figure 6 Basic Functionality of LMDS Switch

The core unit is an ATM multiplexer which accepts data from each interface, after conversion into an ATM like cell structure. The traffic is then transmitted on the air interface with a TDM/TDMA protocol on the down- and uplinks. The MF-TDMA protocol features a dynamically re-configurable time frame, in which various types of traffic are assigned both differing priorities and length of time slots, depending on their instantaneous requirements. The MF-TDMA allows several traffic streams to be frequency multiplexed and switched between channels to allow the optimum traffic distribution to be established within a given cell. Uplink data rates for individual users can be varied from 64 kbit/s to several Mbits/s.

## 2.9 Base station

### 2.9.1 Antenna designs

A number of novel antenna designs [12] for the base station have been proposed for LMDS systems. The basic antenna design for the base station is a near omni-directional antenna, which distributes power uniformly throughout a nearly square shaped cell. When traffic increases the cell can be split into four quadrants, allowing independent traffic in each quadrant by re-using the two frequencies and polarisations. A further improvement can also be gained by splitting the 90 % quadrants into five separate sections, thus allowing a further five fold increase in traffic throughput. Thus a near 20 fold increase in traffic could be accommodated, without increasing the bandwidth, by replacing the original omni-directional base station antenna with a more complex device. Another interesting feature being studied [12] is that of beam shaping in the vertical direction to produce the maximum gain at the greatest range. Improvements of ~ 4 dB can be achieved over a conventional design.

## 2.10 Frequency re-use strategies

The initial interference prediction [13], which was investigated by using cell modelling techniques, has shown that the particular properties of LMDS at 42 GHz result in very low adjacent cell interference environment. A single frequency plan is not possible due to diplexer considerations. Rejection of the transmission from the uplink feed into the downlink receiver at the user unit requires a significant frequency separation of about 500 MHz for low cost technology. A basic frequency plan is shown in figure 7 where the band is split into several basic frequency slots. Several hundred MHz are allocated to the MPEG and ATM downlink transmissions. The extremities of the band are reserved for the uplink traffic. (A further band is needed to accommodate the trunk backbone traffic between base stations which could well be carried by radio in the initial phase of an operational system.) The overall plan provides four pairs (dual frequency / polarisation) of up- and downlinks. In any one cell the downlinks are allocated ~ 860 MHz with the uplinks accommodated in 120 MHz. Separation between up- and downlinks is always > 880 MHz.

This is a basic plan that could need to be modified if more than one operator wished to provide services in the same franchise area. Although the scheme is simple and provides maximum uplink/downlink rejection, it requires the RF equipment to operate over a 2 GHz bandwidth.

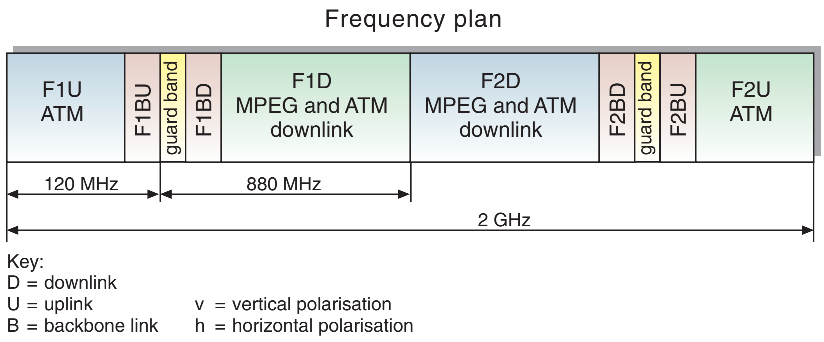



*Figure 7 Dual frequency and polarisation re-use plan*

## 2.11 LMDS Connections to locations which do not have a clear line-of-sight

Three possible situations exist where potential users of an LMDS system cannot be connected directly through a line-of-sight radio link at 42 GHz. These are

- individual locations shielded by buildings, vegetation or trees;
- occupant of high rise apartment blocks;
- small groups of houses in suburban areas which are shielded from the local base station.

A number of options are possible which include

- an integrated radio fibre system connecting the local users through a master RF transceiver located on the roof of an apartment block;
- a local radio LAN which could be either in band (RNET) or out of band (eg. spread spectrum at 2.5 GHz);
- a micro cell repeater, which retransmits all the transmissions in the main cell at the same frequency but on an orthogonal polarisation. These repeaters could be either active or passive.

The integrated radio fibre system and the micro cell approaches provide all the services available in the main cell but the radio LAN method might only be able to re-transmit some fraction of the services, due to bandwidth limitations.

## 2.12 Backbone connections linking cells base stations clusters

The connection to the main franchise control centre (figure 2) could be made through a combination of fibre optic, coax, terrestrial radio or satellite connection. It seems desirable that the distribution from the main control centre to the base stations in the franchise area is accomplished either in ATM (on both up- and downlinks at 25 Mbit/s) or through MPEG-2 coded traffic multiplex into 34 Mbit/s channels for the TV downlinks. The ATM downlinks are embedded in MPEG frame structure so that the set top box can decode either streams. Thus the main control centre acts as a buffer/multiplexer which converts input/output traffic from the main networks into two well defined standards for re-transmission within the franchise.

It should not matter then which medium is used (ie. fibre/coax or radio) as far as distribution is concerned as the protocols would all be similar.

In the roll out of an operational service it is likely that the initial cluster of cells would be connected directly to the main co-ordination centre through a fibre/coax trunk. However subsequent additions of cells or cell clusters might well be connected, at least initially, until traffic increases to a desirable level, by a radio connection. Figure 8 shows this situation, where the first four cell clusters are served by a fixed fibre/coax trunk but the next cluster is connected by a radio trunk. This trunk radio connection with its in band (42 GHz) transmission should have an availability at least one order of magnitude greater than that of the individual cell level (ie. 99.99 % required for ATM based traffic). Thus a link margin of at least 99.999 % on the trunk is desirable. This requires a margin of up to ~55 dB on a 4 km path to be effective in most regions of Europe. However the antenna gain of 45 dB proposed for the trunk link connections produce an additional 35 dB (but is reduced by 6 dB to compensate for the additional path length) over the link budgets in tables 3 and 4. A 50 dB margin is achieved overall. This could be increased by using one RF (~27 dBm) for two 34 Mbit/s channels, thus improving the margin to 58 dB. The TV MPEG transmissions would be picked up off-air, the additional margin 15 to 25 dB being sufficient for broadcast services with required availability of 99.9 %.

Unless some more spectrally efficient modulation scheme than QPSK is used on the trunk links, the ATM links would need to occupy as much spectrum on the trunk path as that allocated to the cells which they were serving. Either 16 QAM or 64 QAM, which achieve in practical systems between ~3 bit/Hz and ~5 bit/Hz, would be a preferred modulation scheme on the trunk links, although improved spectral efficiency is traded for a smaller overall link margin (Eb/No margin reduced by 5 dB for 16 QAM and 9 dB for 64 QAM, all other parameters remaining the same).

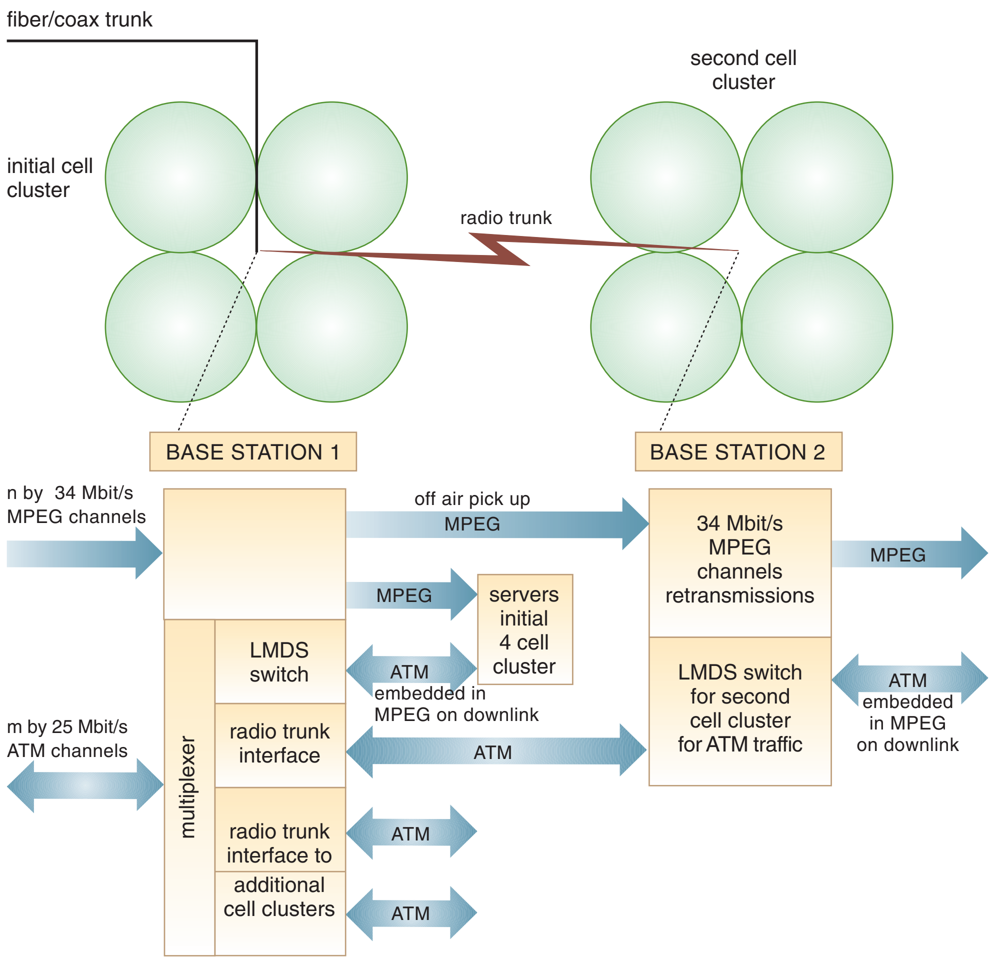



*Figure 8 Fibre/coax connection to initial cell cluster with radio connection to next cell cluster*

## 3 Summary

This paper has given an overview of the next generation LMDS system, which has been developed during the CRABS project. It covers such topics as the cellular concept, cell size constraints due to propagation and traffic consideration, link budgets, system parameters, traffic types and requirements, antenna designs and RF parameters, demand access systems, connection to users in both micro cells through active repeaters and in multiple occupancy apartment buildings, connection of the base station to the fixed broadband terrestrial networks and interconnections between base stations.

## 4 Acknowledgements

The concepts discussed in this paper arose from the collective discussions and studies within the CRABS project on the design of systems architecture for the next generation LMDS. All the participants in this part of the project concerned with this design have made some contribution and they have also been considerably assisted in their deliberations with contributions from the studies on propagation effects, operators, manufacturers and users requirements and experiences gained from the trials.

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# An interactive return link system for LMDS

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**An ATM-based communications system has been developed within the CRABS project which supports interactive return links on LMDS channels. Originally designed for VSAT applications, it was modified for the special requirements of a cellular radio link infrastructure at 40 GHz. The system supports at present Ethernet, ISDN, G.703 and RS.449 interfaces. The ATM cell switching concept ensures a guaranteed quality of service. Typical applications are fast Internet access, application sharing, video conferencing and ISDN telephony. The system has been successfully applied in a tele-education field trial in Norway.**

## 1 Introduction

The demonstration of interactive services over an LMDS infrastructure has been an important goal of the CRABS project. Different methods for providing interactivity have been investigated, among them the use of a modified DECT and a modified VSAT system called *Local Network Interconnection Using Satellite Systems*. This solution has some advantages, particularly the compatibility with ATM, the availability of the required network components and subsystems (thus providing access to LANs, ISDN exchanges and other isochronous services like video conferencing). Seamless communications between satellite VSAT networks, local ATM distribution and the LMDS environment can be supported.

ATM provides a common multiplexing for different services. The small cell size provides fast switching and low latency enabling both isochronous and bursty traffic to share the same network. ATM components have recently become more readily available. Interface cards are already sold at prices below 100 Euro. With lower-cost switches local ATM can be regarded as one possibility to replace current lower-speed LAN technology. For this reason, compatibility with ATM has been considered important for several communications developments (HDSL, VDSL).

The satellite-based system [1], [2], [3] exploits already *internally* the method of ATM cell switching and multiplexing. Therefore it was agreed to use this system with adaptations for the LMDS environment in the Scandinavian trial.

It is vital that the interactive system is demonstrated involving real users. For this purpose it was decided to set up a three-site pilot demonstrator in Norway, where an LMDS infrastructure is available.

High-speed Internet access using IP over ATM, video conferencing together with application sharing are the main applications to be demonstrated. In addition, long-term measurements of bit error rate, ATM cell loss probability, tolerance of the various applications to cell losses have been carried out and system improvements made based on the results. An important element is the evaluation of the user perception of the various services. In the following section a description of the concept is given and in section 4 an outline for the design of the future system is provided.

## 2 Overview of the TDMA concept

The bandwidth of the interactive radio channel is currently 2 Mbit/s shared by a larger number of users in TDMA *(time division multiple access)* mode. Significant increase of the network bandwidth is possible by extending the scheme to multi-frequency TDMA (MF-TDMA). To utilise the valuable resource of the radio link capacity in an efficient way, advanced access techniques are implemented. Dynamic demand-assignment TDMA is advantageous for mixed-media traffic with fast varying load. The core of the system is the Interactive Return Link Gateway (IRLG).

### 2.1 The gateway

The access to the network is provided by the Interactive Return Link (IRL) controller (Gateway). The gateway is designed to enable the transmission of different traffic types (LAN, voice, video, multimedia applications). In the current implementation, four types of interfaces are supported [4]:

- IEEE 802.3 10-Base-2 Ethernet;
- Basic Rate ISDN;
- E1; and
- RS-449/EIA-530.
- A generic ATM network interface can easily be connected to the gateway, enabling the integration of ATM switches/islands or ATM user equipment over LMDS.

The main tasks of the IRL controller are:

- to enable the wireless connectivity of different data interface types (Ethernet, ISDN, Stream, ATM);
- to provide controlled access on demand to the radio channel resources;
- dynamic bandwidth distribution among the active stations on demand;
- automatic synchronisation of all stations;
- to enable system configuration by an operator via a control PC.

The main components of the gateway are shown in figure 1.

The central part of the system (core) is an ATM cell multiplexer which is connected to the network interfaces and the transmission subsystem.

Using the Ethernet Interface, LANs and WANs can be interconnected by the wireless network. The ISDN interface provides access to a PABX. The third interface type is the Stream Interface. It enables the connection of stream devices like video codecs with a G.703 or RS-449 interface to the wireless network.

One of the design goals was to allow the adaptation of the gateway to connect to an ATM network. It is worth noting that gateway-internal switching and routing concepts are based on ATM, ie. that information segmentation and reassembly, bandwidth allocation, addressing and routing takes place in form of ATM cell streams.

Each interface buffers the arriving data and makes a conversion between the network-specific data format to the cell format used inside the IRL controller. Data arriving at one of the network interfaces are buffered and broken into standard sized cells. Depending on the network interface, this is done by using a modified version of AAL 5 (ATM Adaptation Layer 5) for the Ethernet, or a stream packetisation protocol (AAL 1) for the Stream and the ISDN Interface.

On the transmission side, the TDMA module enables the access to the modem. This module is responsible for the exact timing, the generation and detection of the begin of bursts by Unique Words. It also contains the half-rate convolutional encoder/Viterbi decoder and the phase ambiguity correction.

The software module structure is shown in figure 2. The access module ACC contains the Access Agent which is responsible for distributing the available bandwidth dynamically among the stations. The other modules of the CORE provide basic functions which are used by the Access Agent. The output of the Access Agent is the Allocation Plan (AP) which contains the burst start time and the burst length.

The decisions of the Access Agent are executed in the Burst Assembly module (BA). The BA module receives the Allocation Plan from the Access Agent and requests cells for transmission from the interfaces. A further task of the BA is to provide the signalling transport over the radio link and to protect each ATM cell with a CRC (cyclic redundancy check).

The Burst Disassembler BD receives frames from the transmission interface. The ATM cells are extracted and the CRC of the header is checked. If an error is detected, the whole cell is discarded, to avoid miss-routing of cells. Subsequently the cells are forwarded to the interfaces. Because bursts from all stations are received from the radio channel, filtering of cells is necessary. The filtering is based on the VPI/VCI values in the cell headers. Another task of the BD is to extract the signalling information from the receive frame.

Each data interface is connected with the IRL controller by one bi-directional serial link to the CMUX module. It consists of the two processes TXMUX (transmission multiplexer) and RXMUX (receive demultiplexer) which uses the VCD values to send the cells to the correct interface.

The TDMA module contains the hard- and software for the channel access.

#### 2.1.1 ATM cells

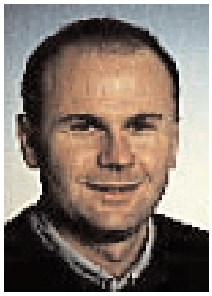
Each communication inside the system is based on the ATM cell format. All communication with the network interfaces as well as the communication between modules inside the system are based on this format.

The purpose of the VPI/VCI (virtual path identifier / virtual channel identifier) values is to provide connectivity between the network interfaces of different stations. Each VCI/VPI pair identifies either a point-to-point or a point-to-multipoint connection. For efficiency reasons, the header of the cells transmitted over the LMDS (or satellite) network is reduced to 3 bytes (2 for the Virtual Connection Descriptor, into which the VCI/VPI values are mapped; and 1 for a CRC to allow checking of the header).

#### 2.1.2 Traffic types

The IRL controller supports the following three classes of connection-oriented traffic services (corresponding to ITU-T Recommendation I.362):

Service Class A:
Traffic with a constant bit rate and a timing relation between the source and destination (eg. constant bit rate video).



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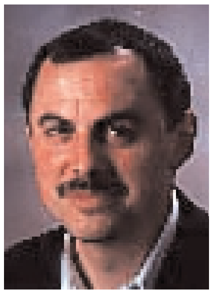

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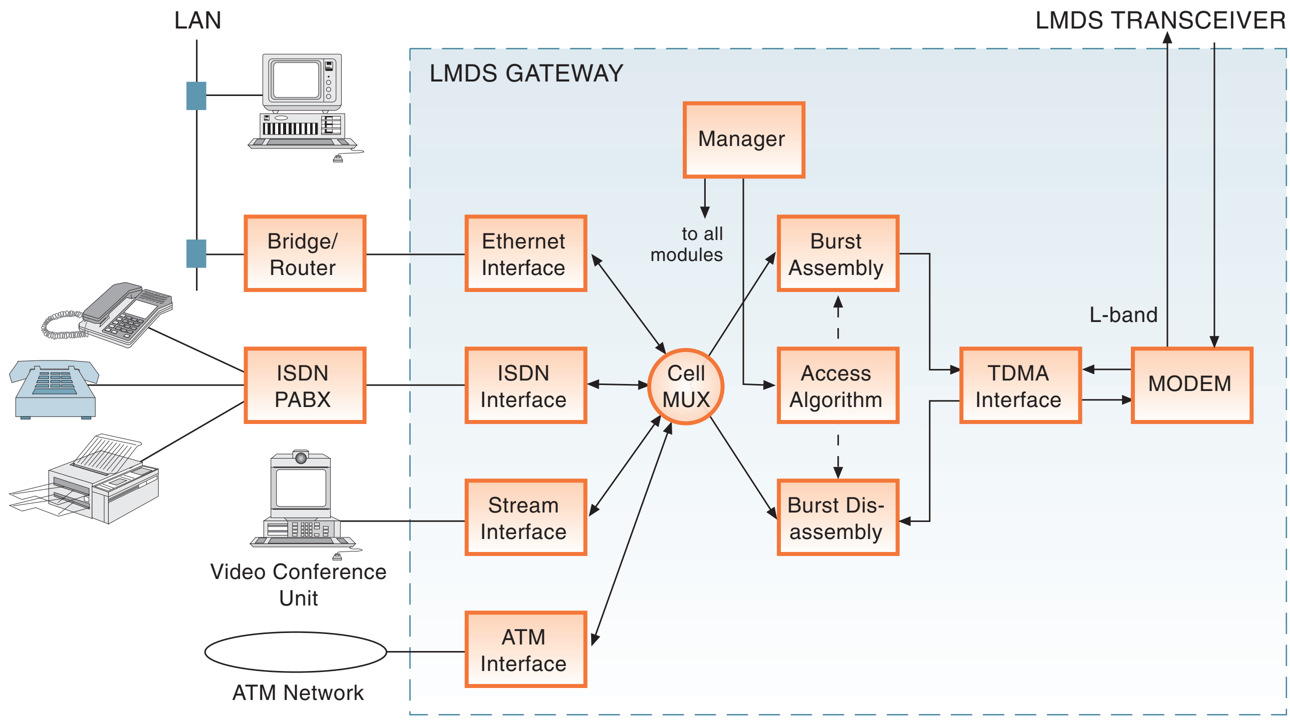


*Figure 1 Block diagram of the gateway*

Service Class B:
Traffic with a variable bit rate and a timing relation between the source and destination (eg. variable bit rate video and audio).

Service Class C:
Traffic with a variable bit rate and no timing relation between the source and destination (eg. data transfer, interactive computer access, mailing, ...).

Ethernet data is of class C, stream data of class A or B. The ISDN interface makes use of two connections, one of class A (2B-channel) and one of class C (D-channel).

For the access scheme only two types of traffic exist: traffic for which bandwidth is guaranteed (class A and B), and traffic for which no bandwidth guarantee is given (class C).

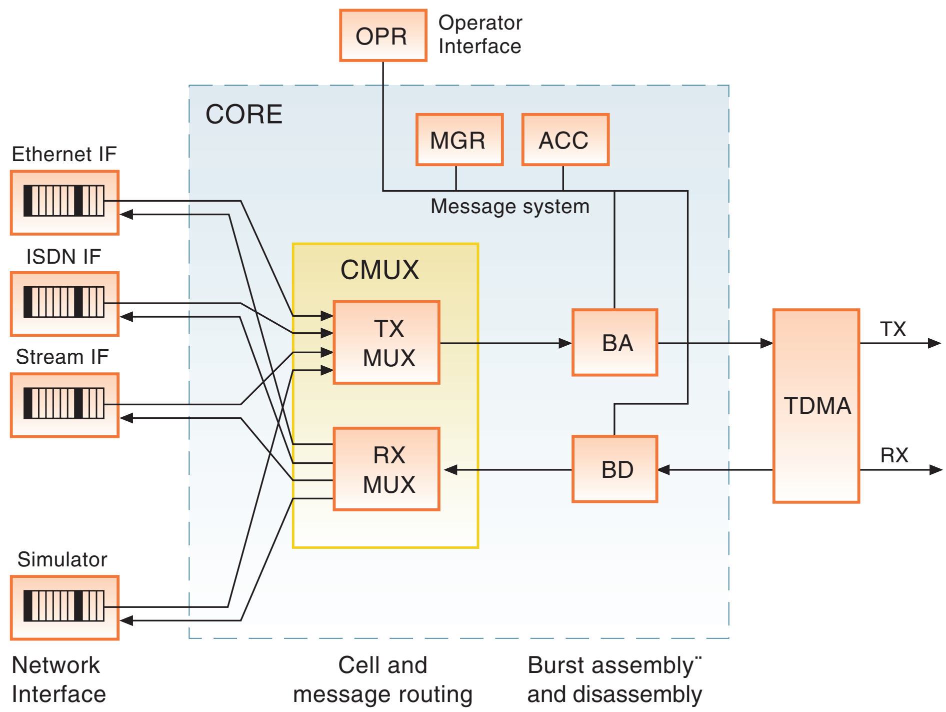


*Figure 2 Module structure*

## 2.2 Access algorithm

### 2.2.1 Method for single-frequency operations

The implemented access algorithm is based on centralised control from a dedicated station which is called *master*. All other stations in the network are the *slave* stations.

The master controls the whole network, distributes the resources and provides the synchronisation for the slave stations. The implemented access algorithm combines the Reservation Access with the Free Assignment method. Each station sends bandwidth requests via the signalling channels to the master station. The access algorithm in the master distributes the available channel capacity among the active stations. All stations are then informed about the new Allocation Plan via the outbound signalling channel embedded in the reference burst. In each station, a further algorithm distributes the assigned bandwidth among the active interfaces.

The following three categories of connections are defined internally:

AB-Connections:
Class A or B traffic. The desired bandwidth is guaranteed from the system (eg. ISDN-2B and the stream data).

C1-Connections:
Class C traffic with high priority (ISDN-D channel). The transmission of the cells cannot be delayed too long. For example, cells for the ISDN-D channel need not be transmitted immediately, but within three to four seconds. Otherwise the whole ISDN connection breaks.

C2-Connections:
Class C traffic with low priority (Ethernet). The transmission of the cells could be delayed for a longer time.

The time of the radio channel is divided into periodic *frames* of a constant duration $T_f$. A longer period of 32 frames (1.024 sec) is chosen to schedule events varying with a lower frequency, eg. the first access for slave stations. This period is called *super-frame* (figure 3). The first burst in each frame is sent by the master station (reference station). The occurrence of

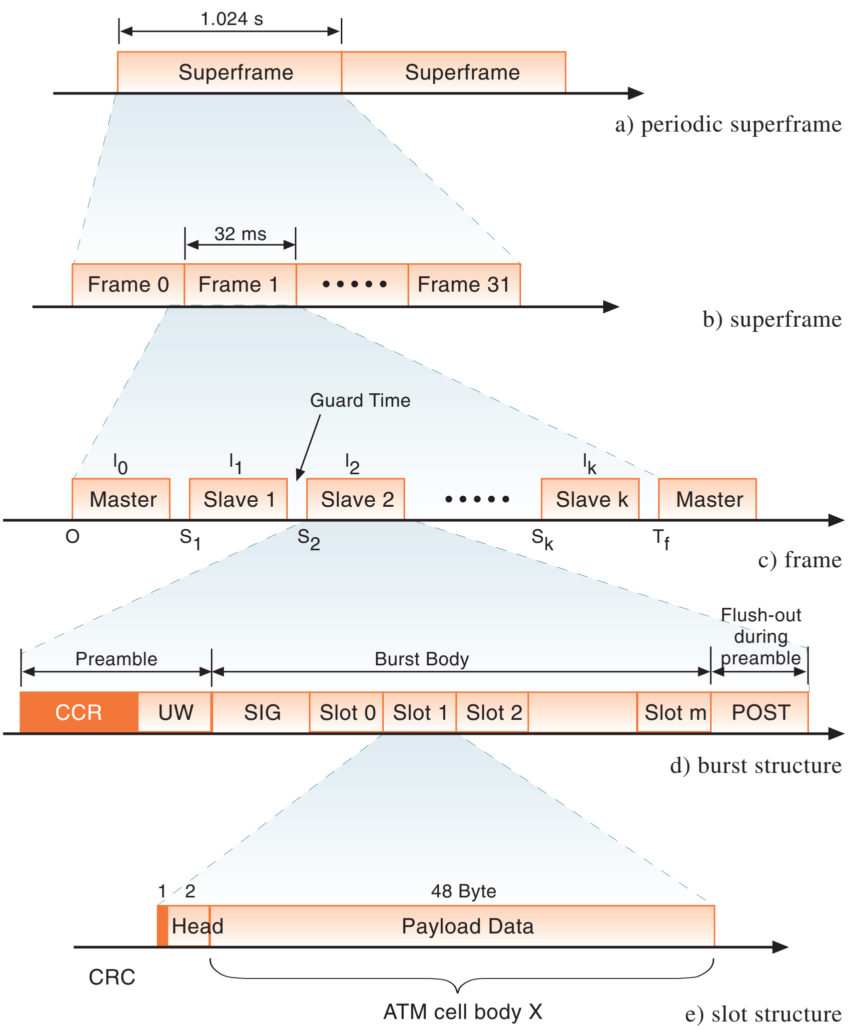


*Figure 3 Frame and burst structure*

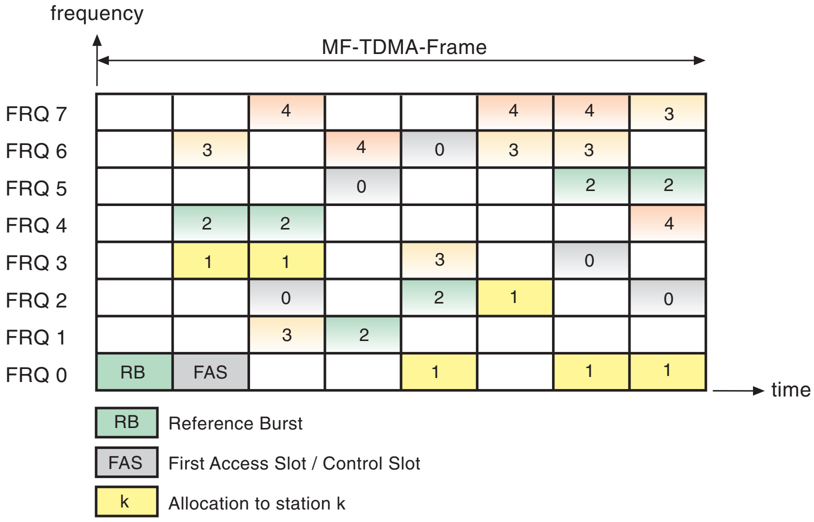


*Figure 4 Multi-frequency capacity allocation*

the master or reference burst is used by the slave stations to derive their transmit timing synchronisation.

A short guard time is required between bursts originating from several stations accessing the radio channel to ensure that the bursts never overlap.

Each burst begins with a sequence of symbols which enable the demodulator to recover the data and clock properly. This sequence is called Carrier and Clock Recovery Sequence (CCR). The main difference in the access scheme between the satellite and the LMDS system is that the stations cannot receive themselves. All transmissions from the user stations are however received by the head-end. The continuous round-trip delay measurements and adjustments of the transmission windows of the satellite system are also unnecessary due to the static constellation (no moving satellite, no Doppler shift).

The frame length of 32 ms has been taken over from the VSAT system. It works satisfactorily with a smaller number of users. Recent simulations, carried out by the CRABS partner Thomson suggest a frame length of 8 ... 16 ms, if the number of users is large. A further recommendation is to use a contention-based method for initial capacity request, if the number of users is large [6].

### 2.2.2 MF-TDMA for the future system

The access concept for the original satellite system could be adapted for multi-frequency operations in the future system. The access agent for the MF-TDMA modem is, however, more complex, because additional system parameters must be considered.

The allocation plan has to describe a two-dimensional array: the allocation of bandwidth in terms of time slots and frequencies. An example of the allocation plan for MF-TDMA operation is shown in figure 4 for eight frequencies.

The first slot on frequency 0 contains the reference burst (RB), always sent at the lowest data rate utilised in the network, to ensure that the reference burst can be received by each station. This burst is sent by the master station at the begin of each frame. The reference burst contains the allocation plan.

The second slot on frequency 0 is reserved for the signalling channel (First Access Slot – FAS and Control Slot – CS). In this slot the master always listens for bursts from other stations. This procedure is needed if the signalling is done through a dedicated radio channel (as in the CRABS trial). The alternative is to embed the signalling and synchronisation into the MPEG transport stream.

In the single-frequency system, three parameters are necessary for the access algorithm: the guaranteed bandwidth, the source and the destination.

For MF-TDMA operation the access algorithm has to take into account the following parameters:

*Source*: The "source" of a connection contains the interface from which data originate.

*Destinations*: The "destination" of a connection defines the interface which receives data of the current connection. Multicast connections have more than one destination.

*Quality of service*: The access algorithm must ensure that bandwidth for real-time traffic is guaranteed.

*Traffic type*: For AB-traffic the connection must be established and the bandwidth must be guaranteed. For C-type traffic only the connection must be set up. In the MF-TDMA system the slots for transmitting the AB- and C-type traffic can be separated. In the original system both traffic types were transmitted in the same burst.

*Available frequency bands*: At connection set-up the frequency for transmission is assigned. If there is a bi-directional connection, both stations could transmit on one frequency in different time slots or the stations transmit on different frequencies at the same time instants.

## 3 Modem

The original satellite system used a 2 Mbit/s QPSK burst modem which has a capture range of 25 kHz from nominal frequency and requires a frequency stability of +/– 1.5 kHz between bursts. This is too stringent a requirement for low-cost LMDS transceivers. Therefore it was decided to build a simple FSK modem for the evaluation and demonstration phase in the CRABS project. The following functions were implemented in the modem card for the gateway:

- symbol interleaving;
- line clock encoding;
- pulse shaping/filtering;
- FM modulation of L-band carrier;
- carrier switching to enable the burst mode transmission;
- FM demodulation;
- clock recovery;
- symbol deinterleaving;
- clock decoupling (FIFO control).

The future system will use a spectrally more efficient modulation scheme. GMSK is proposed for this purpose. It is less demanding in terms of frequency stability and phase noise requirements. DQPSK may be another possibility, since it would be spectrally more efficient and require a lower Eb/No for the same BER performance. However, automatic level control in the transceiver would be needed.

Since GMSK can be regarded as a certain kind of binary digital modulation, its BER performance bound in AWGN channels is approximately described as $p_b \approx \frac{1}{2}\, erfc\, \sqrt{d_{\min}^2 \gamma/4}$ for higher values of $\gamma = E_b / N_0$. But this bound can be approached only if a maximum likelihood detector is implemented. With respect to coherent detection the performance can be roughly expressed by $p_b \approx \frac{1}{2}\, erfc\, \sqrt{\alpha\gamma}$ if a Gaussian predetection filter with $BT = 0.63$ is used. This formula is also easily applied to Rayleigh fading channels with the result that $p_b \approx 1 / (4\alpha\bar{\gamma})$.

To enable multi-frequency operations, a frequency-agile modulator and demodulator is needed. For this reason the up-/down-converter to and from L-band shall be implemented using an NCO approach in order to allow fast frequency switching between bursts.

## 4 Integration of up- and downlink

The interactive return link system was integrated with the already existing DVB-based downlink facilities at Telenor at the beginning of July 1998. The initially used ISDN return links were replaced by the IRL. High-speed Internet access, video conferencing and applications sharing are being tested and demonstrated. Figure 5 shows the configuration. The head-end provides high-speed access to a local server and the Internet. IP packets are embedded in the MPEG transport stream. The downlink uses a DVB transmission system. The user PC contains an MPEG card connected to an LMDS receiver. The server-client data transfer is using this path (broadcast

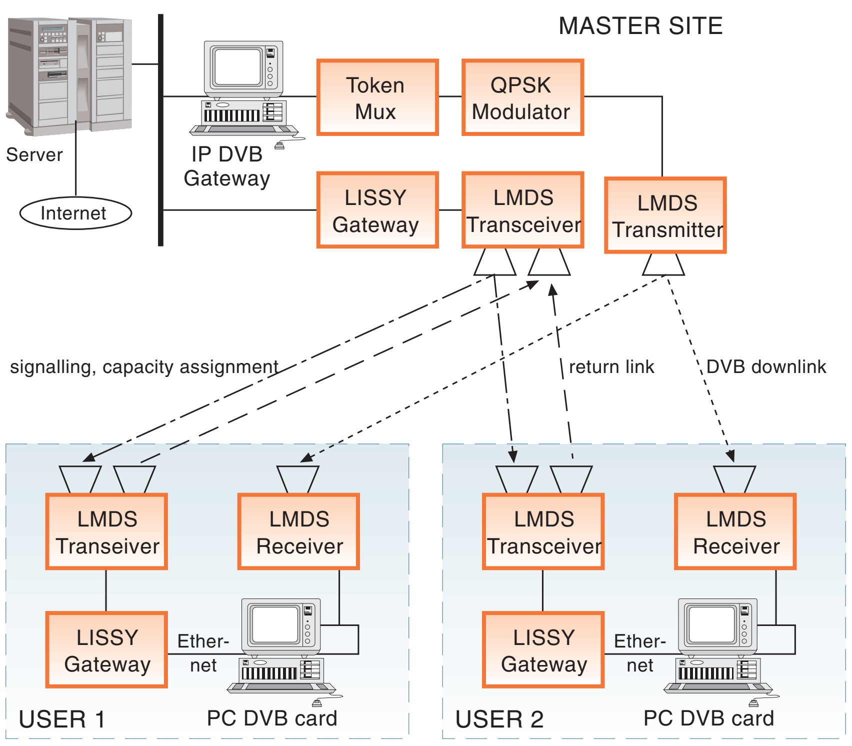


*Figure 5 Combination of DVB downlink and return link*

channel). The return link is provided by the IRL system (return interaction channel). The connection between user PC and the IRL gateway is done via Ethernet. At the head-end the gateway delivers the IP packets (requests and acknowledgements) via Ethernet to the server. It should be noted that there is another downlink for the IRL system which is needed for TDMA synchronisation and signalling (capacity request and assignment). According to the ETSI reference model for interactive DVB systems this corresponds to the forward interaction path.

For the future system all TDMA or MF-TDMA functions as described before will be integrated on a PC card. The modem functions could also be implemented on this card. The present system was realised by an array of parallel processors. This was very convenient for developing the prototype, but not a cost-efficient solution. The future system should be designed such that the ATM cell multiplexer, the burst assembler/disassembler and the TDMA-related functions are handled by a single processor. Time-critical functions (eg. TDMA timing) will be implemented in hardware to reduce the processor load. This requires that on this processor a real-time operating system is running. QNX has been identified as a suitable real-time operating system, whereby the existing complex access software (including ATM cell multiplexing) could be transferred with reasonable effort.

There are two possibilities for the future network architecture. The first solution is to maintain the scenario with 2 downlinks (one for the DVB channel and one for the interactive system) as shown in figure 5. The "downlink" for the interactive system is however only needed for synchronisation and signalling. The alternative is shown in figure 6. TDMA synchronisation is derived from time stamps in the MPEG transport stream. Signalling from master to slaves (assignment of capacity) is also embedded in the MPEG transport stream. For the signalling only a small amount of capacity is needed. The second scenario requires only a single transmitter and a single receiver at the master cell site and the user sites.

For the reception of the DVB signal standard PC cards which are already available at low cost can be utilised.

## 5 Summary

The adapted VSAT system has proven to provide a good solution for the interactive return link for the CRABS LMDS environment. The internal method of ATM cell multiplexing allows to guarantee the required quality of service for different user applications. Furthermore, the connection to existing local ATM infrastructure is easy. Due to its flexible design, the speed for the individual user and the network capacity can be increased with moderate effort. The

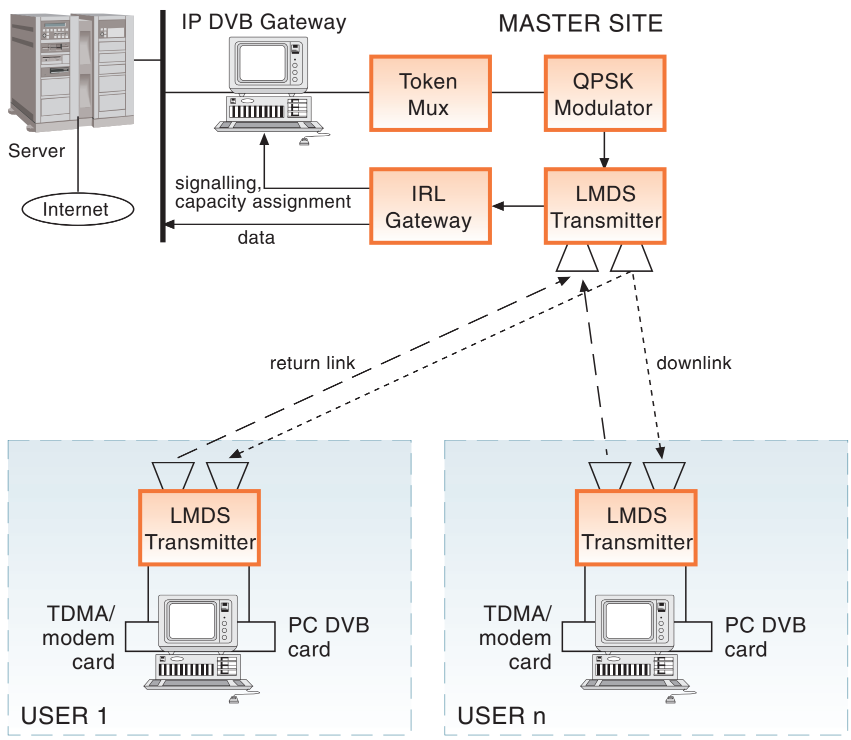


*Figure 6 Future Scenario*

developments for the next generation system will include MF-TDMA operations, whereby the capacity is assigned in time and frequency, the development of a spectrally more efficient modem using eg. GMSK and a low-cost implementation of the gateway. The cell multiplexer and the TDMA controller functions will be concentrated on a single card. This solution has the advantage that standard network interface components can be used, resulting in a significant cost reduction.

## 6 Acknowledgements

The development of the satellite system was done under an ESA contract. The authors are grateful to the technical officers at ESTEC, Dr. J. Hörle and Mr. M. Lugert, for their valuable contributions and support. Special thanks are due to Prof. W. Riedler (head of INW and IAS departments), and the Austrian Ministry of Science and Transport for the continuing support without which the project would not have been possible. The authors also wish to acknowledge the contributions by Dr. W. Gappmair (TU Graz), Prof. C.J. Adams (Rutherford-Appleton Lab and Buckingham University, UK) in network architectures and ATM, Prof. H.D. Clausen and his team at Salzburg University in novel protocols and applications.

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# Cellular radio access for broadband services: propagation results at 42 GHz

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**The European ACTS Framework 4 project "Cellular Radio Access for Broadband Services" (CRABS) has developed and demonstrated interactive, Local Multipoint Distribution Systems (LMDS) at 42 GHz. This paper describes the radiowave propagation work. It includes area coverage, availability, performance and interference issues and the development of new propagation planning procedures for millimetric LMDS.**

## Introduction

Millimetre wave radio is increasingly seen as a competitive means of delivery of broadband services to the home and businesses. In this paper these systems will be referred to as "Local Multipoint Distribution Systems" (LMDS), although there are now a plethora of acronyms describing variants of the same basic type. Compared to other delivery methods such as cable, LMDS has the advantage of rapid deployment, and is suitable for low population density areas where cable may be uneconomic. Relatively large amounts of radio spectrum have been made available around 40 GHz (in Europe) and 28 GHz (in North America and other parts of the world) for broadband services, and the demand for this spectrum is confirmed by recent (and upcoming) spectrum auctions.

Of course reliable radio delivery at any frequency is subject to the vagaries of the propagation path between the transmitter and receiver. At the higher, millimetre wave, frequencies there are new propagation issues that need to be tackled for such a service to be viable. The European ACTS Framework 4 project "Cellular Radio Access for Broadband Services" (CRABS), which ran from 1996 to 1999, developed and demonstrated interactive LMDS at 42 GHz. The work involved a number of trials in several countries and included market and user surveys, technical tests, system studies, and propagation trials and studies. This paper summarises the main results of the CRABS group responsible for carrying out propagation trials and studies. The aim of this group was to develop propagation planning procedures for the design of millimetric LMDS systems.

The work included transportable measurements of received signal parameters in a large number of locations at various LMDS sites. These provided new statistical results for coverage and interference, and validation of the propagation models being developed by the group. Long-term measurements were also made on fixed links at 42 GHz to investigate the fading and enhancement statistics of rain and anomalous propagation for coverage and interference. New

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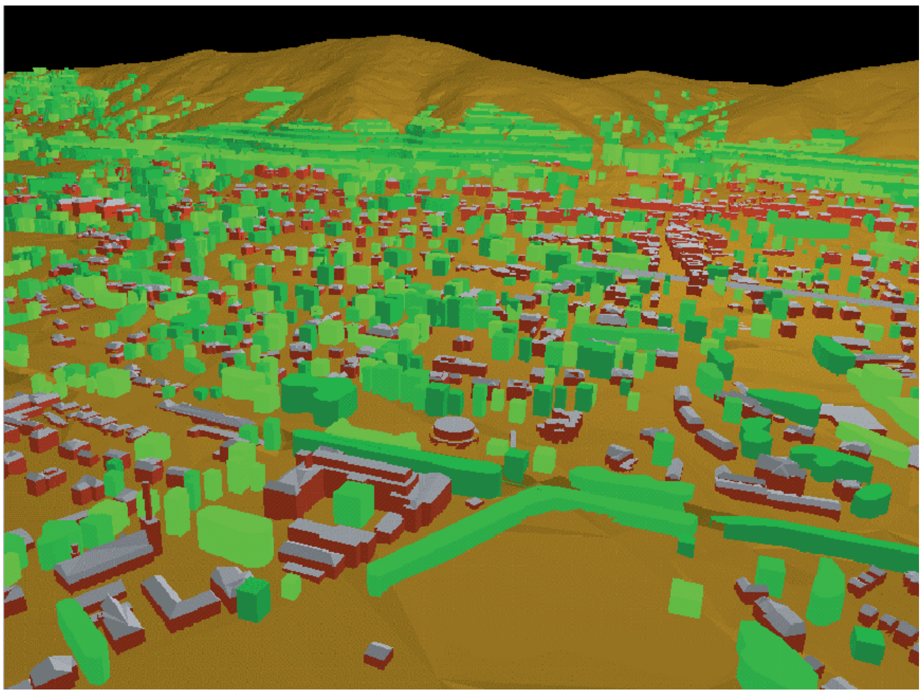


*Figure 1 An example of a 3D database showing terrain, buildings and trees*

propagation tools were developed for site-specific cell planning, as well as statistical procedures for network planning, of millimetric LMDS systems.

The results are presented in the sections below in terms of area coverage, availability, performance and interference. Further information on this work is available in the Final Reports of the CRABS project [1–4].

## Area coverage

"Area coverage" refers to the potential area (or more particularly, the number of homes, offices or other premises) covered by one or more LMDS transmitters in clear-sky, non-rainy conditions. These conditions occur for most of the time, and can be taken to represent median conditions.

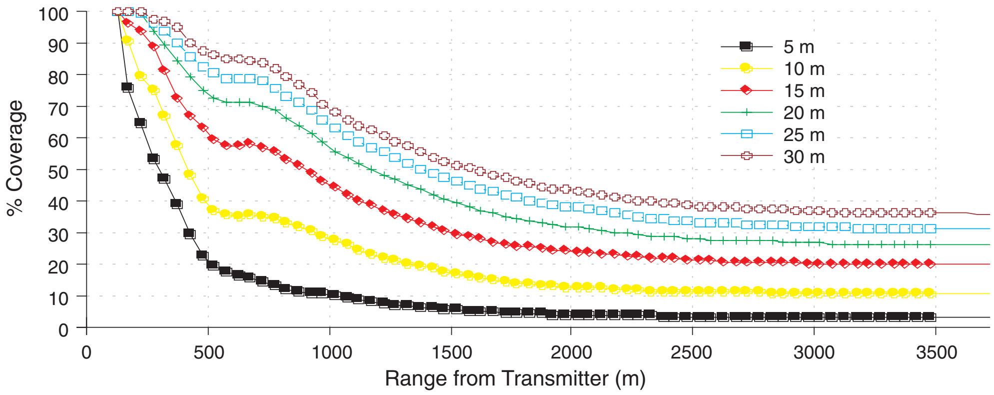



*Figure 2 Example of building coverage (Site 2) with base station antenna heights 5 – 30 m above local terrain*

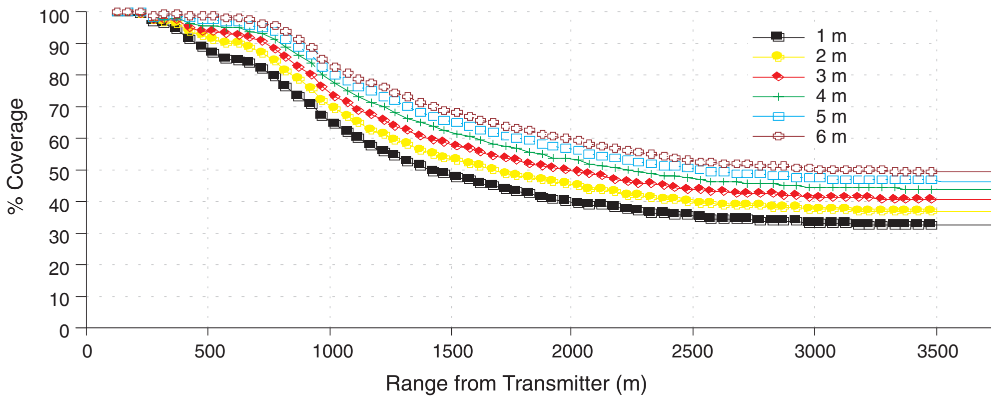



*Figure 3 Example of building coverage (Site 2) with user antenna heights 1 – 6 m above roofs (base station antenna at 30 m above local terrain)*

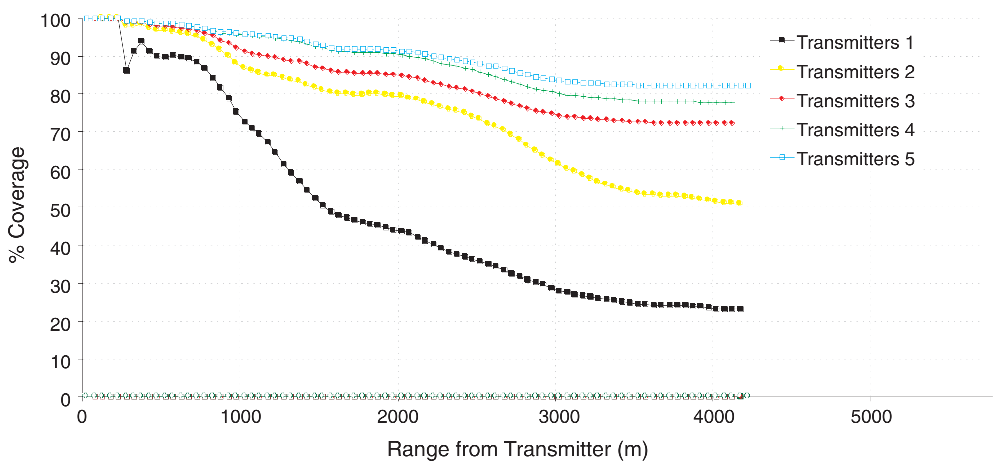



*Figure 4 Example of building coverage as a function of range from any base sation for 1, 2, 3, 4 or 5 base stations assuming all at 30 m above local terrain*

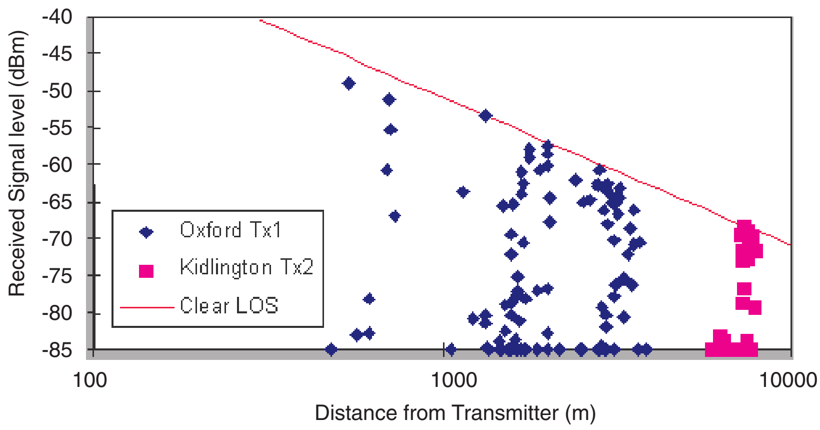



*Figure 5 Received signal strength as a function of distance from the transmitter*

heights, the advantage of multiple server diversity, and the significance of vegetation blockage.

Existing propagation models can generate maps or contours of field strength over large regions and give a good indication of trouble spots where coverage is likely to be low. However, the scale of the significant features in the data is generally topographic and accurate modelling at the high frequency chosen for the LMDS system requires finer detail than is currently available. At these frequencies, diffraction over and around buildings is minimal and line-of-sight blockage has a very high correlation with loss of service. Thus, variations in the height of an obstruction of only a few metres can have a very significant effect.

A service provider has two requirements: (a) in the network design phase, to calculate the topology of his network of transmitters in order to provide a service to a specified fraction of potential customers in an area; (b) in the deployment phase, to be able to quickly determine whether or not a particular customer can obtain a service. Both of these requirements were tackled by developing deterministic propagation tools based on high resolution clutter data and ray tracing models. Such tools can tackle the deployment requirement directly, but more importantly perhaps, they were considered the best way of investigating the "parameter space" of network design (such as coverage dependence on antenna heights or number of transmitters) and generating statistical results.

Significant advances in the numerical techniques of ray tracing using building databases were made. These have allowed very large databases to be used for coverage calculations. For example, one database covers an area of 31 km$^2$ and contains approximately 10,000 buildings (figure 1), thus representing a small franchise including several LMDS cells. The models have been used to calculate coverage (based on the level of building and vegetation blockage between the base station and the user premises) as a function of transmitter and receiver antenna heights, the advantage of multiple server diversity, and the significance of vegetation blockage.

Examples of calculations for the Malvern area of the UK are shown in figures 2, 3 and 4. Figure 2 shows that the coverage in terms of distance from the base station is gradually reduced with range taking base station antenna height above local terrain as a parameter. Clearly, the higher this antenna is, the better the coverage. An even better coverage can be achieved by raising the user's antennas above the roof (figure 3), but this may not be a practical solution. Finally, provided that many base stations can serve the same area a dramatic increase in coverage is obtained if the customers can select between two or more base stations (figure 4).

Measurements of building and vegetation effects were made in the UK, Norway and Italy. These gave direct insight into the problems of coverage and performance at 42 GHz. They also helped to validate the ray tracing models, which in turn could be used to simulate a wider range of network geometries. In the UK, measurements of received signal strength from two transmitters were made at over 130 locations, and thus were sufficient to generate statistics of the various parameters measured. When the received signal level is plotted as a function of distance from the transmitter, at any given range the level varies from free space down to the system noise level, depending on the visibility or otherwise of the particular receiver location (figure 5). This is not really a surprise, but it does rather rule out simplistic two-slope path loss models for cell planning at this frequency.

The results of these studies showed (not unexpectedly) that coverage can be very site-specific, especially if topographic features or exceptional building blockage occur near the transmitter. However, investigations at several different urban/suburban sites gave typical coverage figures of 40 – 60 % for a 2 km cell and a 30 m transmitter mast height. The coverage was observed to increase by a few percent for each metre of mast height increase. Increasing the antenna height at the user premises was more effective than raising the base station mast height (3 – 4 % per metre as compared to 1 – 2 % per metre). A cell architecture that allows receivers to select from more than a single base station provides a significant increase in coverage. For example, for 30 m transmitter masts, the coverage in a 2 km cell increased from 44 % for a single base station to 80 % for 2 stations and 90 % for 4 stations (figure 4), even though the base stations had not been specially selected to have good visibility individually.

A new empirical model for building clutter was also derived from these results [5]. It is designed to provide a fast estimation of area coverage based on limited statistical information of the building densities and heights. It also allows more extensive simulations of server diversity and interference to be made than can be done by a direct application of the numerically intensive raytracing model.

Blockage by trees is very site dependent and varies in different parts of Europe. About 10 – 20 % of buildings were found to be obstructed by trees in two UK towns. A new model for signal loss through trees as a function of vegetation depth was developed and validated by an extensive set of measurements (both existing measurements at a range of millimetric frequencies, and new measurements of various tree types made in Norway at 40 GHz). Tree attenuation is severe at 40 GHz. The attenuation rate depends on tree type, moisture content and path geometry, but a rate of 4 – 5 dB per metre of vegetation depth can be used as a guide (although the attenuation does saturate at some value, typically 20 – 40 dB).

## Availability

Once it has been established that a user has an unobstructed line-of-sight to the base station with an adequate free space system margin, it is then necessary to calculate the percentage of the time that the service will be (un)available as a result of atmospheric degradations. The presence of rain, snow, or sleet on the path between the user and the base station can cause a service outage. These effects determine the upper limit for a cell size that can be contemplated for a given availability of service. Rain attenuation increases rapidly with path length, and maximum path lengths of 2 – 5 km are typical for the service availabilities considered for LMDS services (99 % to 99.99 %). The rain attenuation at a given time percentage also depends strongly on climate, and for example can be a factor of 3 greater for southern Europe than for northern Europe.

Figure 6 shows the rainfall rate not exceeded at 0.01 % of an average year across Europe using the latest revision of the ITU-R recommendation [6]. The plot is interpolated based on the 1.5 by 1.5 degrees tabulated numbers. Using these data for horizontally polarised links at 42 GHz, the attenuation for a given path length can be predicted for time percentages ranging from 0.001 to 1 of an average year or an average worst month [7]. Or, having a given margin available for rain attentuation the path lengths can be predicted. For edge-fed cells that path length becomes the cell size. The prediction shown in figure 7 is the maximum cell size where service can be provided up to 99.99 % of an average year given 15 dB rain attenuation margin. In the prediction a lower limit of 10 mm/h rainfall rate was used. Similarly, figure 8 gives the result for 99.9 % of the time. If another margin than 15 dB is used, figure 9 shows multiplication factors (or relative path length) for rainfall rates ranging from 10 to 80 % and 99.99 % and 99.9 % of the time, in a) and b) respectively. These factors can be used to estimate cell sizes with other rain attentuation margins than given in figures 7 and 8 for climates indicated in figure 6.

Measurements of signal level at 42 GHz were made on fixed links in Norway and the UK for more than a year and statistics of fading derived.

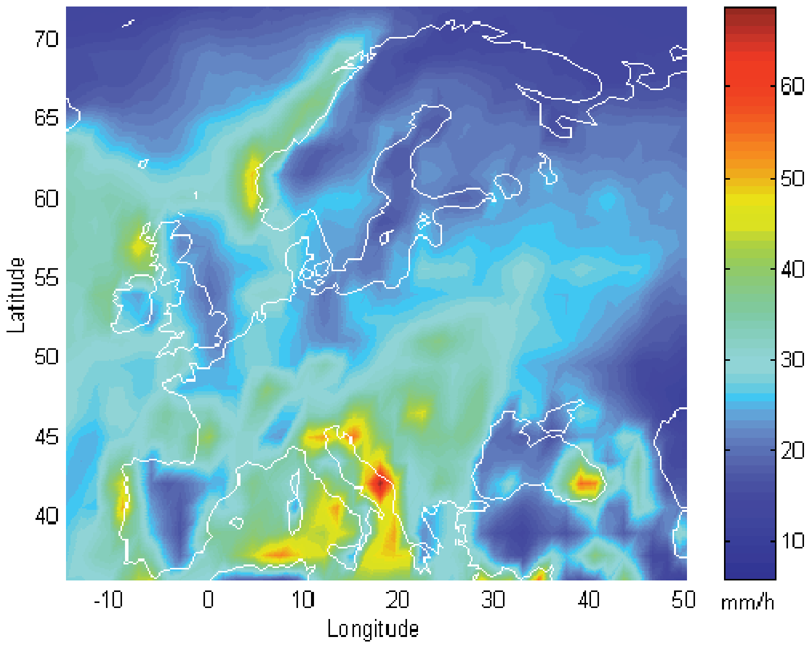



*Figure 6 Rainfall rate not exceeded for 0.01 % of an average year*

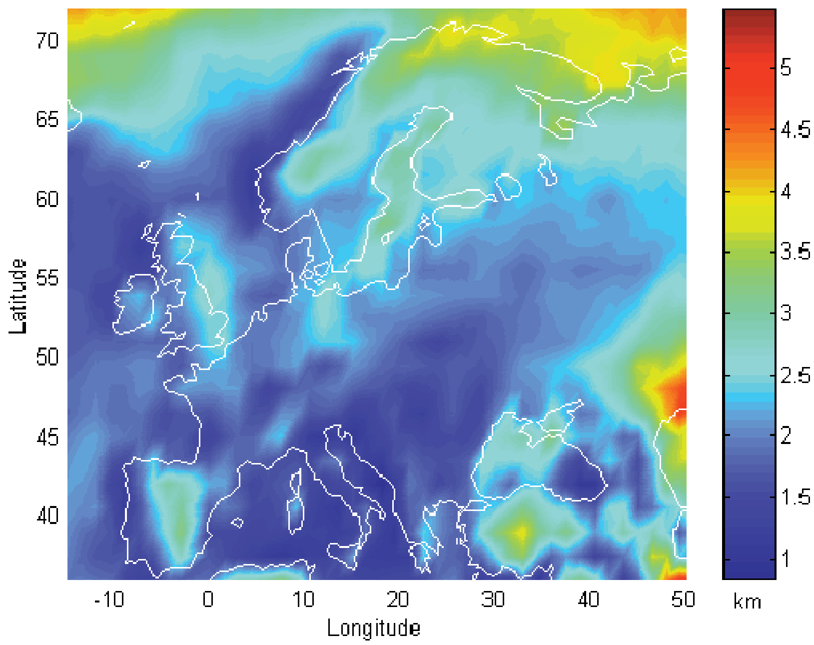



*Figure 7 Possible cell size (edge-fed) with 15 dB excess rain attenuation margin for 99.99 % availability*

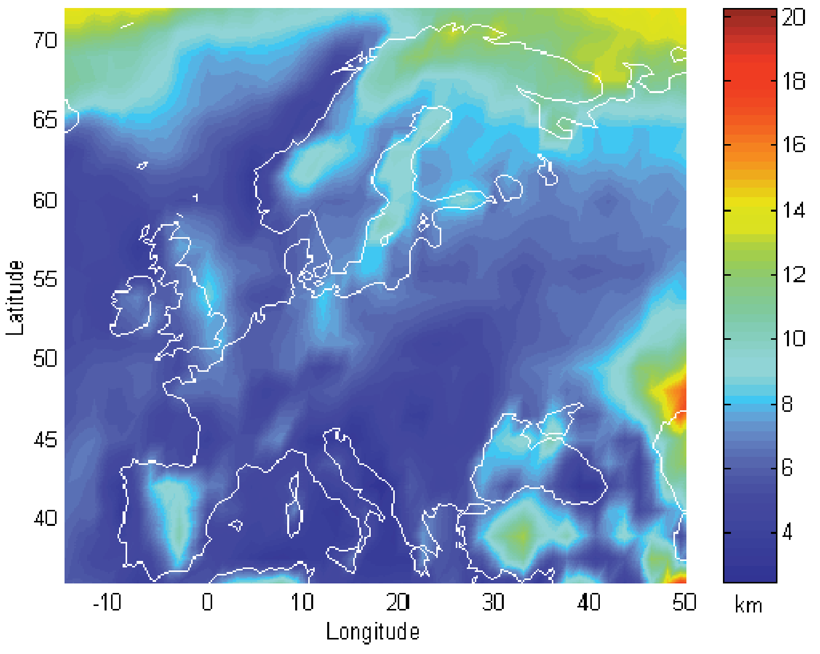



*Figure 8 Possible cell size (edge-fed) with 15 dB excess rain attenuation margin for 99.9 % availability*

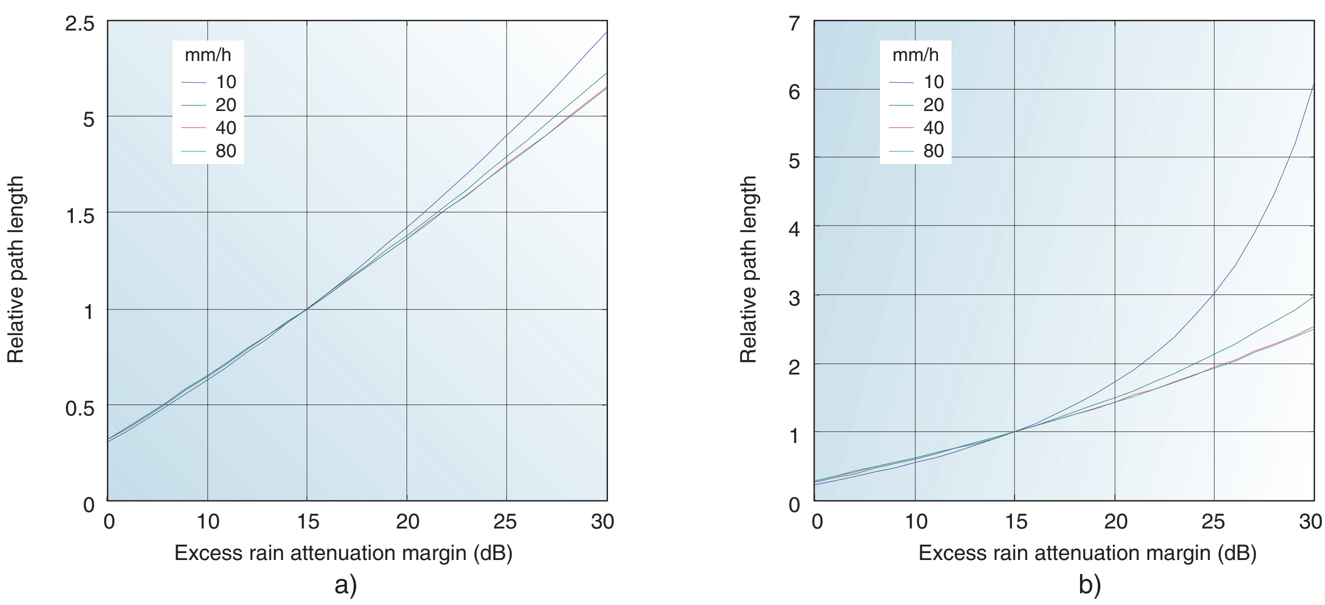
In Norway, the paths were configured as a 6-link star-network, figure 10, with path lengths ranging from 0.5 – 5.6 km. The measured statistics, see figure 11, from 99 % to 99.999 % for these point-to-point paths agreed with the predictions of the methods given in ITU-R Recommendation P.530 [7]. However, account had to be taken of the fact that the year of operation was drier than average, see figure 12, and the model calculations were therefore based on the measured rainfall statistics; the attenuations were less than would be deduced from the ITU-R rain climate model.

Very significant fading events (tens of decibels) were observed in Norway, caused by wet snow and sleet. Much of this attenuation was due to the wet snow packing the antenna, rather than an atmospheric effect. Both the measurements and modelling confirm that these deep fades are real and that snow and ice cannot be ignored in the design of links in northern climates. Protection against these is clearly required.

A great deal of new work was done on the effects of the spatial distribution of rain. This is important for (a) calculating the benefits of server diversity as a countermeasure to rain fading, and (b) calculating the statistics of instantaneous area coverage within a cell when a rain event is taking place. Data from the star-network of 40 GHz links in Norway gave statistics of diversity improvement for a realistic network. These compared well with path angle diversity improvement and gain results derived from rain radar measurements of the three-dimensional spatial structure of rain in the UK. For example, a non-diversity service offering 99.9 % availability (corresponding to a 15 dB fade depth) could obtain the same availability with 4 dB less margin, or alternatively increase availability to 99.97 % for the same fade margin, with two-way diversity on a path length of 4 km (figure 13). These significant diversity gains will be most beneficial for users requiring very high availability or very high data rates.

Before this work began, there was no model for calculating the availability of rain-limited area coverage, since existing broadcast services are at much lower frequencies where the effect of rain is of little significance. However, there is a need to distinguish the availability of a service to a particular user, and the availability of a given number of (unspecified) users in a service area; the latter is relevant to considerations of data loading and efficiency in a network. A completely new approach to the definition and calculation of area coverage in the presence of rain has been proposed for use at 40 GHz [3]. The

*Figure 9 Relative path length at rainfall rates given in the legend and at availability of a) 99.99 % and b) 99.9 %*



method resulted from a combination of simulations based on analytical rain shower models and analysis of the spatial distribution of rain cells from rain radar data. The only previously existing method is the point-to-point reduction method of the ITU-R, and this was shown to significantly underestimate the coverage available at a given availability level, if extrapolated to area coverage predictions.

Calculations of the effects of atmospheric gases, fog and scintillation on availability confirmed that these mechanisms, while not negligible, are of secondary importance at 40 GHz, resulting in no more than a few decibels of attenuation on path lengths of interest. The existing ITU-R method for fading by atmospheric multipath predicts fading as deep as 10 dB for 0.1 % of the time and 20 dB for 0.01 % of the time, on a 5 km path at 40 GHz. However, these figures should be considered conservative: the ITU model is based on lower frequency paths, all of which are longer than 7 km. Multipath activity is likely to be less on short, cluttered paths in an urban environment. More work is required in this area.

## Performance

Even when a user is in the coverage area of a server, and the service is not unavailable due to one of the causes given above, it is still necessary to consider the performance of the service. The performance depends on system parameters as well as propagation factors. The effects of vegetation dynamics and building and terrain multipath on the propagation channel have been considered.

A user may be located in a location where one or more trees encroach on the path between the receiver and the server. Even if the average attenuation is not severe enough to prevent an adequate system margin, the movement of the tree(s) in the wind causes very significant time variability of the propagation channel, with deep nulls. Measurements on various tree types in Norway and the UK showed the occurrence of fades of tens of decibels with duration from 10 ms to 1 second. Although the deep fading is intrinsically caused by phase cancellations due to multiple scatter, the frequency selectivity is believed to be small (ie. it will appear to be flat) across a 34 MHz channel. This was confirmed by (a) simultaneous measurements of fade depth and MPEG picture quality showing that the picture only failed when the signal dropped below the (flat fade) system margin (figure 14), and (b) filterbank measurements at IF which confirmed that the rapid time variability seen in the broadband channel was also seen in each of the narrowband filter channels.

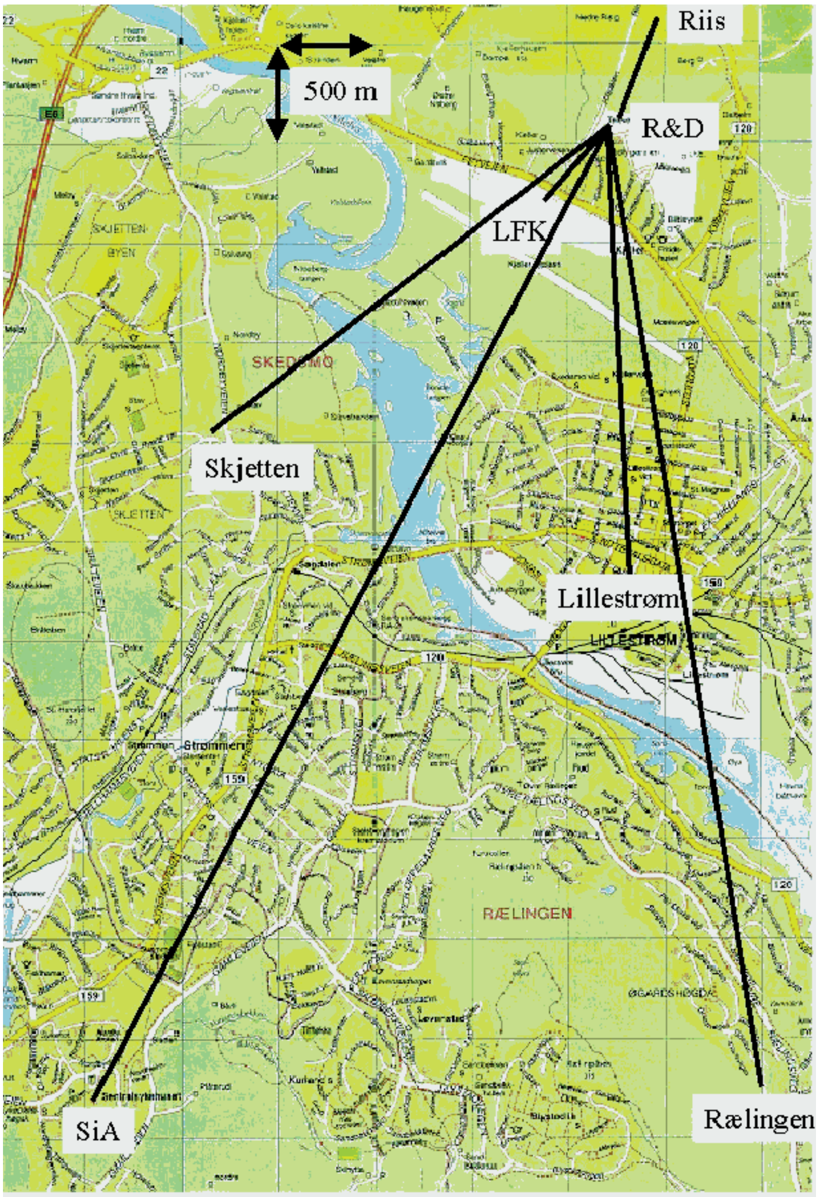
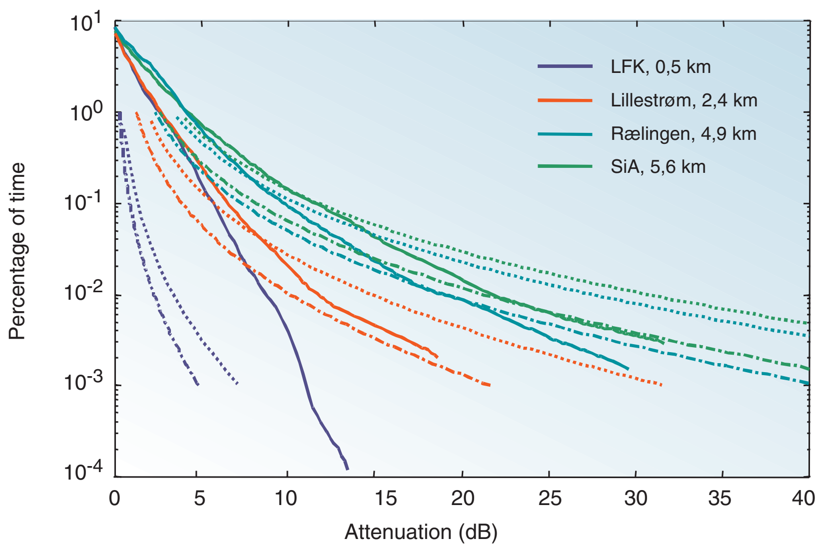



*Figure 10 Links in the star-like network in Lillestrøm*

*Figure 11 Attenuation distribution due to rain in the period October 1997 through September 1998*



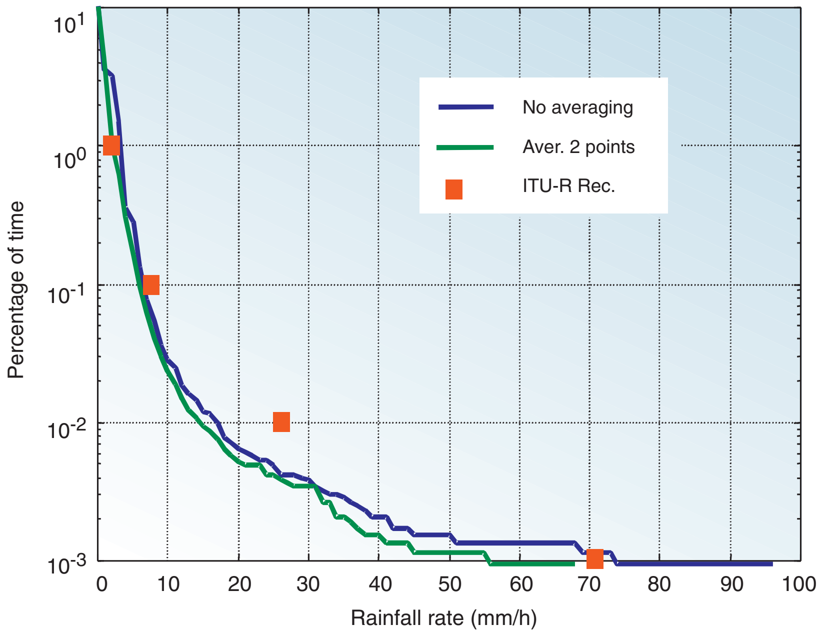



*Figure 12 Rainfall rate distribution in the Kjeller area in the period October 1997 through September 1998*

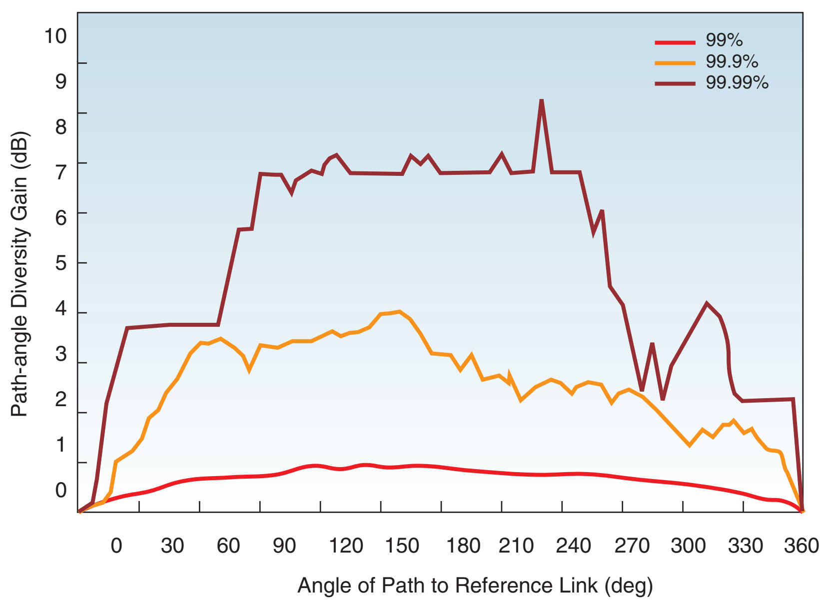
*Figure 13 Site diversity gain for a 4 km path length at 42 GHz for 3 levels of availability*

Building reflections and multipath were extensively studied by measurement, ray trace simulation, and heuristics. In the UK field measurements, azimuth (360°) and elevation (6°) scans were made at each receiver location, on both vertical and horizontal polarisation, with a narrow beamwidth (3°) antenna to identify the directions of reflected signals. One of the two transmitters was modulated with a frequency sweep to enable the channel dispersion to be measured.

From the frequency-sweep measurements, it was determined that multipath is not a major problem when a line-of-sight path exists between the transmitter and receiver. When an adequate line-of-sight signal was available to provide a service, the ripple across a 100 MHz channel was generally small. It was less than 6 dB for 95 % of locations and less than 3 dB for 50 % of locations. Much of the 'ripple' is in any case believed to be due to time variability during a channel scan (which took 2 seconds) caused by scintillation and vegetation movement, rather than due to multipath. The predicted rms delay spread values are tiny (an average of 0.01 ns in Oxford), corresponding to a coherence bandwidth of 15 GHz. This will be of no consequence for a service at 40 GHz. The relative unimportance of multipath is due to the very small receiver antenna beamwidth (3°) which effectively isolates the receiver from ground or building reflections.

The intrinsic levels of the reflected signals (such as would be measured by an omni-directional antenna) are shown in figure 15, where the azimuth scans at all receiver locations have been overlaid, and the results normalised to the line-of-sight signal on boresight. The majority of significant signals come from the expected line-of-sight direction (0°), but there are also several significant reflected signals at other incident angles. It may appear from figure 15 that reflections could be used for coverage fill-in when the direct line-of-sight is blocked. However, the measurements given in figure 16 showed that very significant ripple can occur across the signal channel for reflected signals (compared with the flat channel observed for line-of-sight paths), and the use of reflected signals for coverage fill-in cannot be recommended.

Depolarisation by building reflections and scatter is relatively unimportant. The cross-polar discrimination did fall below 10 dB for about 20 % of receiver locations, figure 17. However, this figure was obtained by looking at reflected signals received from *all* directions, and not just those received within the (narrow) antenna beamwidth. Bearing in mind that the 'wanted' server was used as the source of these cross-polar 'interference' signals and therefore experiences less path loss than a signal from a genuine interferer, and also that the latter is more likely to suffer blockage, it will be seen that the occurrence of interference from depolarised, reflected, interfering signals will be negligible.




## Interference

When planning a network of cells, the effects of interference must be considered. Indeed interference determines the frequency allocation plan, and hence the efficiency of spectrum usage. Short-range interference (for example within a single cell) where a line-of-sight potentially exists between users is largely a matter of geometry (antenna beamwidths and path orientation). Long-range interference (between cells or fran-

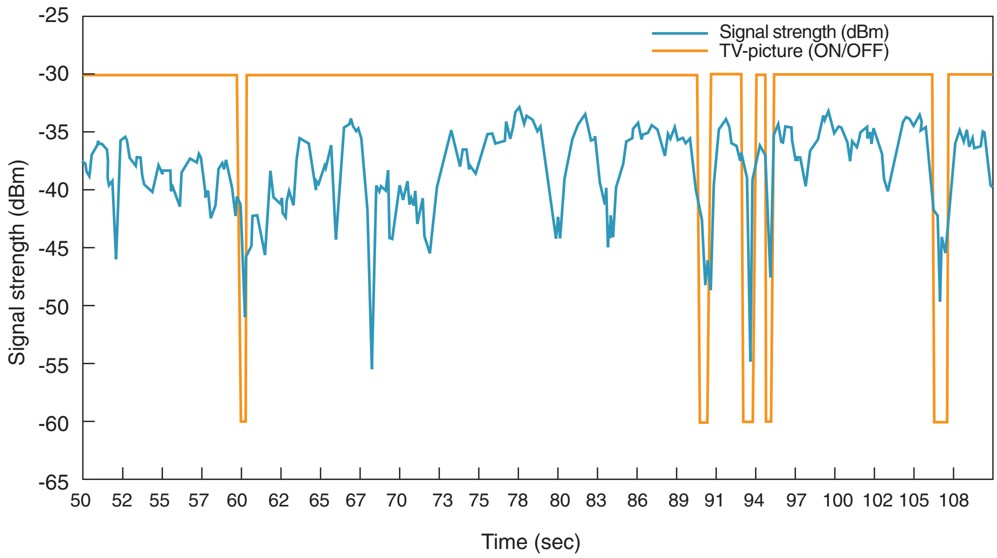



*Figure 14 Comparison of measured signal strength through a tree and availability of digital TV picture*

chises) depends on issues such as terrain and building blockage, and on enhancements to signal levels caused by multipath and ducting.

Two new tools for estimating coverage and interference for a cell network have been developed [3]. One uses a terrain database and a statistical clutter model, together with meteorological information, base station locations and system parameters to calculate and display carrier to noise or interference ratios and coverage for the downlink. The other uses simplified propagation models to rapidly generate statistics of users and interferers on the uplinks back to the hub.

As is the case for multipath, the very narrow antenna beamwidths (3°) in use at the user premises mitigate against the likelihood of interference. From the propagation point of view, it appears that single frequency re-use in adjacent cells is quite possible. To do this, between 5 and 20 % (depending on the clutter blockage model assumed) of the spectrum would need to be reserved to deal with interference geometries as they arise.

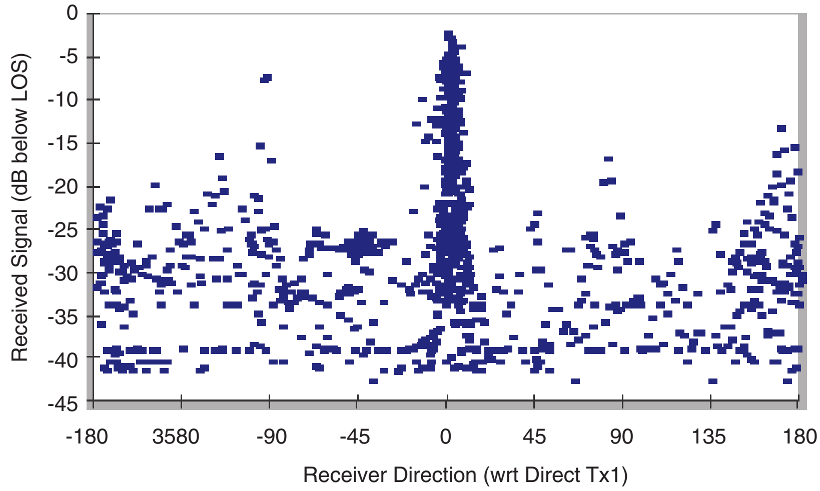



*Figure 15 Distribution of incoming signals*

The service of users near the edge of cell coverage could be disrupted by enhanced interference from base stations that are normally well beyond the line-of-sight. Calculations based on existing ITU-R procedures [7], for example, show that the signal from a cell 30 km away will be enhanced for 0.1 % of the time by between 9 and 12 dB, depending on geographical climate. Mea-

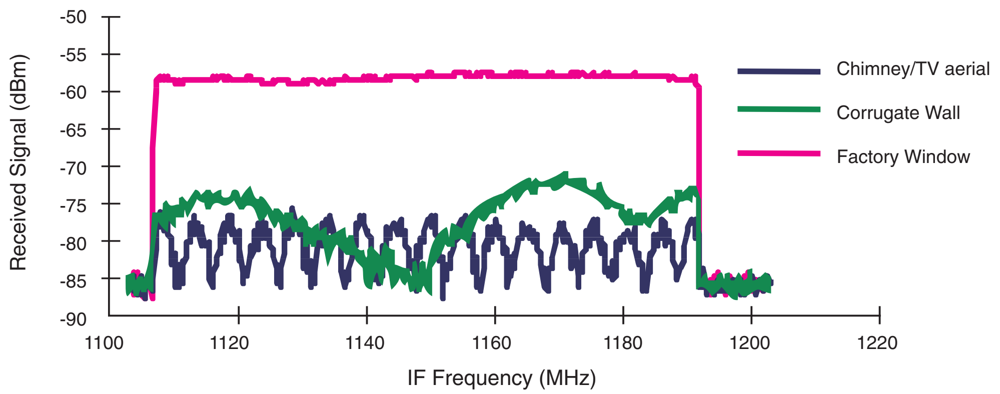



*Figure 16 Frequency response for measured reflections at 3 different locations*

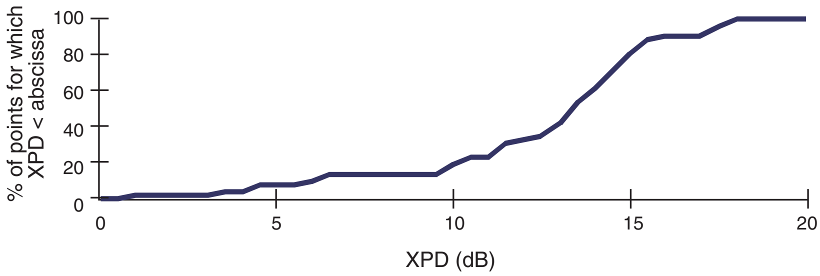



*Figure 17 Distribution of the XPD as percentage of locations for which co-polar signal is greater than noise + antenna XPD for all incoming directions*

surements on a 27 km transhorizon path for a year have shown reasonable agreement with the ITU-R Recommendation P.452 [8] at 42 GHz. However, simultaneous measurements at 10 GHz suggested that the clear-air component of the procedure (which has not been tested at this frequency, or for similar path geometries), needs to be investigated further.

## Conclusions

The propagation studies carried out within the framework of the CRABS project have made a significant contribution to the design of LMDS networks at millimetre wave frequencies. The work has confirmed the viability of such systems, although care is needed in the system design, and countermeasures against propagation effects may be necessary for high availability services.

A new Recommendation on "Propagation data and prediction methods required for the design of terrestrial broadcasting millimetric radio access systems operating in a frequency range of about 20 – 50 GHz" was submitted to the International Telecommunication Union Study Group 3 meeting in March 1999 and adopted later the same year. It is now an "in-force" ITU-R Recommendation [9].

Future work will include extension of the coverage models to a wider range of building types (for example, urban and high-rise) and further measurements in support of these studies; development of rainfall area availability statistics for more climatic regions; and further measurement of the levels and time-variability of clear-air interference and vegetation attenuation. It is also proposed to study possible countermeasures, such as diversity, that could significantly improve the coverage, availability and performance of millimetric LMDS.

## Acknowledgements

The authors wish to thank all their colleagues who have contributed to the success of the propagation trials and studies described here. Thanks are also due to members of the CRABS consortium for providing stimulating interaction and useful feedback on the propagation work. The first author also acknowledges financial support from the Radiocommunications Agency in the UK as part of the National Radio Propagation Programme.

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# Virtual classroom using interactive broadband radio access at 40 GHz


FILOMENA PAPA, SANDRA SPEDALETTI, STEFANO TEODORI AND VITTORIO DEL DUCE



**The present paper is related to virtual classroom situations realised using interactive multimedia systems. In particular the user aspects are discussed from the point of view of the human factors discipline. The investigation in progress in the CRABS (Cellular Radio Access for Broadband Services) project of the EU Acts Programme is described. Some results of the first phase (a laboratory experiment) are presented. These results include some tools to maximise the usability of multimedia systems by teachers and learners: procedures for training teachers and learners in interacting with the multimedia system, some indications for designers related to the multimedia system configuration. These practical results were employed in a field investigation using broadband radio systems.**



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## 1 The virtual classroom using interactive broadband systems

Cellular radio access for broadband interactive services gives some advantages over cable access like lower realisation cost and the possibility to provide interactive service access for geographical areas (eg. rural) in which cable infrastructures are limited. However, the quality of the transmission provided by the radio channel is not constant due to climate, terrain and interference constraints. In developing such kinds of systems it is very important to carry out trials involving users of different application fields of interactive services, in order to improve service acceptance by users.

Tele-education is one of the most promising applications of broadband communication technologies. In particular this kind of technology gives the opportunity to realise technologically advanced and interactive virtual classroom situations in which spatially distributed people (users) are involved in a learning/teaching real-time process using multimedia systems. These systems, obtained by the integration of video communication with personal computer facilities, allow:

- The real-time communication between a number of remote locations using different media to present information: speech, music, text, drawings, still images, full motion images, etc. This allows multimedia communication between the teacher and the learners as well as among the learners;
- The utilisation by the teacher of the multimedia chair providing the facilities to handle educational aids, eg. slides, transparencies, video recorded materials, computer based training tools, etc.

At the moment there is evidence that the availability of multimedia systems does not automatically ensure their actual use in distance learning. Some investigations (Abbolito, Papa & Spedaletti 1995; Riel 1994) have demonstrated that the main barriers to the diffusion of tele-education are related to difficulties of interaction between users and technologies and to teachers' and learners' reluctance to change traditional educational methods.

In dealing with these problems a very useful contribution is provided by the human factors discipline.

The key concept of the human factors discipline is the usability evaluation. Usability is a very broad concept which is related to the equipment's ease of use, to the effective use, and to user satisfaction in relation to the system.

One of the tools made available by the human factors discipline is the so-called *emulation approach* (Orlando, 1992). This approach takes into account the user needs at the first stages of the design process of a new telecommunication system/service with the main aim to maximise system usability and service diffusion. The emulation approach is realised by laboratory experiments. In the case of tele-education applications it allows:

- Presentation of the principal features of a new distance learning situation using a flexible hardware and software system;
- Evaluation of the usability of the system and the effectiveness of this new distance learning situation, involving a sample of potential users (eg. teachers and students);
- And, of course, separation of what is complex in real life into more simple variables that can be experimentally manipulated to better understand their singular and composite contributions.

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In this way it is possible to test different system configurations in order to select the best system functions and features, saving a lot of time and money in building prototypes and in setting up pilot experiments in the field.

## 2 The virtual classroom investigation in the CRABS project

As stated above in order to investigate human factors aspects in virtual classroom situations realised by use of cellular broadband systems a co-operation investigation was developed between RAI and Fondazione Ugo Bordoni (FUB) in the CRABS Project.

The general objective of the investigation was to experiment virtual classroom situations realised by cellular broadband systems. The main aims may be summarised as follows:

- To evaluate usability aspects of the multimedia tele-education system in terms of ease of use, learning climate, telepresence, user satisfaction;
- To evaluate learner performance in virtual classroom situations realised by cellular broadband systems;
- To identify a multimedia system configuration in order to maximise usability by teachers and learners;
- To identify the most adequate features of the multimedia chair;
- To identify adequate procedures for training teachers and learners in utilisation of the virtual classroom equipment.

The investigation was developed into two main phases:

*Phase 1*. Laboratory experiments were realised in order to prepare the phase 2 field trial, emulating a broadband system in the human factors laboratory and involving a sample of potential users. The main aim of the laboratory experiments was to identify:

- A system configuration for maximising system usability by learners and teachers;
- A procedure for training teachers in interacting with the multimedia system and in delivering a lesson in the virtual classroom;
- A procedure for training learners in interaction with the system.

In this way it was possible to identify the main requirements of a multimedia system configuration and the procedures for training learners and teachers. Such operational results were of fundamental importance in successfully setting up the field trials.

*Phase 2*. A field trial is set up using cellular broadband systems made available by RAI. The main aim of the trials was to evaluate system usability for learners and teachers, and to evaluate learner performance taking into account the constraints of the telecommunication system.

## 3 Phase 1: the laboratory experiment

In the first phase, a laboratory experiment was carried out in the Human Factors Laboratory at Fondazione Ugo Bordoni using the emulation approach. In this experiment subjects participated in six experimental sessions of tele-education. A multimedia system was implemented to allow the interaction between learners and teacher and among learners.

### Objective

The main objective of the experiment was to compare the usability of two multimedia system configurations differing by rate of the interactivity allowed for learners. In fact, the two configurations of the system were different with regard to the equipment used by the learners.

Moreover, the effectiveness of the tele-education was tested comparing the learning performance for the two configurations.

### Method

#### Apparatus

A virtual classroom environment using the broadband network was emulated in the laboratory. The laboratory is composed of contiguous rooms (a principal room and three smaller rooms A, B and C). Each room emulates a remote location and contains the equipment for multimedia communication (cameras, monitors, keyboard, printer, video recorder, microphones and loudspeakers) (Gnisci, Papa & Spedaletti, 1997).

#### Experimental conditions

Two experimental conditions were compared.

*Condition A:*
The multimedia system allows:

- Video and audio real-time communication between teacher and learners and among learners;
- Use of a multimedia chair.

*Condition B:*
In this condition, the main features of the system configuration were the same. Moreover, the system allowed:

- The learners to use a camera for documents and objects;
- Everybody (teacher and learners) to use shared whiteboard on the computer.

### Measures
The following measures were included in the usability questionnaire:

*Some background information.* These included information about: gender, age, education, present job and previous experience with the personal computer.

*Learning climate.* The learning climate has been defined as the perception (by the learners) of the interpersonal relationships between the teacher and the learners, and also the relationships among the learners themselves (Rogers, 1969). Four items were used; subjects answered using a 5-point scale (scores from 0 to 4). The items refer to friendliness, cooperation, promoting learning climate and participation.

*Conversation*. The used measures refer to different aspects of the conversation (Sellen, 1995). Nine items were used; the learners were asked to indicate their answers on a 7-point scale (scores from 0 to 6); scores ranging from "strongly disagree" to "strongly agree".

*System helpfulness*. The used measures refer to the evaluation of how much the tele-education system has been helpful to participate in the lesson (to enquire, to ask, to make the observations, to give personal contribution, etc.) and to perform the practical activity. Six items were used, the first item refers to participation in the lesson, the other five items refer to performance of the practical activity; subjects answered using a 5-point scale (scores from 0 to 4); scores ranging from "helpful" to "hindering".

*Learning self-evaluation*. The used measures refer to three different aspects: self-evaluation of learning, evaluation of available resources for learning and evaluation of the learners' contribution. The first aspect was measured by an item administered to evaluate subjects' self-perception of learning. It is a closed-end question with 10 possible answers ranging from 10 % to 100 %. The resources available for the learners included six 5-point items. Learners contribution was evaluated by three 5-point items.

*Aspects related to telepresence*. The used measures refer to some aspects of the system that are expected to be related to a sensation of shared presence (ie. telepresence; Muehlbach et al., 1993): visual contact and image reproduction quality. Eleven items were used; subjects answered using a 5-point scale (scores from 0 to 4); scores ranging from "very bad" to "very good".

*Ease of use*. A scale constructed by Davis (1989) was adapted. The scale included three items; subjects used a 5-point scale (scores from 0 to 4) to answer the questions. A reverse format was preferred for item 2 to avoid response set biases.

*Learners' training evaluation*. Learners' training was evaluated by three items concerning clarity, exhaustiveness and recall of the instructions; subjects used a 5-point scale (scores from 0 to 4).

*System functions evaluation*. Only the subjects of condition B were asked to evaluate the usefulness and the ease of use of the functions of the tele-education system (camera, shared whiteboard and video switching) that distinguished condition B from condition A. Six items were administered; subjects used a 5-point scale (scores from 0 to 4).

*User satisfaction*. Seven semantic differential scales were adapted from the QUIS (the Questionnaire of User Interaction Satisfaction, 1989–1993) to evaluate user satisfaction. Subjects answered using a 7-point scale.

### Experimental design
An independent group's experimental design (Cook & Campbell, 1974) was adopted. Each subject evaluated the usability aspects of only one of the experimental conditions (A or B). From the total number of subjects involved in the experiment (36 subjects), two groups of subjects were selected: the first group (18 subjects) evaluated condition A, the second (18 subjects) evaluated condition B.

In both experimental conditions a repeated measures design was adopted to evaluate learner performance during the lesson. In this kind of experimental design the subjects complete a learner performance test before and after the lesson (pre-test and post-test).

### Experimental sessions
A small group of six learners was involved in each experimental session; the teacher (a woman in this experiment) was located in the principal room and the learners were placed in experimental rooms A, B and C (2 learners in each room).

### Subjects

An adequate procedure was established to select the necessary subjects.

Subjects were selected taking into account their previous experience in the use of the computer and their attitude towards the co-operation, the computer and towards the course.

A sample of RAI employees (N = 36, 15 males and 21 females) took part in the experiment. The age of the subjects ranged from 25 to 51 (mean age = 36). All subjects were graduates (32 high school and 4 university).

### Experimental task

In both conditions the experimental task was the same. For each session the teacher gave the same lesson (duration approximately one hour). This was an introductory lesson to a "Windows Workstation" course. The lesson regarded the basic information on a personal computer. For each topic of the lesson the learners were asked to perform a practical exercise; in each experimental condition the learners used different technologies to perform this practical exercise.

### Data collection

Data about learner performance were collected by the same test administered before and after the lesson. Data about system usability were collected through a questionnaire handed out to learners at the end of the session. Non-participant observation and video recording were used to collect qualitative data on user behaviour during the experimental sessions. Finally, other qualitative data come from an interview with the teacher.

### Preparation of the experiment

The preparation phase included the following main steps:

- The teacher who participated in the experiment was previously trained to use the multimedia system: the communication system and the multimedia chair.
- The most adequate multimedia system configuration was identified in cooperation with the teacher.
- A preliminary experimental session involving a reduced number of subjects (6 subjects) was performed.

### Experimental procedure

An adequate procedure was adopted for all six experimental sessions using a standardised protocol of interaction between researchers and subjects.

### Data analysis

Besides the basic descriptive analyses on all the data to get a general picture, the Analysis of Variance (ANOVA) was used to compare the two experimental conditions. Cronbach's Alpha was used as a measure of the reliability of the adopted scales.

All statistical processing was performed by the Statistical Package for Social Science (SPSS).

## 4 Results of the laboratory experiment

### Usability and learner performance evaluation

The main purpose of this study was to compare the effects on the users of two multimedia system configurations that provide different degrees of interactivity but allow the same task-related goals. In table 1 are shown the results related to the usability aspects. A One Way ANOVA was performed to identify differences between conditions A and B.

The first column reports the aspects measured by the experiment on which we performed the analyses; the second and third columns report the mean values of the associated aspects (with the standard deviation in brackets), respectively in conditions A and B; in the fourth and fifth column three statistical indexes related to the differences between conditions A and B are provided: Fisher's F, its degrees of freedom (df) and its associated probability (p).

In general, Cronbach's $\alpha$ of the used scales ranges between .76 and .87. With regard to conversation we calculated the reliability of the scale proposed by Sellen (1995); this is very low. For this reason we performed a factorial analysis that allows identification of the possible factors that the scale consists of. Two factors were identified. Factor 1 can be viewed as a factor revealing self-expression and other subjects' participation in the group, a *socio-emotional factor*; while factor 2 reveals the perception of the behavioural development of conversation in terms of naturalness, spontaneity, fluidity (*structural* factor).

In summary, the results of table 1 show that no significant difference was found in the learning climate, in the two factors of conversation, in the helpfulness of the tele-education system, in the telepresence, in user satisfaction, in the instructions provided for the equipment use between conditions A and B. Moreover, the subjects' evaluation of all these aspects was highly favourable in both conditions.

| | MEAN VALUE (S.D.) | | ANOVA | |
|---|---|---|---|---|
| | Condition A | Condition B | F (df) | p |
| Learning climate | 3.51 **a** (.68) | 3.44 **a** (.58) | .11 (1) | .74 |
| Socio-emotional factor of conversation | 5.22 **b** (.80) | 4.86 **b** (1.20) | 1.14 (1) | .29 |
| Structural factor of conversation | 4.82 **b** (1.40) | 4.89 **b** (1.20) | .03 (1) | .87 |
| Helpfulness of tele-education system in general | 3.56 **a** (.78) | 3.78 **a** (.54) | .97 (1) | .33 |
| Tele-presence | 3.39 **a** (.78) | 3.11 **a** (.83) | 1.07 (1) | .31 |
| Ease of use | 3.52 **a** (.46) | 3.31 **a** (.62) | 1.26 (1) | .27 |
| User satisfaction | 3.55 **a** (.34) | 3.43 **a** (.46) | .90 (1) | .35 |
| Clarity of instructions | 3.89 **a** (.32) | 3.56 **a** (.70) | 3.32 (1) | .08 |
| Exhaustiveness of instructions | 3.72 **a** (.46) | 3.44 **a** (.70) | 1.96 (1) | .17 |

**a** is a 5-point scale (0-4) **b** is a 7-point scale (0-6)

*Table 1 Comparison between condition A and B (Mean Values, Standard Deviations and ANOVA)*

Another aspect evaluated in the experiment was learner performance. As a general picture, the virtual classroom lesson delivered in this experiment improves correctness in the learners' answers to the performance test in both condition A and condition B, and thus promotes and facilitates learning. Still, although both configurations enable the users to learn, our analyses show that the increase of users' learning performance in the less interactive condition is better than in the more interactive configuration (Gnisci, Papa & Spedaletti, 1999).

## 5 Discussion of results

One of the main results of the experiment is the surprisingly high subject evaluation of the multimedia system in both configurations – irrespective of the degree of interactivity provided by the different configurations. This means that in the virtual classroom, when the users are provided with the same possibilities to accomplish the task-related goals and to realise the same interaction functions, improving the technological equipment available to the learner (ie. interactivity) leaves the usability and the socio-relational context aspects almost unchanged, but decreases the learning performance. Hence, usability and socio-relational context factors being equal, the less interactive configuration is preferable as it requires less technological and training resources. In the virtual classroom, when faced with different degrees of interactivity allowed by the multimedia system, it seems that the common saying "less is more" is perfectly appropriate.

Of course, this finding is related to the kind of learning task considered in this experiment (a lesson including explanations by the teacher and related practical exercises by the learners). More complex configurations will be needed when more complex tasks require additional functions (eg. groupware to allow learners to share documents and applications) not permitted by the simplest configuration considered in the present experiment.

The positive results related to usability and learner performance presented above should be explained considering:

- Some features of *both* the multimedia system configurations;

- The procedures adopted for training teachers and learners in equipment use, which are the same in both conditions.

These aspects are considered in the following.

### Features of multimedia system configuration

As far as our results show, the benefits of the proposed multimedia system are strongly based on its multiple features of usability, on the generally satisfactory climate that it contributes to create, and on the exchanges that mediated conversation permits, as well as the possibilities for learners to get an educational result. These experimental findings suggest that we have identified and validated an effective multimedia system for virtual classroom. The main features of this system, shared by both the experimented configurations, can be summarised as follows:
a) audio continuous presence, ie. all participants are continuously audible during a session;
b) video continuous presence for the teacher, i.e. all learners are continuously visible by the teacher in order to have a visual feedback;
c) "self view", ie. each participant can see

his/her own image; d) different multimedia educational support utilised by the teacher (eg. a camera for documents and objects, telepointing and teledrawing facilities, a "tilting" camera, groupware systems); e) an adequate procedure to switch video signals for presentation to learners.

The results of the experiment suggest that the multimedia system to be used in the virtual classroom should satisfy the previous basic requirements. These requirements suggest useful guidelines for designers of multimedia systems to be utilised in a virtual classroom situation.

## A procedure for training teachers

The procedure adopted for training the teacher for the experiments was evaluated in a positive way by the teacher. Furthermore, the positive results related to learner performance indirectly support the effectiveness of the training procedure. As a consequence we suggest a procedure developed through the following steps:

1 Presentation to the teacher of potentialities of the multimedia system both in terms of multimedia communication and multimedia chair (by demonstration).

2 Analysis of delivery methods, educational aids, time use, etc. usually adopted by the teachers in the face-to-face classroom (interviewing teachers).

3 Identification of objectives of training, delivery methods, development of contents, educational supports, time use, multimedia system configuration, etc. in the virtual classroom situation.

4 Setting up preliminary trials for training teachers in interaction with the multimedia system.

5 Helping teachers to adequately prepare the educational aids.

6 Providing the teacher with adequate indications for promoting and managing the communication among learners in the virtual classroom.

Steps 3 – 6 have to be performed in an iterative way, with the main aim to provide teachers with the necessary skills to deliver lessons in the virtual classroom.

This procedure is specially oriented towards training teachers in interactive virtual classroom situations in which relationships among learners are of fundamental importance (co-operative learning situations).

## A procedure for training learners

The procedure adopted for training the learners before the experimental sessions was evaluated in a positive way by the learners. Furthermore, the positive results related to learner performance and usability aspects indirectly support the effectiveness of the procedure. As a consequence we suggest a procedure developing through the following steps:

1 Providing learners with information about the virtual classroom situation and its opportunities for learning.

2 Presenting the learners with the multimedia system configuration (without details) including:
- learner equipment;
- audio-video and computer communication features.

3 Providing the learners with indications about the behaviour to be adopted during the session including:
- use of the camera;
- possible equipment failure;
- protocols of interaction.

4 Providing instruction about equipment use (by demonstration).

5 Setting up some simple practical exercises about system utilisation, involving the learners.

6 If necessary, providing the learners with some written instructions depending on users skills and complexity of the system configuration.

Steps 4 – 5 have to be performed in an iterative way, with the main aim to provide learners with the necessary skills to use the system correctly giving the learners the sensation of being able to master the multimedia system. In fact, in a previous study we found some evidence that if the learners think they are able to master the distance learning system their performance improves (Papa, Perugini and Spedaletti; 1998).

This procedure has to be used before the virtual classroom session starts. Typically, the duration of such training procedures is half an hour. Of course this depends on the particular system configuration and on some characteristics of the learners: previous experience with computers, age and gender, and individual attitude towards the multimedia system.

## 6 Phase 2: the field study

The results of the laboratory experiment show that tele-education is not only possible but also effective and satisfactory for both the learners and for the teacher. As we demonstrated, not only the technological apparatus provided by the laboratory but also the specific system configurations planned for experimental aims, seem to work best, at least in terms of system usability and learning performance. This strongly encourages the future continuation of this kind of research and investigation of this kind of application in genuine learning situations.

Anyway, although a laboratory-based experiment could give an encouraging outcome, the validity of our results should be tested in the *field* where the user perceives the environment as his/her own "natural" setting. This should have the following advantages:

1 It allows checking the realisation of the tele-education system in conditions of actual distance learning where different users are actually placed in different remote sites;

2 It allows evaluating usability aspects and learner performance in the virtual classroom taking into account the constraints of the radio communication system, eg. channel bandwidth, atmospheric conditions, delay;

3 It allows verifying the consistency of previous laboratory experiment results in real settings and thus eventually generalising the results to conditions closer to real life.

On the other hand, as said before, the operational results coming from the laboratory experiment (the multimedia system configuration and the procedures for training teachers and learners) provide a very useful tool in the realisation of the field experiment.

Connections between four remote sites, one site in which the teacher is placed, and three remote sites where the learners are placed, were set up. The multimedia system configuration identified during the laboratory experiment has been reproduced in the field.

Usability aspects and learner performance were evaluated in the field realising a co-operative learning task in which interaction between teacher and learners and among learners are of fundamental importance.

## 7 Phase 2: technologies

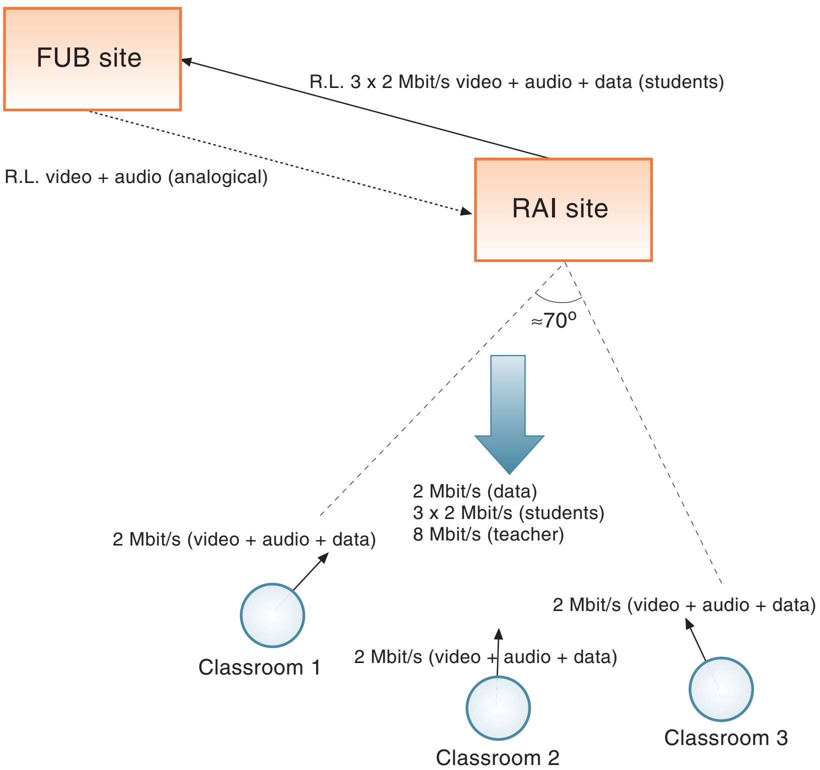
The structure of the communication system utilised in the field study consisted of a TV program broadcast from the teacher to the students via a 40 GHz transmitter and a high capacity (2 Mbit/s) return radio link to the 40 GHz cell base station for each user. The goal was to obtain full interactivity betweem a teacher and students located at four different sites as well as between students.

To implement these services each classroom received a DVB-S (Digital Video Broadcasting-Satellite) TV program: video and audio from the teacher (8 Mbit/s). The teacher was able to receive video and audio (standard H261 video and G711 audio) and to exchange data with each classroom using a 2 Mbit/s bi-directional digital link: 1.5 Mbit/s were dedicated for the video and the audio and 0.5 Mbit/s for the data.

Figure 1 shows the practical architecture which was implemented for the trial: since the distance between the teacher site and the 40 GHz transmitter was outside the coverage of the cell, analogue and digital radio links were used to implement a telecommunication backbone.

The Radio Access Network to the user sites (down-link) was realised using an LMDS transmitter at 40 GHz while two different wireless systems at 38 GHz and 40 GHz were used as return paths (up-links) from the classrooms to the radio links of the TLC network.

*Figure 1 Practical architecture for "Virtual Classroom" phase 2 trial in Rome*



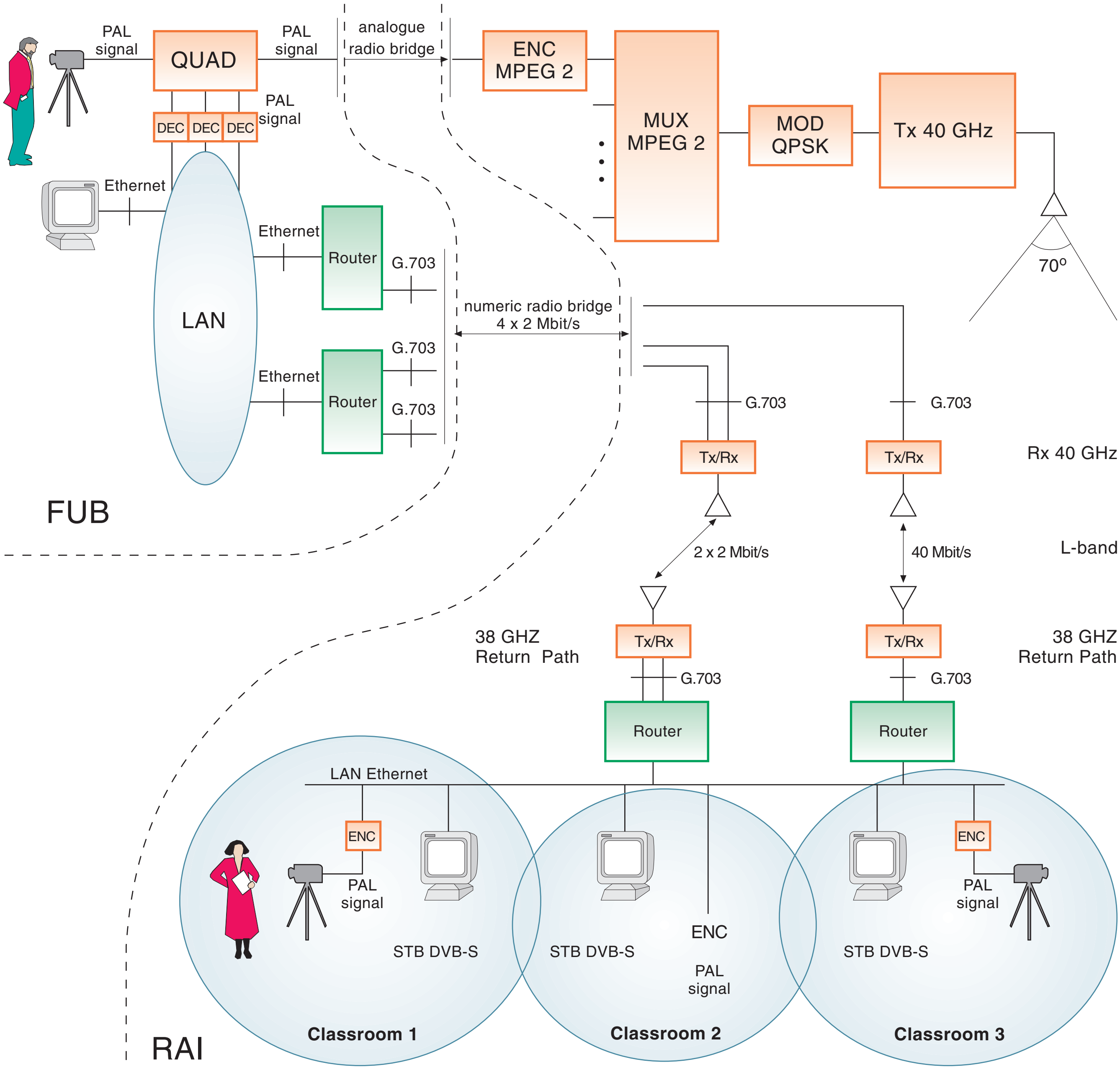



*Figure 2 System overview*

Figure 2 shows an overview of the whole system.

## 8 Future developments

Future research could be developed into two directions:

- To study the interactive modalities that allow delivering the lesson in tele-education when more than four remote locations are involved;

- To study how the existing telecommunication services should be selected and integrated in distance learning, taking into consideration the needs of the users and the features of the particular task in which the users are engaged.

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# Techno-economics of broadband radio access

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**This paper presents an analysis of the overall economics of broadband access network upgrades in downtown, urban, suburban and rural areas in Europe, with particular emphasis on the deployment of broadband radio access. The paper contains a detailed cost analysis of the LMDS (local multipoint distribution system) architecture, as well as a business case analysis of a new operator applying LMDS technology and other available options for broadband access. Finally, the business cases of the new operator competing with cable TV-operators and telephone operators in the same residential broadband market are compared. The paper reports work performed in the EURESCOM[1] project P614 during year 1998. The methodology and tool initially developed by the RACE[2] 2087/TITAN[3] and the ACTS[4] 226 OPTIMUM[5] projects, and now under further development in the ACTS TERA[6] project have been applied in the techno-economic analysis.**

## 1 Introduction

The rapidly increasing competitiveness in the telecommunications market forces the actors in the telecommunications market today to minimise costs and to maximise revenues. Provisioning of new, advanced services through the introduction of modern technology is commonly expected to be a crucial prerequisite as the incumbent and new operators position for the expected future service battle [1]. Following the recent dramatic Internet growth interactive broadband[7] services are now emerging, widely recognised as potentially decisive for the capability of the actors to defend and eventually expand the current revenue base. However, the future interactive broadband arena, and in particular the residential market, is characterised by a high uncertainty both with respect to service take rates and willingness to pay. Furthermore, there is no infrastructure in place for the delivery of interactive broadband services to the residential market segment.

Telecommunications operators or public network operators (PNOs) have several alternatives to upgrade their access networks towards a full-service network. The choice of which way to follow depends on many factors including the technical characteristics of the architectures, economical considerations and the actual situation of the telecommunications operators. Analysing the alternatives for the evolution of the access network requires a thorough examination of the costs and of the possible returns on investments.

Radio is obviously an attractive alternative for broadband access, because it alleviates the need for cable infrastructure investments in the last drop towards the customer, infrastructure investments which sometimes are very high. This applies in particular to new entrant operators, because they do not have the existing cable infrastructure that they could utilise by using XDSL modems (telecommunications operators) or cable modems (cable TV operators). Several alternative broadband access technologies are available, with the main options being local multipoint distribution system (LMDS), point-to-point systems, point-to-multipoint systems and Radio LANs, of which LMDS is considered to be the most promising solution in the short to medium term [2]. However, broadband radio access technologies are still emerging technologies. They are not as mature as some of their wireline counterparts. That means that high uncertainties are associated with the techno-economic studies of these technologies.

## 2 Broadband radio studies in EURESCOM P614 Task 6

The main objective of the techno-economics work in the EURESCOM project P614 "Implementation Strategies for Advanced Access Networks" is to identify economically viable implementation strategies for an effective multiservice

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[1] *EURESCOM: European institute for research and strategic studies in telecommunications.*
[2] *RACE: Research in advanced communications in Europe.*
[3] *TITAN: Tool for introduction scenario and techno-economic evaluation of access networks.*
[4] *ACTS: Advanced communications technologies and services*
[5] *OPTIMUM: Optimised network architectures for multimedia services.*
[6] *TERA: Techno-economics results from ACTS.*
[7] *Broadband: Capacity per customer ≥ 2 Mbit/s.*

access network introduction, taking into account profitability and risk of such investments. This consists of an analysis of broadband access network upgrade and investment strategies, including techno-economic assessment of project values of broadband introduction in a competitive environment in downtown, urban, suburban and rural areas in Europe. Results such as the investment costs, life cycle costs, revenues, net present value and payback periods are calculated for different evolutionary paths and scenarios. The analysis covers several migration alternatives for access network providers, including the different options available for traditional telephone operators, cable operators and new entrant operators.

The EURESCOM project P614 has performed detailed studies on broadband radio access solutions. The studies include aspects influencing the dimensioning of a radio network such as the maximum achievable radio range, cellular coverage, structure of coverage and network upgrading strategy. The two main broadband radio network options of LMDS and point-to-multipoint have been analysed. In this paper the analysis of LMDS is presented. The analysis is split into three main parts, the first of which is a detailed cost analysis of the LMDS architecture. In the second part of the LMDS analysis, the business case of a new entrant operator is examined in more detail, with emphasis on the comparison of LMDS with other technology options for the new operator. In the third part, the business cases of this new operator are compared with the business cases of the competing cable operators and telephone operators, which are likely to deploy other technologies than the new operator. Thus, the complete LMDS analysis will contribute to the identification of the role of LMDS and radio access in general in the battle for the future broadband service customer.

# 3 Area and service scenario framework

The techno-economic analysis has been carried out on the basis of a framework which is established in order to enable a fair comparison and analysis. The economy of broadband access network upgrades to a large extent depends on the expected future service demand and corresponding revenue streams and variations in existing infrastructure and network area types. For instance, areas with different density of living units have significantly different cost structures. At a strategic level some simplifications with respect to these key parameters are needed. This advocates a segmentation of network areas into suitable network area groups, despite the fact that the definitions of area types are somewhat subjective. In addition the market evolution, including the characteristics of the services to be offered, must be defined.

## 3.1 Area segmentation

The analysis covers non-greenfield upgrades in four network area types within the time period 1998–2007: a downtown area, an urban area, a suburban area and a rural area [3]. The initial assumption is that each of the areas under study have 4,096 living units[8)]. We have mainly differentiated based on the density of living units (density of potential subscribers[9)]) in the area, even though this parameter may vary significantly throughout Europe. The same segmentation is in principle applied to both non-greenfield and greenfield areas. The 'nominal' densities are assumed to be 9,200 subscribers/km$^2$ in the downtown area, 1,000 subscribers/km$^2$ in the urban area, 365 subscribers/km$^2$ in the suburban area and 200 subscribers/km$^2$ in the rural area. In the downtown and urban areas the subscribers live in apartment blocks, whereas the suburban and rural subscribers live in single house dwellings.

For a fair comparison between wireless and wireline broadband upgrade alternatives, a segmentation based only on the density of living units is not sufficient, even if this is one of the key parameters. Typical European figures for availability of existing ducts and surface conditions with corresponding cable deployment type and civil works costs have been defined, mainly for reflecting the area differences with respect to the deployment of new fibreoptic or copper cable. The average civil works costs per metre depend on the surface conditions in the area, the cable deployment method and very often the network distribution level. The three types of cable deployment assumed include digging trenches in asphalt pavings/tarmac roads, digging trenches in areas with tarmac-free surface and suspension of aerial cables along cable posts. The average civil works costs per metre are based on the assumed deployment of cables in the respective areas, and the cost ranges for the various deploy-

*8) The actual number of subscribers connected to one local exchange in the area may of course be higher than 4,096. In the case of local exchanges with more than 4,096 subscribers connected, this analysis is limited to a segment of this local exchange containing 4,096 potential subscribers.*

*9) We assume that the potential number of subscribers for broadband access equals the number of households. Please note that the subscriber or household density is different from the population density, in Northern European countries there are typically twice as many inhabitants as households.*

ment options. The ranges of costs are assumed to include the effect of the variation in labour rates in Europe [4]. Area related ranges of duct availability have been assumed. The duct availability as used here refers to the unavailability of ducts for installation of optic fibre cables or copper cables.

### 3.2 Service penetration scenarios

To evaluate the alternative technical options for a broadband access network upgrade, we need to define the services to be provided by the access network operator. This study focuses on broadband bearer services for the mixed residential and small business market only. According to several studies [5, 6, 7, 8], there will be a future demand for asymmetric and symmetric broadband services in the residential and small business market segment. In the residential market services such as Internet, digital broadcast, video on demand (VoD) and distance learning are expected to be required. The broadband services are typically asymmetric in nature and generically defined in this study as asymmetric switched broadband (ASB) services. We assume that the transmission capacities related to the asymmetric services will be in the range from 2 Mbit/s to 26 Mbit/s (downstream) and 64 kbit/s to 2 Mbit/s (upstream). In the small business market services like data communication, video based communication, co-operative working are expected to be required. The broadband services are typically symmetric in nature and generically defined as symmetric switched broadband (SSB) services. We assume that the bandwidth related to the symmetric services also will be in the range from 2 Mbit/s to 26 Mbit/s.

The saturation level of the total broadband market penetration is assumed to be equal in all areas. The service basket considered consists of asymmetric and symmetric 2 Mbit/s, 8 Mbit/s and 26 Mbit/s capacities. It is assumed that the bearer services with lower capacities will have an early take up and reach higher penetrations in the final year compared to services with higher capacities. The access network operator will thus be faced with a continuous capacity 'migration' during time from lower towards higher bandwidths, expected to provide all bearer services in all areas at the same time.

According to results from [5–8] a broadband service penetration level of 20 % to 30 % is forecast in the served areas by 2007. Total broadband saturation level in this study is assumed to be 25 % in the final year (2007). Each of the defined bearer services are described by a certain penetration level with respect to time, as shown in figure 1. The penetrations are given in percentage of total number of potential customers in the area. Downtown areas are assumed to be dominated by small business customers mixed with a minor group of residential customers. Areas like urban, suburban and rural are dominated by residential customers mixed with a minor group of small business customers. The distribution between asymmetric and symmetric switched services reflects the assumed distribution of customers based on typical figures found from internal studies in some European countries. In the downtown area 80 % of the customers demand a symmetric broadband connection, whilst the remaining 20 % ask for an asymmetric connection. The symmetric service demand decreases with the density of living units, with exact figures as follows: 30 % symmetric demand in urban areas and 20 % symmetric demand in suburban and rural areas.

### 3.3 Revenue assumptions

The access network operator revenues typically consist of connection, rental, usage and churn revenues. Only connection and rental revenues are included here. The *connection tariff* is charged once for every new connection to a service and the *rental tariff* is an annual or monthly tariff charged per connection to a service. The connection revenue includes revenue from any installation fee charged for a new connection. Based on a European survey a unique connection revenue per connection of 100 EURO is defined. The rental revenue reflects the performance of the service in terms of service type (asymmetric and symmetric) and the speed (2, 8, or 26 Mbit/s) of the service. The model is based on a rental cost per service connection. The current tariff structures have been surveyed, and it is assumed that the customers are willing to pay 50 % more for symmetric services than asymmetric services. The 8 Mbit/s services are charged twice the 2 Mbit/s service rental and the 26 Mbit/s services are charged 3.5 times the 2 Mbit/s service rental. The monthly rental cost for a 2 Mbit/s asymmetric switched service con-

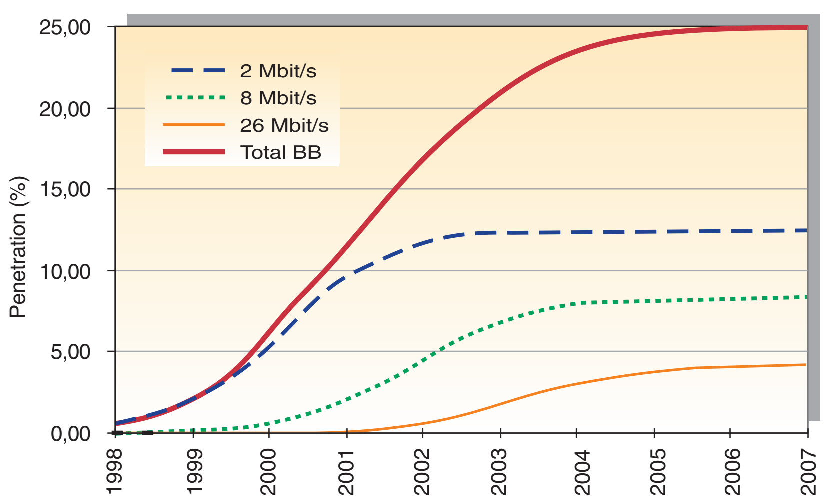



*Figure 1 Market penetration for the 2 Mbit/s, 8 Mbit/s and 26 Mbit/s broadband bearer services*

nection is set to 30 EURO. The rental costs take into account the high quality of service provided to the customer and used for the network dimensioning (1 % blocking probability at 0.1 user activity factor), which is certainly better than the quality of service assured by current HFC based Internet Service Providers.

### 3.4 Operation and administration costs model

A simplistic model for operation and administration (OA) costs has been used in this study. It is based on the assumptions that implementation of new broadband architectures involves running costs for the network operator, which may be divided into administrative, operations and maintenance costs. The administrative costs are generated by administrative staff, which cover technical resources, economical resources, sales and marketing resources. The operations costs are generated by operational staff, which operate and manage the networks and services. The maintenance costs are generated by maintaining network and services in operation, principally by repairing failed equipment and failed network elements. The maintenance costs are already a part of the OPTIMUM methodology, as described in section 4. The additional operation and administrative costs are modelled based on information of one European Telecom operator. The relevant information to be extracted is the OA costs per connection since this work is only concerned with access network bearer services.

The network staff proportion is evaluated by the ratio of the number of employees working in the network division divided by the total number of employees. The network staff proportion excluding logistic and headquarter staff is about 35 %. The turnover of access network services (which essentially cover the access copper network for POTS and ISDN, but exclude switching and long distance services) divided by the turnover of all network services is about 20 %. The access network staff size is estimated by the product of the total number of employees and the two above ratios. The annual cost of an employee is given by the product of the average of paid hours (1,800 hours/year) multiplied by the cost per hour (50 EURO/hour). This gives 90,000 EURO/year. Thus, the OA cost per line per year given by this analysis is rounded to 30 EURO per connected broadband user per year.

## 4 Techno-economic methodology and tool

The methodology and tool initially developed by the RACE 2087/TITAN and AC 226 OPTIMUM projects and now under further development in AC 364 TERA have been applied in the techno-economic analysis [9, 10, 11]. The objective of OPTIMUM is the calculation of the overall financial budget of any kind of access system. This includes: the discount system cost; operation, maintenance and powering costs; life cycle costs; and the cash balance of the project. The ability to combine low-level, detailed network

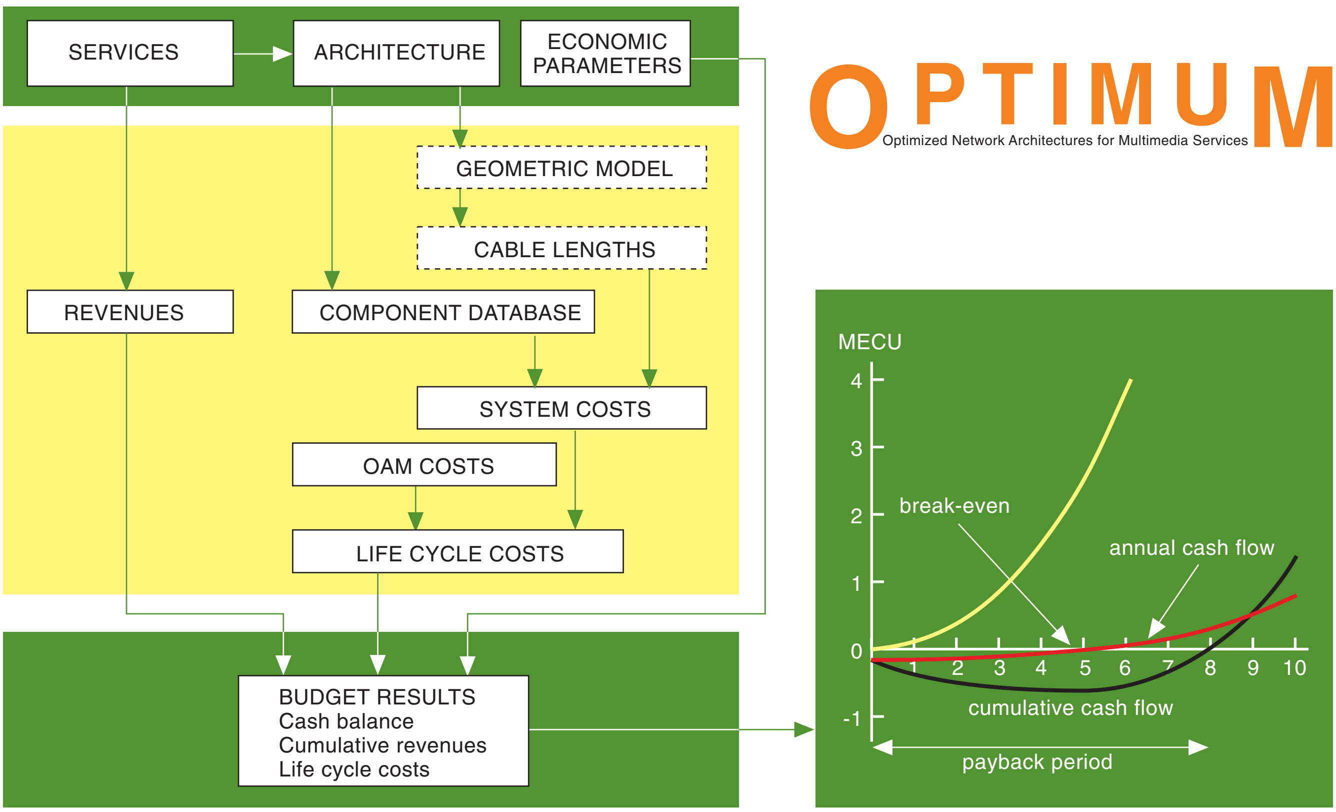



*Figure 2 The OPTIMUM tool structure*

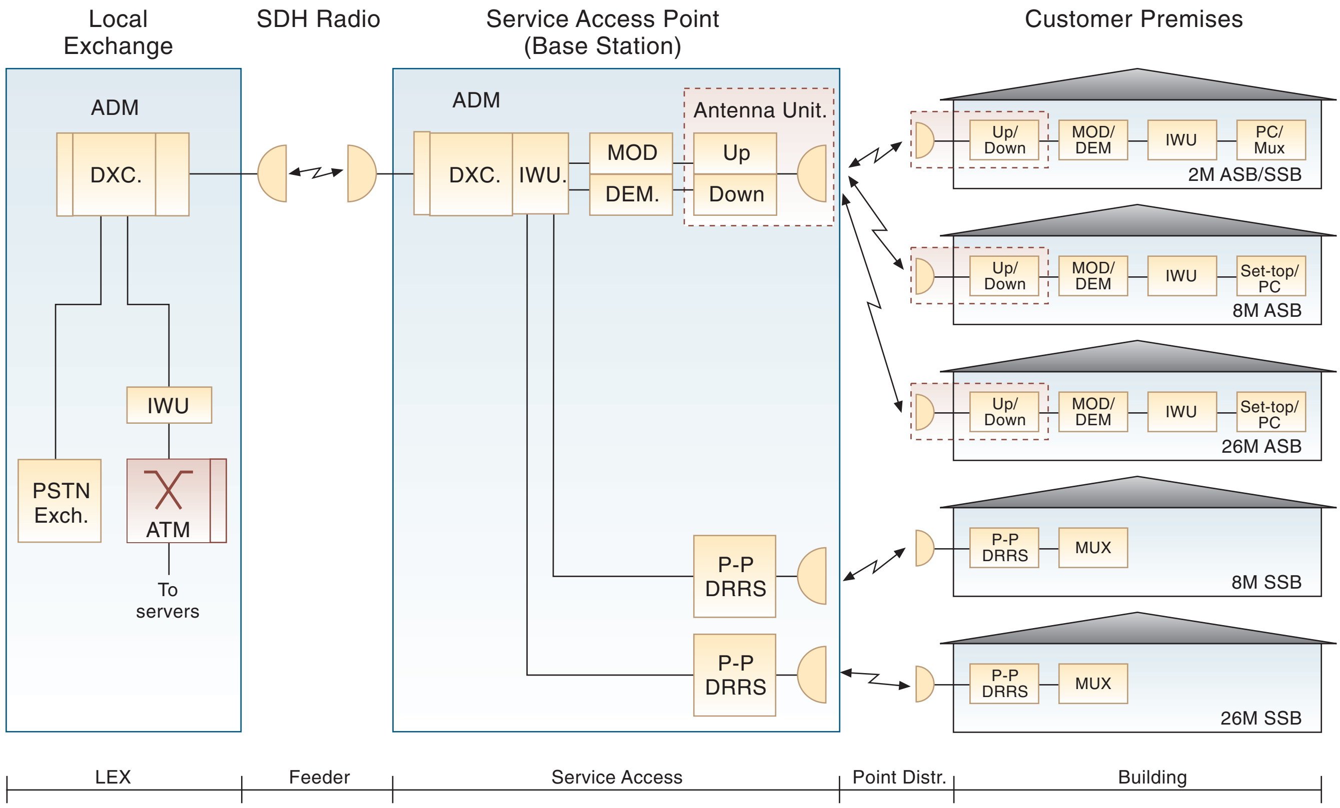



*Figure 3 LMDS architecture*

parameters of significant strategic relevance with high level, overall strategic parameters is a key feature of the OPTIMUM methodology and tool, as compared to other similar assessment methods and tools recently reported. In OPTIMUM the network costs are calculated taking the evolution of component costs into account. The structure of the OPTIMUM tool is shown in figure 2.

### 4.1 Maintenance cost model

The maintenance costs are automatically calculated by the tool, and consists of two elements, namely the cost of repair work and costs of spare parts. The input parameters are *Cost of work hour*, $P_1$ [ECU/hour], which is defined in the time series sheet, *Mean Time Between Repairs*, MTBR [years], which is defined in the database for each cost component, and finally the *Mean Time To Repair*, MTTR [hours], which is defined in the database for each cost component.

### 4.2 Cost database

A database including costs at a given reference year for components, installation and civil works costs has been developed within the OPTIMUM project and the EURESCOM P614 project [12]. The cost trends of the various network elements are derived from initial costs. The cable lengths in case of wireline network architectures are calculated using geometric models.

## 5 LMDS system architecture

This chapter briefly describes the features of the LMDS system under study. LMDS is a point-to-multipoint type of radio solution, which typically operates at frequencies around 28 GHz or 40 GHz [2]. Figure 3 shows the LMDS network architecture analysed.

The feeder link is represented by a point-to-point (P-P) SDH radio link. Also wireline solutions are possible in the feeder, eg. SDH fibre rings. Radio equipment which provides the services to the customer through the air interface is installed at the access point. Two different sets of radio equipment are assumed to be deployed in the radio network:

- LMDS (or P-MP) systems, which are able to provide service to more than one customer but with an upper limit to the supported bit rate at the customer premises;
- Point-to-point (P-P) radio equipment, also called DRRS (Digital Radio Relay System) for higher bit rate.

Taking into account that the LMDS system should be able to support 40–50 Mbit/s downstream, the upper limit for the downstream bit rate at the customer premises is assumed to be 26 Mbit/s. In addition, considering the limited amount of spectrum allocated in the 28 GHZ and

40 GHz bands for the up-link traffic, the maximum up-link bit rate is assumed to be 2 Mbit/s. Thus, the 2 Mbit/s symmetric service and all asymmetric 2 Mbit/s, 8 Mbit/s and 26 Mbit/s capacity services are provided by LMDS.
8 Mbit/s and 26 Mbit/s symmetric capacity services are provided by point-to-point radio links.

The basic LMDS system equipment is called base station. The base station in figure 3 is, for simplicity, described by two main building blocks, the *antenna unit* and the *LMDS modulator*. The antenna unit represents, generally speaking, the outdoor part of the base station and consists of the antenna, a diplexer, a radio frequency (RF) low noise amplifier and a down/up converter. In practice, the antenna unit is the interface between the LMDS mo-demodulator (whose input/output is at the intermediate frequency, IF) and the air interface in which the propagation is performed at RF.

The LMDS mo-demodulator performs many functions. The downstream information flow must be modulated over separate RF channels. One of the most common implementation strategies dedicates some RF channels just for video traffic (MPEG streams) and some other RF channels for the data traffic, eg. Internet, POTS, videoconferencing, etc. In other words, each flow is separately encoded (according to the standard encoding methods), modulated and mixed together over the IF cable connected to the antenna unit. The number of RF channels that can be supported by an LMDS modulator depends on factors such as:

- Capacity required in the area covered by the base station;
- Number of RF channels granted to the operator;
- Frequency reuse factor.

The base station is equipped with a sectored antenna (90º or 45º) so that more than one base station is generally installed in the same radio access point, and the supported capacity is consequently increased. In up-stream the LMDS demodulator performs the opposite task: the received signals are demodulated, a forward error correction is applied and the obtained stream is sent to the interworking unit (IWU), which represents the interface between the feeder network and the radio equipment.

At the customer premises, an antenna unit is installed at the rooftop performing the same functionality as previously described. Connected to the antenna unit with an IF cable, the mo-demodulator performs more or less the same tasks as the base station mo-demodulator. The mo-demodulator at the antenna unit selects the proper downstream channel to be demodulated, performs a forward error correction and sends the information flow to the IWU. In the up-link, the IWU accepts traffic from the user terminal, segments and reassembles it and sends this flow to the modulator. The modulator applies the proper encoding and modulates the stream onto IF for delivery to the antenna unit.

## 6 Key assumptions

In this work LMDS is analysed only for the downtown and urban areas, assuming LMDS is maybe best suited for areas with high population densities. The size of these areas are respectively 0.44 square kilometer (downtown) and 4.10 square kilometer (urban). LMDS is still an emerging technology, not as mature as some other broadband access alternatives. There is not much detailed information about the technical implementation and products. Furthermore, reliable information about the cost structure and about the product costs is not readily available. Due to the nature of the LMDS technology, many assumptions about technical implementation and costs must be made when performing techno-economic evaluations.

The area and service definitions are described in detail in section 3. We have assumed that each customer has its own LMDS network termination (NT) and a roof-mounted transceiver. This is due to the fact that it may be difficult to agree on a common NT between different customers. In addition, the number of LMDS customers in a building can be limited, eg. when LMDS is used as a new operator solution. Internal cabling inside the building is not included in the evaluation to be consistent with other studies in EURESCOM P614 [13, 14, 15].

Broadcast TV probably plays an important role in the first implementations of LMDS. Broadcast TV specific equipment is however not included in the present study to be consistent with the other studies in EURESCOM P614. Supported capacity of one downstream LMDS RF channel is assumed to be 46 Mbit/s. Each base station can radiate five downstream RF channels. Supported capacity of one upstream LMDS RF channel is assumed to be 2 Mbit/s. Each base station can radiate 20 upstream RF channels. We assume that four base stations can be installed in each radio site, ie. four sectored antennas.

The LMDS base station can be divided into two main parts: basic part and modem cards. The basic part includes all the equipment in common with all the modem cards. This part includes antenna, down/up converter, power amplifier, IF down/up converter, IF filtering, power supply, etc. It is common with a great number of modem cards and must be bought even with just one

| Cost Component | Price | Year | Description |
|---|---|---|---|
| LMDS Base station basic part | 16,000 EURO | 1997 | LMDS base station basic part. Modems (8 up and 8 down) cost 2/3, basic part 1/3 |
| LMDS Base station modem | 2,000 EURO | 1997 | LMDS modem for one 40 MHz (46 Mbit/s) downstream channel or LMDS modem for four 2 MHz (2 Mbit/s) upstream channels |
| LMDS NT and transceiver | 1,500 EURO | 1998 | Includes a roof-mounted transceiver, a downconverter, and an interface to the customer equipment |
| LMDS NT installation | 200 EURO | 1997 | Installation cost of LMDS antenna and NT |
| LMDS radio site | 50,000 EURO | 1997 | Cost of BS site, ie. mast, land, powering, (cabinet) |

*Table 1 LMDS cost components*

active modem card. The price of the first part is usually 1/3 of the price of the fully equipped radio system so that the remaining 2/3 of the price will be shared between the modem cards. For the LMDS systems in our calculation it was assumed that each modem card for the downlink direction supports one RF channel instead of the uplink modem card, which supports four RF channels. The cost relevant to the modem cards can be assumed to be shared equally between the cards for the downlink direction and the cards for the uplink direction.

The dimensioning of the base station equipment (basic part, LMDS modems) is made by simulation supposing 0.1 Erlang traffic for each service, a grade of service (GOS) of 1 %.

Radio sites are connected to the head end / local exchange by SDH point-to-point radio links. In downtown area no feeder is assumed because of the very small size of the area under study.

Possible loss of customers due to inability to provide the service (line of sight requirement) is not taken explicitly into account. This is comparable to digital subscriber line (DSL) technology in which cross talk or too long subscriber loops might prevent some users from getting the service.

As previously mentioned, reliable information about the cost structure and about the product costs of the LMDS systems is not readily available. The cost information presented here is partly from ACTS projects OPTIMUM and CRABS. The cost information is based on technology complexity evaluations, expert opinions and on an assumption that there will be reasonably large markets for LMDS products within the timeframe of this study. The key cost elements are listed and described in table 1.

A cost evolution is assumed so that eg. the LMDS NT and transceiver will cost about 500 EURO in year 2007 (end of the study period). A similar price evolution is assumed for other LMDS active equipment. For installation and sites the price is not assumed to change considerably during the study period. The price evolutions of the key cost components used in the LMDS study are shown in table 2.

## 7 Results

A detailed cost analysis of the LMDS architecture has been carried out. The results from this analysis are presented initially in this chapter. Following these results, the results from the business case analysis of a new operator applying LMDS technology and other available options for broadband access is presented. Finally we present the results from the comparison of the business cases of the new operator competing with cable TV operators and telephone operators in the same residential broadband market.

### 7.1 LMDS system cost analysis

Figure 4 shows the cumulative investment of the LMDS deployment in the downtown area. The analysis of an LMDS upgrade indicates a cost

*Table 2 Price evolution of the LMDS key cost components (EURO)*

| | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|---|---|---|
| LMDS_Basestation_basicparts | 13 914 | 12 111 | 10 558 | 9 224 | 8 085 | 7 121 | 6 314 | 5 651 | 5 116 | 4 698 |
| LMDS_Basestation_modem | 1 739 | 1 514 | 1 320 | 1 153 | 1 011 | 890 | 789 | 706 | 640 | 587 |
| LMDS_Radio_site | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 | 50 000 |
| LMDS_NT_and_transceiver | 1 500 | 1 304 | 1 135 | 990 | 865 | 758 | 668 | 592 | 530 | 480 |
| LMDS_NT_installation | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |

per connected user of 4,500 EURO in downtown and 2,400 EURO in urban areas. The corresponding investment levels for a pure LMDS upgrade without point-to-point radio systems are 1,600 and 1,300 EURO, respectively. The pure LMDS upgrade in the urban area is cheaper than in the downtown area since the urban area benefits from higher cost sharing of common equipment due to the higher number of customers being served.

In figures 5 and 6 the installed first costs are broken down into the following cost element groups:

- Network terminal;
- Point-to-point radio links for 8 and 26 Mbit/s SSB services;
- Base station, including the radio site costs;
- Feeder.

In figure 5 cost breakdowns for provisioning of the full service basket in the urban and downtown areas are shown. Thus the high costs of the point-to-point radio links for 8 and 26 Mbit/s symmetric switched services are included. As can be seen from figure 5 the costs of the point-to-point radio links are very dominant.

Figure 6 shows cost breakdowns for a reduced service basket in the urban and downtown areas. In this case 8 and 26 Mbit/s symmetric switched services are not provided, and thus the high costs of the point-to-point radio links not included. It is clearly seen that the pure LMDS solution has a significantly lower cost level than the combined solution.

Additionally, in our study we compared an upgrading strategy, in which the radio resources are continuously allocated as close as possible to the incremental capacity demand, with another upgrading strategy in which the radio resources are more coarsely allocated initially. The results show that the upgrading strategy influences the investment and the cost per user during the first three years of the study period. In fact, the first strategy needs at least three years to reach the common level of the cost per connected user in the final year.

In conclusion, wired networks can in general be analysed by means of pre-defined structures of network and with consolidated methodologies for the calculation of the average wire length. Radio networks, on the contrary, require a higher effort during the designing and the definition of the relevant inputs necessary for the volume calculation. This is due to the wide range of available products on the market with very different features in terms of supported capacity and frequency of deployment. Therefore, volume calculation must follow a preliminary task

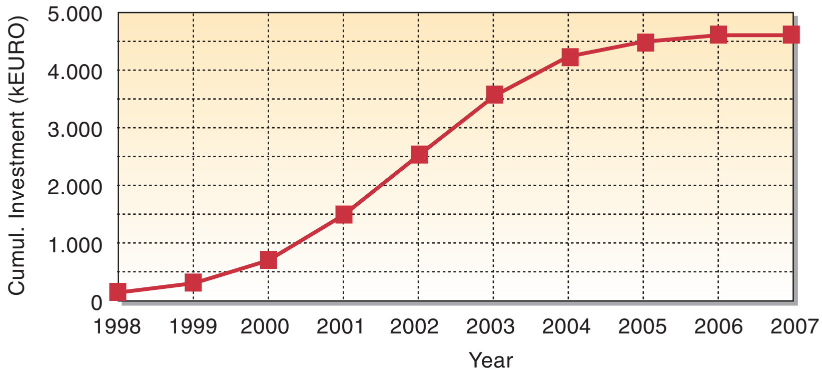



*Figure 4  Cumulative discounted investment for LMDS deployment in the downtown area*

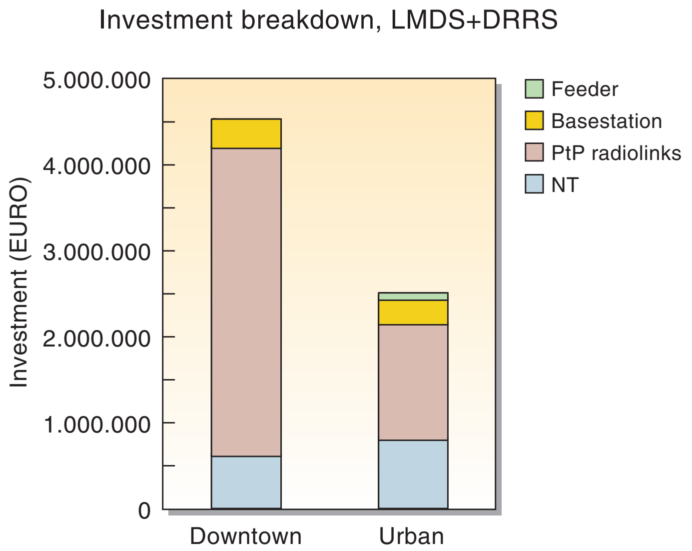



*Figure 5  LMDS cost breakdown, with point-to-point radio links*

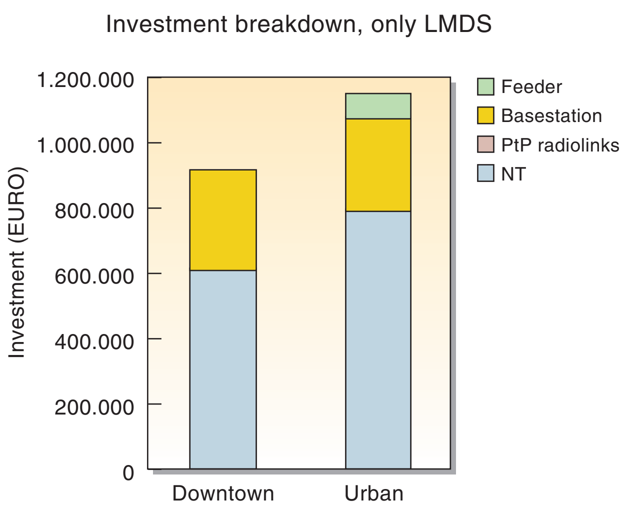



*Figure 6  LMDS cost breakdown, without point-to-point radio links*

of network dimensioning for the definition of the maximum achievable radio range, the structure of coverage, the network upgrading strategy, the maximum number of supported trunks on the basis of the foreseen traffic per customer, etc.

For broadband radio networks deploying LMDS and P-P radio systems, the average investment required per each connected customer over the ten years study period, is about 4,500 EURO in the downtown area and about 2,400 EURO in the urban area. Thus, the cost per user for high capacity broadband access based on a combination of LMDS and point-to-point broadband radio systems is very significant.

Assuming a provision of a full service set including 26 Mbit/s switched services, the average cost per connection is strongly influenced by the cost of the point-to-point radio systems which are needed to provide the higher bit rates which cannot be provided by the LMDS systems. The cost per connection for an LMDS radio access network providing a full service set is much higher than the cost per user for a radio access network providing the limited service set. The deployment of LMDS systems allows the supplying of a reduced set of services (2 Mbit/s ASB/SSB, 8 Mbit/s ASB and 26 Mbit/s ASB) with a more competitive cost per connection. In this case, the average cost per connection is about 1,600 EURO in the downtown area and 1,300 EURO in the urban area.

## 7.2 Business case of a new operator deploying LMDS

Following the detailed cost analysis of the LMDS architecture, one interesting aspect is the analysis of the business case of the new entrant operator, which in addition to LMDS has several other technology alternatives for the provision of broadband services. Access network migration towards broadband is to a large extent related to the existing network, the target architecture, and the corresponding intermediate infrastructure changes required in order to upgrade the network to the target architecture. With the new operator the starting situation is always *no existing infrastructure*. We have identified three different basic alternatives for broadband delivery for a new operator, including LMDS:

1. Rental of access network;

2. Building of own (wireline) access network;

3. Building of own radio based access network, eg. LMDS.

It is assumed in this study that the new operator wants to rent access network capacity from the existing operator at the lowest possible cost level. That means 'blank' copper pairs excluding eg. DSL-modems. The new operator will act as a competing network operator with its own equipment in the access network, not as a service provider utilising the access network capacity of the existing operator. This study concentrates only on the downtown and urban areas as defined in

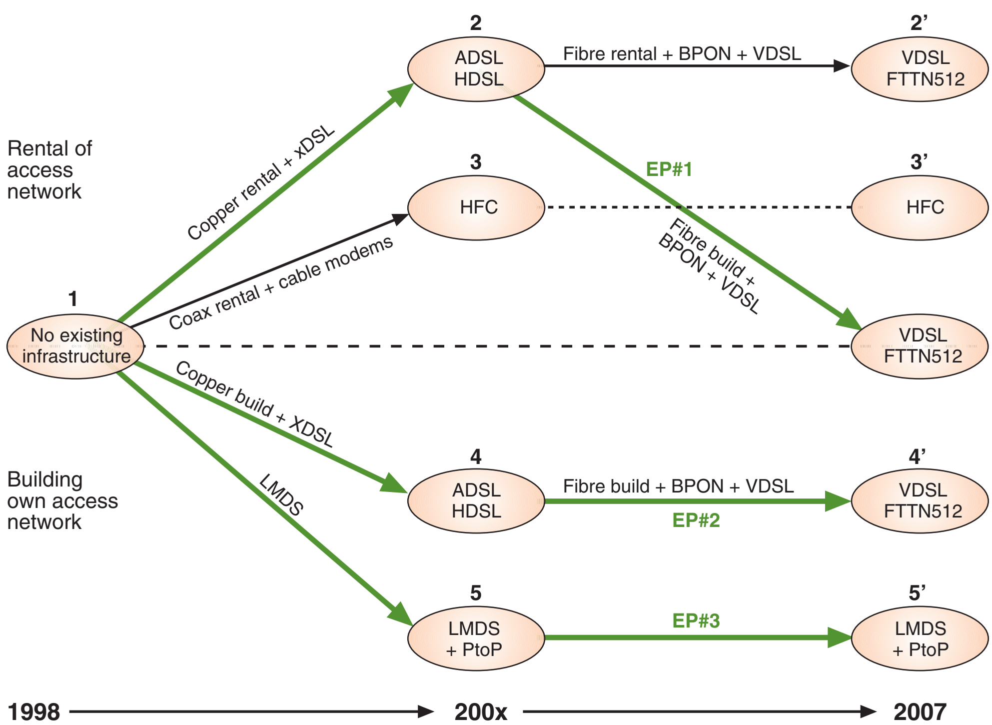



*Figure 7 Selected EPs for a "new" operator*

chapter 3. Figure 7 shows the selected new operator EPs. The circles indicate the network type and configuration at that particular point in time and during the preceding upgrade period. Solid lines between the circles represent network upgrades, whereas dotted lines indicate no infrastructure changes during that particular period. The different proposed migration paths are marked with thick arrow lines from the existing architectures to the final ones.

The installation of radio broadband systems (eg. LMDS) is considered as a reasonable alternative for this situation. From these EPs for the new operator the three most relevant were selected for the more detailed assessment:

- EP 1: No existing infrastructure –> copper rental, use of ADSL and HDSL –> fibre build, BPON, use of VDSL for high bitrate services.
- EP 2: No existing infrastructure –> copper build, use of ADSL and HDSL –> fibre build, BPON, use of VDSL for high bitrate services.
- EP 3: No existing infrastructure –> LMDS.

The three different basic alternatives examined for the new operator are access network rental, wireline build or wireless build. Thus, in the 'New operator' evolutionary path cost analysis the cost per user figure includes the twisted pair annual rental cost in addition to the IFC and maintenance cost. The figure below shows the discounted cost per user for the different evolutionary paths and areas. For LMDS a limited service set, without 8 and 26 Mbit/s SSB services, is considered.

The effective civil work cost, based on different duct availability, is together with rental prices and conditions the main factors dominating the business choices of the new operators using wireline access technologies. Comparing the rental case and the own network build, one of the main differences is the timing of the investments. When building his own network, the new entrant operator will have heavy investments in the first years before any customers are connected. In the rental case the investments in the first years are much less, but the rental cost will be a continuous burden to the business of the new operator. Sensitivity analysis of civil works and copper rental costs have shown that the evolutionary path internal rate of return values vary from 3 % to 50 % depending on the levels of those parameters. Sensitivity with respect to civil works and rental costs shows that these factors heavily influence the economic performance of the project. Fixed broadband radio solutions are obviously an attractive solution for a new operator, because rental cost or the high cable infrastructure costs are not needed.

In the downtown area all EPs (XDSL copper build, XDSL copper rental and LMDS with reduced service set) are feasible solutions for the new operator under the default assumptions. In the urban area XDSL copper build is significantly different than in the downtown area. The longer line lengths mean much higher civil work investments for the building of the copper drops. Only XDSL copper rental and LMDS are feasible solutions for the new operator in the urban area under the default assumptions.

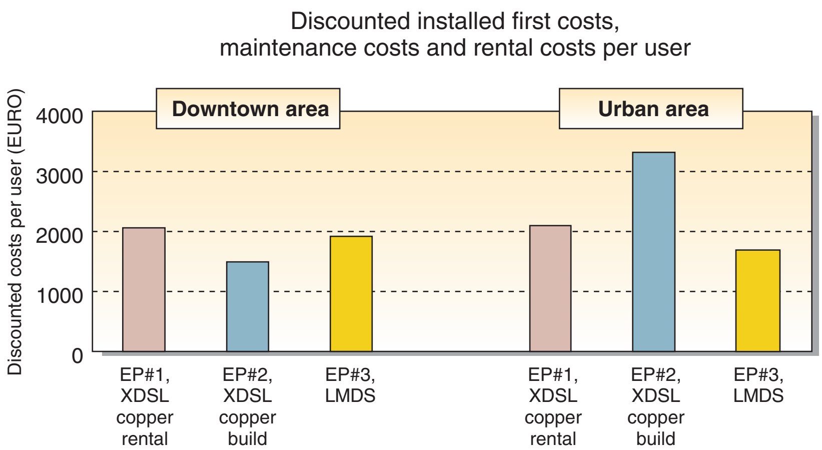
LMDS+P-to-P is an evolutionary path that uses LMDS for all services, expect for 8 Mbit/s SSB and 26 Mbit/s services, where point-to-point radio links are used. The high cost of these point-to-point radio links means that this EP is too expensive a solution in both downtown and urban areas. Evolutionary path, where only LMDS is used and 8 Mbit/s SSB and 26 Mbit/s SSB services are not provided at all, is however a promising solution for the new operator in both areas under the default assumptions.

More mature wireline technologies such as ADSL have experienced a higher cost reduction over the past years, a reduction which is not yet seen for radio technology. In addition, the analysis does not reflect the potential economic benefit gained by the faster deployment of radio upgrades compared to wireline technology roll-out.

### 7.3 Competing operator analysis – the role of LMDS

Finally, the business cases of the new operator competing with cable TV operators and telephone operators in the same residential broadband market have been compared. The analysis covers several evolutionary paths for traditional telephone operators, cable operators and new entrant operators. The evolutionary paths have

*Figure 8 Cost per user, new operator EPs*



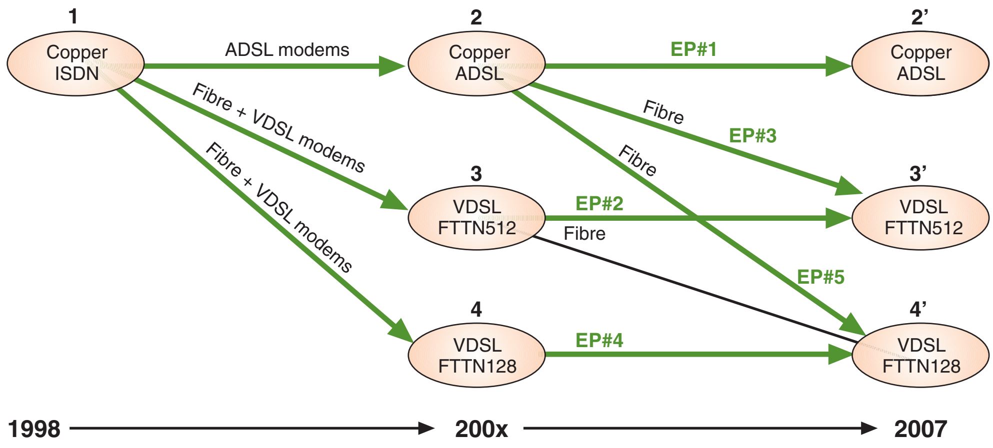



*Figure 9 Selected evolutionary paths for telephone operators with an existing twisted pair network.*

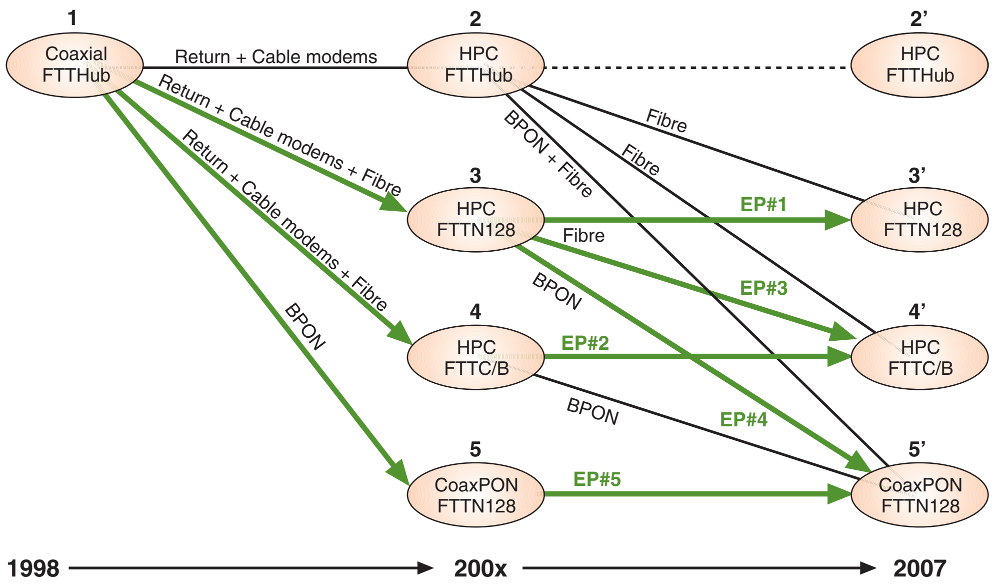



*Figure 10 Selected EPs for cable operators*

been grouped according to three different starting situations for the access network provider:

1. Twisted pair based evolutionary paths;
2. Coaxial cable based evolutionary paths;
3. 'New-Operator' evolutionary paths.

The alternative evolutionary paths towards a future broadband network are depicted in figures 7, 9 and 10. The options for the new operator were described in the previous chapter 7.2. Figure 9 shows the group of twisted pair based evolutionary paths (EPs). These comprise the likely migration alternatives for a telephone operator, which at the initial stage has a twisted copper pair access network. A combination of fibre in the loop and DSL systems is likely to constitute the future broadband access network for operators with an existing twisted pair infrastructure.

The group of coaxial cable based EPs include the migration alternatives for a cable operator, which initially has a coaxial cable based access network with no return capability, used for distribution of analogue television signals. Figure 10 shows the EPs for the cable operator. Upgrading the coaxial cable network to interactive broadband usually implies the installation of cable modems and return amplifiers. In addition a splitting of the coaxial cable network into smaller segments by the use of fibreoptic feeder cables and HFC technology will most likely be required in order to achieve the required return path capacity.

Table 3 and figure 11 show the summary of the internal rate of return results for the different operators and their different evolutionary paths applied in various areas.

The results indicate that all of the evolutionary paths examined give acceptable levels of internal rate of return in the downtown area, with an

| | | Downtown | Urban | Suburban | Rural |
|---|---|---|---|---|---|
| **Telephone operator** | ADSL | 59 % | 40 % | 32 % | 26 % |
| | FTTN512 | 43 % | 27 % | 20 % | 21 % |
| | ADSL/FTTN512 | 58 % | 41 % | 33 % | 31 % |
| | ADSL/FTTN512 (no mig.) | 59 % | 44 % | 36 % | 34 % |
| | FTTN128 | 31 % | 17 % | 12 % | 16 % |
| | ADSL/FTTN128 | 55 % | 35 % | 27 % | 31 % |
| | *Average* | 51 % | 34 % | 27 % | 27 % |
| **Cable operator** | Cable Modem 256 | 23 % | 7 % | 1 % | |
| | HFC-CPON | 41 % | 21 % | 12 % | |
| | CM256/HFC-CPON | 35 % | 19 % | 12 % | |
| | *Average* | 33 % | 16 % | 8 % | |
| **New operator** | XDSL copper build | 30 % | 7 % | | |
| | XDSL copper rental | 34 % | 21 % | | |
| | LMDS | 22 % | 27 % | | |
| | *Average* | 29 % | 18 % | | |
| | ***Average total*** | 41 % | 26 % | 21 % | 27 % |

*Table 3 Summary of the internal rate of return results (in %) for the different operators and their different evolutionary paths applied in various areas*

average internal rate of return for all projects of 41 %. The internal rates of return of the projects vary from 22 % to 59 % in downtown areas. In the downtown area, the evolutionary paths of the telephone operator are on average more profitable than the evolutionary paths of both the cable operator and the new operator. The telephone operator projects have an average internal rate of return of 51 % in downtown areas, whereas the cable operator and new operator projects have average internal rates of return of 33 % and 29 % respectively with the given assumptions.

In the urban area, all of the evolutionary paths examined for the telephone operator give acceptable levels of internal rate of return, with an average internal rate of return for all projects of 34 %. The internal rate of return of the telephone operator projects varies from 17 % to 44 % in urban areas. Only some of the cable operator and new operator projects have acceptable economical results. The advanced cable modem projects for the cable operator, including the full service set have acceptable levels of internal rate of return above 20 %, whereas the conventional cable modem upgrade with a limited midband

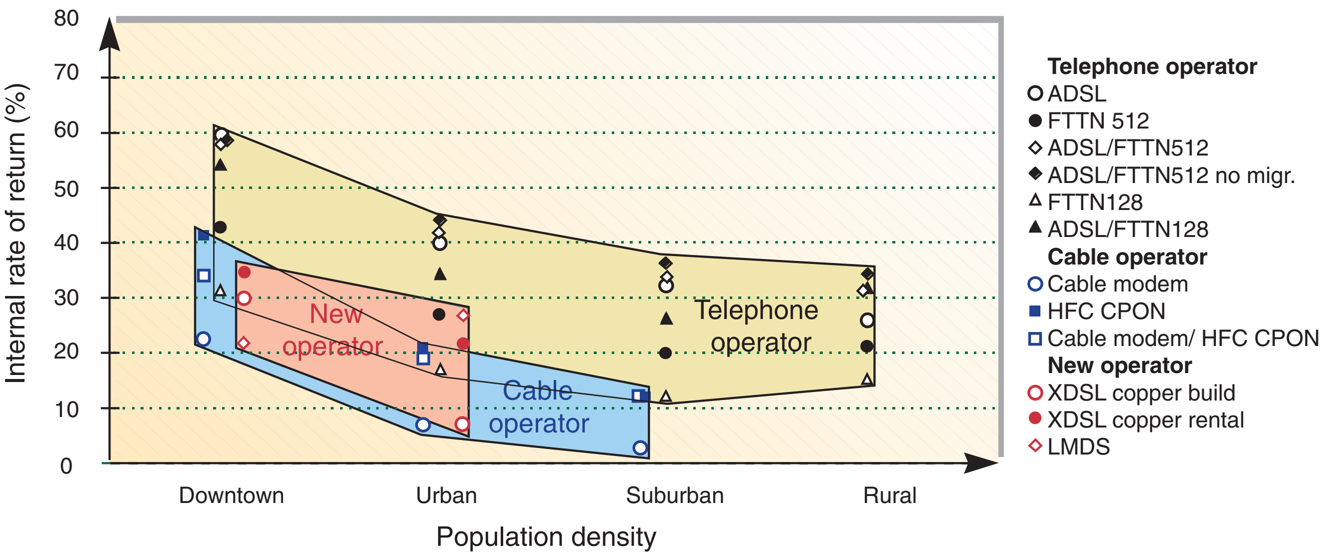



*Figure 11 The internal rate of return results (in %) for the different operators and their different evolutionary paths applied in various areas*

service set has an internal rate of return of 7 % only. For the new operator the XDSL copper rental and the LMDS upgrade with a limited se vice set have acceptable levels of internal rate of return above 20 %. The XDSL copper build upgrade however, has an internal rate of return of 7 %.

In the suburban area, most of the evolutionary paths examined for the telephone operator give acceptable levels of internal rate of return. All of the evolutionary paths examined for the telephone operator give acceptable levels of internal rate of return, except the most aggressive 1998 roll-out of an FTTN configuration with 128 homes passed per node. The average internal rate of return for all telephone operator projects in the suburban area is 27 %, varying from 12 % to 36 % in suburban areas. In the suburban area, none of the cable operator projects have acceptable levels of internal rate of return above 20 %. The average is 8 %.

In the rural area, most of the evolutionary paths examined for the telephone operator give acceptable levels of internal rate of return. Only telephone operator projects are examined for the rural areas, and they all give acceptable levels of internal rate of return above 20 %, except the above mentioned aggressive 1998 roll-out of an FTTN configuration with 128 homes passed per node. The average internal rate of return for all telephone operator projects in the rural area is 27 %, varying from 16 % to 34 % in these areas. The average is in fact similar to the average in the suburban area.

## 8 Concluding remarks

In EURESCOM project P614 a study on broadband radio access solutions has been performed during year 1998, with the following main findings and conclusions:

Radio is obviously an attractive alternative for broadband access, because it alleviates the need for cable infrastructure investments in the last drop towards the customer, infrastructure investments which sometimes are very high. This applies in particular to new entrant operators, because they do not have the existing cable infrastructure that they could utilise by using XDSL modems (telecommunications operators) or cable modems (cable TV operators).

Also for the existing operator, broadband radio access solutions such as LMDS are very interesting, maybe particularly as an alternative drop technology to VDSL in combination with a fibre feeder infrastructure. Nevertheless, LMDS and VDSL are different with respect to the coverage area, and possibly also regarding quality of service. Thus, depending on factors like the radio propagation situation and the condition of the existing twisted pair network, the incumbent operator may utilise both LMDS and VDSL in different areas.

However, broadband radio access technologies are still emerging technologies. They are not as mature as some of their wireline counterparts. More mature wireline technologies such as ADSL have experienced a higher cost reduction over the past years, a reduction which is not yet seen for radio technology. In addition, the analysis does not reflect the potential economic benefit gained by the faster deployment of radio upgrades compared to wireline technology roll-out. Broadband radio access technologies, like LMDS, also offer possibilities for convergence between broadcasting and telecommunications.

In spite of high uncertainties associated with the techno-economic studies of broadband radio technologies it is easy to see promising possibilities for LMDS like systems. Further studies should include revision of the cost information, when LMDS products start to emerge on the market. Also dimensioning of the radio network such as the maximum achievable radio range, cellular coverage, structure of coverage and network upgrading strategy must have more emphasis in the next phase. These, together with service quality issues, are important aspects in a fair comparison and analysis between wireless and wireline solutions.

## Glossary of terms and acronyms

| | |
|---|---|
| ADM | Add and Drop Multiplexer |
| ASB | Asymmetric Switched Broadband |
| ATM | Asynchronous Transfer Mode |
| DRRS | Digital Radio Relay System |
| DXC | Digital Cross-Connect |
| GHz | Giga Hertz |
| IF | Intermediate Frequency |
| ISDN | Integrated Services Digital Network |
| ITU | International Telecommunication Union |
| IWU | InterWorking Unit |
| LEX | Local Exchange |
| LMDS | Local Multipoint Distribution Services |
| LOS | Line Of Sight |
| MPEG | Motion Picture Expert Group |
| MVDS | Multi Video Distribution Service |
| P-P | Point to Point |
| P-MP | Point to MultiPoint |
| POTS | Plain Old Telephone System |
| PSTN | Public Switched Telephone Network |
| RBS | Radio Base Station |
| RF | Radio Frequency |
| SDH | Synchronous Digital Hierarchy |
| SSB | Symmetric Switched Broadband |
| TS | Terminal Station |

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# User reactions to interactive broadband services

RICH LING AND SIRI NILSEN

**New interactive technologies are starting to enter the private sphere. The social integration and social distancing caused by these technologies is examined in this paper. The analysis takes up the interviews of 13 families who participated in a trial of video-on-demand in Oslo, Norway. The technology was integrative in that it provided a focal point for the social interaction of the family. It was a system around which they could build up minor celebrations of unity and it provided a framework upon which they could set into life their common perceptions. It was also integrative in that it forced them to make obvious their preferences in terms of program selection and pacing in a way not available with broadcast TV. At the same time, the technology can be a wedge between family members as it can be the focus of ideological disagreements and a crystallization of gendered identity as it plays on already existing distances and predispositions**

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## 1 Introduction

In setting the stage for this paper, we are interested in the role of technology, and technical objects such as those associated with LMDS, in the organization of people's lives. The examination of social meaning of physical objects has long been a part of academic tradition. The anthropological literature in particular has focused on the integrative (and for that matter disintegrative) functions of artifacts (see for example Mauss 1990; Malinowski 1961). Technology, of course, has the ability to alter institutions. Others (Cottrell 1945, Sharp 1952) have described the social effects of various technological innovations ranging from iron axes to diesel motors. Following this line, this paper is not so much about a new technology but rather it focuses on how persons in society strive to place technology into the context of their everyday lives.[1)]

We take our point of departure from a field trial of a video-on demand (VOD) system called *Videotorg*.[2)] It is the introduction of this system into the homes of trial participants in Oslo, Norway that provides us with the chance to focus on the role of new technology in the definition of the modern home. While the paper describes a specific technology and a specific service, the results are generalizable to a broader issue, that of the integration of interactive services into the routines and the homes of people in everyday life. It is obvious that there is a broad range of technologies that will transport material into our homes in the future, broadband radio being one of them. It is also obvious that there is a whole set of services that are yet to be imagined, let alone implemented.

In short, the data we examine here reveals that there are two forces at work. The first is that the broadband technology provides a focal point for the social interaction of the family, a device and a system around which they can build up minor celebrations of the family's unity. It can provide them with the chance to set into life their common perceptions and it can be a prop against which they can develop and form new conceptions of their interaction. At the same time, the technology can function as a type of wedge between the members of the family. It can be the focus of disagreements. And can become a symbol for the gendered identity, and thus the embodiment of gender differences.

New technology is particularly prone to this indeterminacy since, by its very nature, it disturbs the routine and occasions the development of new approaches to everyday life. In the case of *Videotorg*, the technology was a force pushing toward more integration at the small group level. At the same time, the centrifugal forces of the technology were pushing toward more and more individualization. On the one hand, greater choice, and more interactivity – as afforded by systems such as that described here – mean that there is more interaction within the home when it comes to the choice, timing and pacing of TV viewing. Thus, many of the respondents experienced *Videotorg* as more social than traditional broadcast TV. On the other hand, each individual is increasingly able to follow their own muse and find the material that is most of interest to them. On the one hand, the technology brings

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[1)] *This paper is an edited version of the paper entitled "The examination of social integration and differentiation as modulated by new video technology" by Rich Ling, Siri Nilsen, Stefan Granhaug.*

[2)] *This is the name of the VOD trial carried out in Oslo in 1996.*

together the family in common experiences and provides them with the chance to spin a tighter web of interaction through the integration and use of the technology into their lives. On the other hand, the technology can solidify the already existing distances between individuals, genders or generations. Thus, the system seemed to both integrate and distance the users in a variety of ways. The fact that the technology and the services in the trial were, and still are relatively undefined means that its social meaning moved in both directions at various moments of its consideration. According to Winner:

> Many technical devices and systems important in everyday life contain possibilities for many different ways of ordering human activity. Consciously or not, deliberately or inadvertently, societies choose structures for technologies that influence how people are going to work, communicate, travel, consume and so forth over a very long time. In the processes by which structuring decisions are made, different people are differently situated and possess unequal degrees of power as well as unequal levels of awareness. (1985)

We now turn to a short discussion of the data and the methods used in the analysis. This is followed by the presentation of the data and its examination.

## 2 Description of the trial and methods used in the study

In 1995–1996, Telenor, the former PTT in Norway, carried out a trial of the VOD system under the title *Videotorg*. In this paper, we will examine interview material from 17 households that participated in the trial.[3)]

The VOD system developed in the trial involved a switched and networked video retrieval system. The users could, with the help of a remote control and a set-top box, order and view films and other video material from a central server via the telephone lines.[4)] This system is fundamentally different from broadcast technology that sends the same material to all viewers simultaneously. Via the use of *Videotorg*, the users could select the material in which they were interested and view it at the time they wished. They were able to stop the material, rewind it or to jump forward. The system was, in effect, a virtual video machine, the major difference being that they avoided the trip to the video store.

The server mentioned above is in essence a large computer that can store the video material electronically on hard disks. Transmission systems can include, for example, satellite, coaxial cable, and radio signals or, as in this case, an enhanced version of the existing telephone system. The goal of the *Videotorg* trial was to develop a VOD system, to gain insight into the user's interest in this type of service and examine their ability to navigate in the material. In order to achieve the latter goals a series of films and other video material were placed on the system. This included children's films and cartoons, several genres of commercial films, some music videos, nature programs, documentaries, "how to" programs such as cooking videos and some information programs. There was a total of about 60 commercial films and 100 other titles that circulated through the system during the trial. The trial lasted approximately one year. The participants were not expected to pay for the use of the system. The most popular types of material included cartoons, dramatic films and comedy films.

The participants included 17 families and couples who were given access to the system during the trial period. The participants all lived in central portions of Oslo. They generally had slightly higher income and SES and were somewhat younger than the average.[5)] In addition to the actual use data, 14 of the families were interviewed. The interviews focused on their use and perceptions of the system. It is this set of interviews, and in particular seven of the interviews wherein both partners of a couple participated, that make up the core of the analysis presented here. The interviews took place in the homes of the informants, generally in the evening. They covered the respondents' general perception of the system, a discussion of the physical equipment and its integration in the home, use of the system, the respondents' perceptions of changes

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3) *In addition to these homes the trial included VOD services to several local schools and to a handful of public demonstration sites.*

4) *The transmission system used here was Asynchronous Digital Subscriber Line (ADSL). This is only one of the technologies that can provide broadband access to the household. Others include LMDS, coaxial cable and even the power grid. The perspective in this paper is that of the user and while the characteristics of the various transmission systems vary, this is often of lesser relevance to the end user than the actual services provided.*

5) *It needs to be noted here that within certain limitations, the point of this work was not to generalize to a larger population. The limited sample size precluded this possibility. Rather, the work should be described as descriptive and exploratory.*

in household routines caused by the system, an examination of the economic issues of VOD, and the coverage of any general questions raised in the course of the interview.

The interviews were transcribed and examined using qualitative text analysis techniques (Glaser and Strauss 1967, Lofland and Lofland 1984, Spradley 1979). After the categories and concepts began to take form, the relevant portions of the text were translated from Norwegian to English for inclusion in the paper.

## 3 New technology, integration and distancing

One of the processes made obvious in the interviews, particularly in the seven interviews of couples, was the way in which the technology rendered certain aspects of the couples' shared identity. Usually, early in the interview, when the discussion was at a more general and introductory phase, the couples were more unified in their presentation of themselves. However, as the discussion progressed, and as unexplored aspects of the new technology arose, the couples' common identity was more difficult to maintain.

Some of the difficulty in management impression may be due to a greater willingness to confide in the interviewer as the rapport increased.[6)] However, the difficulties may also have to do with the undefined nature of the technology. Livingstone, for example, talks about the ways in which technologies can encourage either differentiation or similarity (1992). Since *Videotorg*, and VOD in general, were relatively new technologies, the participants had often not been able to fully investigate all the possibilities of the system, nor had they been able to collectively think through the broader social and economic consequences of this type of interactive system. As these previously untouched issues arose the transcripts of the interviews showed that the façade began to show cracks. Small disagreements arose and were either solved, or put aside. In addition, the technology proved to be a foil through which the interviewees' assumptions about social differences were focused. Thus, the interview situation provided insight into both the integrative and distancing aspects of new technology. In the section that follows, we will examine the ways in which the solidarity of the couple was displayed in the interviews. Following that we will go into the ways that VOD led to divergence within the homes.

### 3.1 Social integration and *Videotorg*

At the level of the viewing experience many of the respondents noted that *Videotorg* was more social than broadcast TV. The technology gave the participants a chance for the trial participants to interact in the selection of material and in the way that they paced their viewing.

There was the sense in the interviews that the viewing experience was more like that of seeing a video (Ling, Nilsen and Granhaug 1999), the difference being that one did not need to bother with the process of renting the film. This prompted one respondent to note that VOD provided the oxymoronic potential of efficient relaxation (*effektiv avslapningstid*).

The association with videos led the respondents to compare the viewing of *Videotorg* to that of the broader social context in which one viewed videos. *Videotorg* was described by one respondent, for example, as a box that is installed at home with which one can order a film and *"kose seg."* The literal translation from Norwegian is that one can have a "cozy" time. This reflects the findings of others that have examined the social context of video use. The specific formulation, however, plays on an important Norwegian cultural concept, particularly in terms of the production of domestic space (Gullestad 1984, Gullestad 1992, Guttu, Jørgensen and Nørve, 1985; see also Krugman et al. 1991). The words *koselig* (cozy) and *kos* (coziness) are directly translatable to English, but the cultural meaning and feelings that they evoke are much broader and enjoy much wider use than in English. The Norwegian use of the word includes a sense of relaxation, intimacy and introspection. In the sense used here, the word is a common positive evaluation of a social experience, ie. experiencing a special time with friends or through a contemplative period alone. The sense conveyed in the quote here is that it is not simply a film that is consumed, but rather it is a broader social experience that includes other elements, ie. relaxation, conversation with friends, something to eat, a certain portion of the week, etc.

The respondents described viewing a film, either via *Videotorg* or via a videocassette as a different social experience when compared to broadcast TV. This was associated with the issue of collectively deciding to see a film vs. the more individualistic zapping or surfing behavior of normal broadcast TV. In the words of one informant:

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6) *Confiding the small flaws in one's relationship to a third party can, at one level, be seen as a type of crack in the façade. At another level, however, it can be seen as a sign that one is secure in one's relationship. The jovial and lighthearted revealing of each other's flaws and the banter surrounding these revelations, is a way to show the solidity and flexibility in a relationship.*

> I think the system is more social because you can agree beforehand on what you want to see and so you are sort of social about what you see. But with normal TV people are so captured by the "square" that it doesn't matter what is happening on the screen. Regardless of what it is, it captures your eyes.

Others have noted the idea of video as a social event. Grey writes that the video selection process can be a collective decision, and thus there is a more binding social aspect to the event (Grey 1992, 226). Lindloff notes that a division of labor associated with the preparation of a socially oriented video session in that it is women who are the instigators of social events centered on video viewing.[7)]

> Another common pattern for women's VCR usage – and to a lesser extent, of all family members – was to organize VCR events as social occasions, replete with special food preparations and proper notifications (often after considerable negotiation) of starting times (Lindloff 1988, 180).

In a similar way, Krugman et al. report that while families prepared food to the accompaniment of broadcast TV, food consumption was associated with the viewing of videos (Krugman, Shamp and Johnson 1991).

Another aspect of the system was that it allowed a control over the pacing of viewing not available in broadcast TV.

> [*Videotorg*] is more social in that it does not control you as much. You can pause the film if you suddenly want to do something else. And you can choose the time yourself.

The control of pacing allowed the participants to carry out other activities while not missing the film. It also allowed the respondents the ability to clarify the plot or action in a film via the use of the rewind function (see also Lindloff, 1988). One informant noted that:

> [With *Videotorg*] you can discuss the choice and even stop the film along the way. A video cassette is more social than TV because you can [for example] insist that he held the knife and the other one at the other end of the sofa can say no and so you can rewind and see how it was.

Thus, VOD was seen as supporting social interaction within the home via film selection, arranging the ancillary artifacts, ie. snacks, drink, etc. In addition, one has control over the pacing of the viewing and can even review the action of the film. One can stop the film in the case of disturbances and thus guarantee that all the viewers share the same experience.

#### 3.1.1 Displays of rehearsed solidarity

Turning now from the specific characteristics of *Videotorg* to the more general issue of coupled identity, the interview situation provided insight into how this was managed and presented in the context of discussing new technology. It is clear that the negotiation of these issues will accompany the introduction of new broadband in the home. In the case considered here there were, at various points in the interview, issues that either allowed the couple to display their solidarity, to reaffirm their coupledness, or to question it.

In relation to the first of these, the display of solidarity, it is clear from the transcripts that the interviews often breached questions for which the couple felt they were covering common ground. In these situations the couples provided a common, and perhaps rehearsed[8)], set of meanings about the issue at hand. In relation to *Videotorg*, questions regarding the operation of the system, the program selection and particularly the integration of the system into the decor of the home, often resulted in this type of practised answers.

This latter theme, integration of the system into the decor of their home, led to such exchanges on several occasions. The decoration of the home is a common theme between couples that represents their taste, style and competence in the arrangement of cultural signs. It requires integration, cooperation, and perhaps not just a little give and take, between the two. The achievement of an acceptable display in the home represents an ongoing project and a considerable economic commitment. The couple must think, and talk, through the various aspects of the display. Perhaps it is because of this need to set words to their conceptions of interior decoration that the vocabulary and rhetoric are at hand in the interview situation.

In some of these cases the talk of the informants was so well engrained in their common identity that the two were in effect giving a common

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7) *Grey describes the social nature of video viewing from several perspectives. For example, she discusses the use of videos as the focus of afternoon social interaction among housewives who have finished their regular work at home (1992, 110).*

8) *When the concept of rehearsing is used here it does not refer to a type of coaching specifically for the purpose of the interview, ie. "if he asks about X you can respond with Y." Rather, it refers to the practice of re-applying formulations and concepts that were struck upon in other similar contexts.*

answer. It was almost irrelevant which of the pair was talking because the words were the common property of both. The respondents talked over each other, but the effect was a single sentence coming from two persons.

This style of tightly interwoven interaction is seen in the following sequence where a couple describes the placement of the *Videotorg* equipment. To set the stage, they lived in an exclusive apartment with a well-appointed living room. The husband was a businessman and the wife was an interior designer. Because the style of the *Videotorg* equipment clashed with the interior design of the living room they had placed the system in a bedroom. In the following sequence we see the couple clarifying their action to the interviewers.

> Man: [The *Videotorg* equipment] is not exactly fine furniture, nothing to have ...
>
> Woman: But we have put it in the bedroom, so I don't feel that ...
>
> Man: We have it beside the PC and ...
>
> Woman: Yea, together with the video and this and that. A little more doesn't play any role (laugh)
>
> Man: (laugh[9])

Here the respondents had a taken for granted agreement between themselves regarding the decor in their living room. The problem was to legitimize this to a third party, ie. the interviewers.[10] It is clear that *Videotorg* and other things electronic are not a part of their image of the living room. Thus, there is no point of disagreement here. Rather, the discussion shows that the definition of the apartment was well engrained in the consciousness of the two. Both had a similar set of formulations at their fingertips. Another interviewee described some of the same when she said "We ... overlap each other."

### 3.1.2 Displays of achieved solidarity

Another example of integrating interaction can be seen in the following sequence. As opposed to the previous example wherein a couple displayed a set of rehearsed meanings, here the couple achieves an agreement in the process of the sequence. The specific issue is the pricing strategy for *Videotorg*. One sees that while at the outset there is a seeming disagreement between the couple, who are also both economists, it is managed with reference to their common understanding of economics.

> Woman: I have thought that you could pay a fixed price to have it because otherwise you would feel that you have to be careful with this product. I think it would be a problem for me if I would watch a cooking program just to make dinner. Then I would feel that it is too much luxury. I would have used a monthly charge, and a ...
>
> Man: Yeah, but the system actually gives the possibility for flexibility, namely that you use it as you need it. This is the whole basic idea as I see it. It is exactly that you can select and therefore pay for what you will. You avoid paying for these common bills for things you do not use. That is NRK's little thing, namely that you pay for the whole thing even though you only watch TV2.
>
> Woman: But for me it would be a very attractive product if I could use it a lot, and that means that there has to be more than only entertainment films that I watch every fortnight. It has to be something that gives me something, like, for example, that I watch Norwegian news every day. That way I would be in the system all the time, I have a constant need to update myself. But a unit price for such daily use would be high. I would not allow myself to use it to any degree.
>
> Man: Yeah, maybe it is not really a discussion of what is rational, more psychology. It is not sure that our economy would have been worse off by using it, but in terms of psychological feeling I agree with what you say as a matter of fact. Then you would have considered the system through a monthly rental and ...
>
> Woman: Yeah, and you feel that you must also use the system and ...
>
> Man: Yeah, and that conflicts with one of the strongest advantages here, exactly that you can take out what you want in terms of need and only pay for that ... actually, I am a little interested in the psychology here.
>
> Woman: That is why I say that the system must be more than only films ...

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[9] *Other dimensions of this and the following sequence were examined in an earlier analysis (see Ling, Nilsen and Granhaug 1998).*

[10] *In this case the interviewer is a special type of audience in that they were relatively unknown to the interviewees. Other "audiences" that are perhaps more common are friends and relatives who populate the homes of the interviewees more regularly.*

In this sequence, the two “overlapping heads” literally worked out a common front before our very eyes. This process also reconfirmed their common sense of each other both as economists and as a couple. Like the couple in the initial sequence, they end up speaking over each other in a type of two-person monologue. Their commonly forged understanding of the technology, and perhaps more importantly the process of coming to agreement – becomes yet another brick in the edifice of their relationship.

### 3.1.3 Teams and team playing

These sequences illustrate the process of what Goffman calls team playing. The central team here is the couple. Following Goffman they are, in effect, asked to maintain the appropriate tone or impression. Thus, they may be forced to paper over the differences upon which their private interaction can founder.

If, for example a “team” consists of a single individual that person can make a claim as to the content of reality, and maneuver about in that definition with a free hand. The only thing that the individual needs to be concerned with is the legitimacy of the claim in the eyes of the audience.

As the number of team members increases there is an increased need for the team to keep its story straight. Thus, impression maintenance becomes more complex as the potential number of distracting or contradicting cues increases. The “party line” of the team needs to become more streamlined and the loyalty of the team members to that position becomes more important (Goffman 1959, 85). One can imagine, for example, that while the decision for the first couple to place the *Videotorg* equipment in the spare bedroom was easily taken they had a serious discussion as to which sofa to include in their living room or which color to paint the walls. Once the decision is taken, however, it is far better for both parties to observe and maintain it.

Open disagreement, an unclear line or, as in the case with new technologies that are made possible with broadband access, the discussion of topics for which there is no “party line,” makes the management of an impression difficult. The tactical splintering of loyalty can be seen through the joking and underscoring of the small ironies of the presentation.

Another danger with teamwork is that of mistakes or gaffs. The husband yawning or dosing while entertaining guests, the wife burning the roast or the children making too much noise are all examples of such behavior. In this situation other team members must at the very least “suppress their immediate desire to punish and instruct the offender until, that is, the audience is no longer present” (Goffman 1959, 89). They may also cover over in order to maintain the impression in the eyes of the audience.

Moving now from Goffman’s more general discussion of teams to Berger and Kellner’s (1979) discussion of a particular team, ie. the couple, one sees the importance of long term associations in the development of the common approach to the world seen in the sequences included above. Coupling, and in particular marriage, is one of the institutions in which individuals have the ability – indeed, as we will see below, the responsibility – to build up a set of commonly understood typifications that appear to others as a crystallized institution. Marriage is particularly potent in this context because the marriage ceremony and other trappings, ie. wearing rings, holding hands, appearing with children etc., are open to the examination of others.

When the married couple presents themselves to others as a couple, there is the need to communicate the status of the coupling to the audience. There is, indeed, a social obligation on the part of those in a relationship to provide signs to others as to the nature of the relationship. Failure to do so, or the misinterpretation of signs that are given can lead to difficult social situations. We are provided with a variety of devices or “tie-signs” with which one can give this type of evidence in a short hand manner (Goffman 1971).

The tie-signs include a variety of both verbal and physical signs describing the relationship of the couple. They may even include one of the team revealing slight indiscretions of the other team member to the audience if only to indicate their degree of access. In the case of the interviews for *Videotorg*, the tie-signs were massively obvious to the third parties, ie. the interviewers. It was reflected, for example, in the seating during the interview, ie. the couple seated together on the couch opposite the interviewer(s), etc.

A tie-sign writ large was the fact that the interviews took place in the homes of the participants. The home is, in many respects, the ultimate shrine to the coupledness of the pair (Gullestad 1984, Gullestad 1992, Guttu, Jørgensen and Nørve 1985, Nørve 1990). One can see this referred to with regard to the couple who had placed the system in the bedroom. Their well-rehearsed discussion of the interior decoration in the living room and the exclusion of *Videotorg* shows how the interior design was an evocation of their common identity. Turning to the pair of economists, one literally witnesses their reference to economic thinking as a type of tie-sign. Their discussion and agreement of a pricing strategy for *Videotorg* is an indication of their coupledness.

In these interviews one sees how in contemporary society, there is a reliance on the dyad in the construction of the reality that constitutes marriage. This means that the contemporary institution is more precarious as meaning has to be minted by only two, as opposed to many individuals. In contemporary culture, the marriage represents the crystallization of the private sphere as a separate institution that is segregated from other more public portions of society but that none-the-less draws on generally held conceptions. In addition, it is a sphere where one is provided a space with which to try out their identity and within which one can seek self-realization (Berger and Kellner 1979, 311).

> Every social relationship requires objectification, that is, requires a process by which subjectively experienced meanings become objective to the individual and, in interaction with others, become common the property, and thereby massively objective (Berger and Kellner 1979, 312).

Berger and Kellner state that the "nomic instrumentality" of a couple is made more massive through the various interactions that make up their common everyday lives. The interaction, and in particular their commentaries and embroideries on various experiences, make the coupling socially massive. In a stable, well-functioning marriage with a long history, the outlooks and perceptions of the world shared by the couple may not have validity until they are modulated through the other. One can see this in action in the two citation series above, particularly in the former wherein the common definition of the living room took on institutional proportions. Indeed, this process can go beyond the grave in that the surviving partner may evoke the other's perceived outlook in order to place events and activities into an understandable context.

Here one can also see that the rapid innovation of new technology has the potential to make obvious the differences between the individuals. This is because new technologies, such as *Videotorg*, come at such a rapid pace, and have so many dimensions to be examined, that it becomes difficult for the couple, or even a larger family with children, to examine, and form a common understanding of the various aspects.

In both of the cases described above the situations were successfully negotiated. The identity of the couple survived the speech sequence intact. The actors were able to manage the presentation without foundering on any underlying disagreements. In fact, the sequence describing the two economists touches one as the interaction of a pair that shares not only an emotional life, but also a more ideological life via their common academic orientation. The fact that they encountered and talked through a disagreement shows the way that they were able to evoke these two dimensions in their creation and maintenance of a created common sense of the world.

The fact, however, that the mask slips a bit indicates that the maintenance of the coupled identity is a precarious affair. We see this in the exchange between the two economists in that she spins off an idea that goes against his notion of the way the system should be priced. It went outside the mutual identity that the couple tacitly assumed that they shared at the outset of the interview (see Clark and Marshall, 1981). Since the system allowed contrasting pricing strategies, ie. individual pricing vs. subscription, the new technology opened a breach in the routines of the couples' collective identity[11]. Here one can see – in a minor way – that the maintenance of the situation was precarious. If this difference had drawn on a sore point between the two, i.e. adherence to two warring schools of economic theory, the confrontation could have blossomed into what is called a scene, that is an unresolved conflict available to third parties.

When the performance becomes threatened one must strive to save it. This is what Goffman calls face work.

> By *face-work* I mean to designate the actions taken by a person to make whatever he is doing consistent with face. Face work serves to counteract "incidents" – that is, events whose effective symbolic implications threaten face. Thus, poise is one important type of face work, for through poise the person controls his embarrassment and hence the embarrassment that he and others might have over his embarrassment. Whether or not the full consequences of face-saving actions are known to the person who employs them, they often become habitual and standardized practices; they are like traditional plays in a game or traditional steps in a dance. Each person, subculture and society seems to have its own repertoire of face saving practices. It is to this

[11] *Meyrowitz provides a good discussion of how technology effects social interaction in the home (1985).*

> repertoire that people partly refer when they ask what a person or a culture is "really" like. And yet the particular set of practices stressed by particular persons or groups seem to be drawn from a single logically coherent framework of possible practices. It is as though face, by its vary nature can only be saved in a certain number of ways (Goffman 1967, 12–13).

Goffman goes on to describe the ability to easily save face as a savoir-faire or social skill. This does not necessarily refer to the frequency with which one does this, rather it describes one's ability to keep their feet under them, socially speaking.

The discussion of maintaining face etc. in relation to teaming is rendered particularly open vis-à-vis new technology. In these cases, the dynamics and characteristics of the technology have, perhaps, not been fully understood and thus a common line is not readily available. In the rush to discover a "line" upon which they can agree, the team members may appear uncoordinated and be forced to gloss over the gaps with various forms of social graces and social skill. The presentation proffered by the interviewees can also bring into open display discussions that have a previous history in the couple. The following sequence shows this type of interaction. The respondents in the *Videotorg* interviews were asked about their interest in Internet:

> Woman: I have to say that Internet does not replace so much of things that I use on a daily basis. I think that newspapers are better.
>
> Man: I completely disagree.
>
> Woman: No, if you want to find specific information, then ...
>
> Man: Yeah, if you want to find information on a theme where you do not know specifically what you want . Then you can search several different ways.
>
> Woman: Well, that is nothing that I would use on a daily ...
>
> Man: I would use it ...
>
> Woman: Well, for information, yeah ... No, for the things I am interested in I would rather buy a book, for example a garden book, instead of sitting there and finding a little information here and a little information there.
>
> Man: You can actually find links to ...
>
> Woman: Yeah, but it is pretty tiring, unstructured.
>
> Man: We disagree a little here.
>
> Woman: Yeah, it is not easy to say if it is only a fad or if it is going to be a part of people's normal lives.

Where the two couples cited above almost fell over each other in their completion of a single thought, this couple is hasty in their attempts to cut off the other partner and present their own arguments for or against the Internet. In the end, they avoided a scene by, perhaps temporarily, calling off the discussion. The man turned to the interviewer and stated the obvious that they are in disagreement and the woman followed with a weak platitude regarding the long-term viability of the Internet. The effect is that of poorly executed face-work. A rift has surfaced in the presentation of the interviewees as a couple. Thus, they were put into the position of having to manage the impression and bring the situation back from the possible escalation of the disagreement. This is a transition to the next section on divergences arising from new technology.

### 3.2 New technology and social distancing

The discussion here has bled over from *Videotorg* as a focus of integration to one about individualization and *Videotorg*. Following this lead, we now turn to the ways in which the discussion of *Videotorg* brought out individualization and social distancing within the home.

Silverstone and others have pointed to the notion that new technologies have to be learned and that this process changes both the context in which the technology has been placed, and the understanding of the technology (1994, 96–97). In addition, media technologies have what he calls a double articulation such that both the technology and content are available for various interpretations and uses. In the discussion heretofore we have seen how alternative interpretations have arisen in the description of *Videotorg*. It is not surprising then that *Videotorg* drew out tendencies toward individualization. At the interpersonal level respondents noted that the system allowed them an alternative to the normal broadcast media. One woman, for example, used the system extensively while her husband watched soccer on another TV.

> I have to admit that I had a lot of enjoyment from the system during the soccer world championships. Then I ... watched everything there was on the system while he watched sports.

The ability to seek viewing niches was, however, seen as potentially alienating and isolating. Another respondent noted that "*Videotorg* is less social because you do not get what is happening in the rest of the world." When considering the potential for home shopping this respondent went on to say: "I think it is a little anti-social if all the people sit at home and never leave their living rooms [to shop]." Thus one is drawn away from the public development of shared meaning. Rather there is a turn towards the private.

### 3.2.1 The gendering of *Videotorg*

Beyond the elements described above, the discussion of *Videotorg* also tapped into a broader set of issues. As VOD, and even the conception of VOD was new, the informants needed to locate the system in their social world. (Hirsch 1992, 210, Rasmussen 1997). The selection of metaphors to describe the system, its physical placement and its integration into the routines of the household were all parts of this process (Ling, Nilsen and Granhaug 1999). A particularly salient dimension called upon in this contextualization process was gender.

As is the case with many other household technologies, the respondents were quick to see *Videotorg* in gendered terms. One woman, for example, described the system as "Erik's [her husband's] project." Later in the interview she said:

> Woman: Yeah, [we were willing to participate] as long as he took responsibility (laugh).
>
> Man: I think it is an interesting technology (slightly defensive tone).

Gendering is often a part of the very conception, design, marketing, purchase and adoption of a product. In Akrichs' terms it is scripted into the device at several levels in the production and consumption process. These scripts can be seen in the functions envisaged for the product, its final form, the style and content of the marketing, the justifications used when purchasing the object and the way in which the device is located and used in the home. At each of these levels there are value decisions being made. In effect, these decisions are an integration of previously existing social values (Akrich 1992). This means that there is openness in their design for certain groups, just as there is a closure for others. The openness or closure can be in terms of their physical formation or design. It can also be seen in terms of the very acceptability of persons "of that type" being interested in the object in the first place.[12] At the extreme they will not be allowed access to the items and at the very minimum, appropriation of the items by the wrong type of person means that the individual must operate in spite of that which is taken for granted in everyday life.

Technical and electronic items are quite often gendered. This identity, however, is not simply an issue of functionality, but also of context. In Grey's work on the VCR, for example, she describes opposite gendering of identical technologies as seen in the timer on the VCR vs. the timer on the oven (Grey 1990, 179–80).

Playing on such pre-established conceptions of consumer technology, on generalized social notions of gender relations but also, on the specific interactions within the household, *Videotorg* was often seen as a part of the male domain. One can see this in the following citation wherein the woman mediated her use of the system through the instruction of her husband:

> Interviewer: Do you think the system was easy or difficult?
>
> Woman: Easy. I am not particularly technically gifted but when [my husband] showed me I understood immediately.

This citation echoes one recorded by Grey in her study of the VCR. She reports one of her respondents saying "Well, when we got [the VCR] my husband read the instructions and, you know, he told me." (1992, 165).

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[12] *For extreme scripting of consumption items one can, for example, think of women attempting to buy pipes for smoking or individuals trying to purchase items for "cross-dressing". In this connection we are reminded of some male sociology students who, upon receiving the assignment to go out and break a social norm in order to observe sanctioning behavior, decided to go to try on clothes usually reserved for elderly women in a large department store. The students were stopped by an assistant and asked if the purchases were for female relatives. When they said the purchases were for themselves, the students reported that they were stopped by the assistant and taken into the manager's office. After receiving a clarification for their behavior, the store manager lectured them sternly. As part of the justification for stopping them he noted that the security apparatus for the entire store had been set on alert with the fear that the students trying on the clothes were a diversion and that a robbery was about to take place. In this case the scripting of the objects was so heavy that it proved impossible for the male students to try on and to purchase this type of clothing for themselves.*

Thus, *Videotorg* played into prior social conceptions of gender. It served to further crystallize perceptions of technical competencies that had been, and continue to be, built up through family interaction. It was, in many respects, a reinforcement of pre-existing divisions and stereotypes (Copeland, and Schweitzer, 1993, Cowan 1989, Haddon 1992, 93, Moores 1993, Perse, and Ferguson 1993, Silverstone 1994, 97–98, Tinnell 1985). This is, however, not new. Cockburn notes that "contemporary Western femininity has involved the constitution of identities organized around technical incompetence" (1992, 41) and there are, as Silverstone reminds us, a whole series of technologies that have been defined along the lines of *Videotorg*.

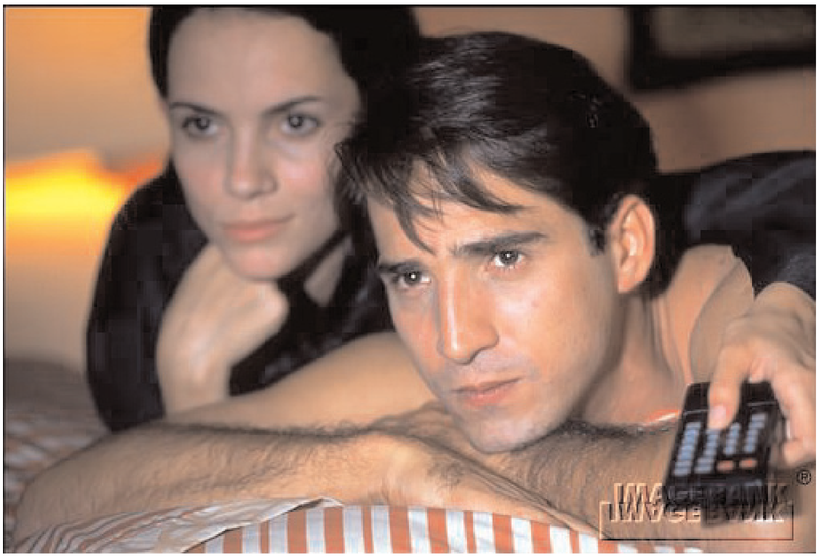

FOTO: © Juan Silva / IMAGE BANK

> The gendering of the tele-technological system is, therefore, a dialogical process, built around the dialogue between publicly defined relations inscribed into the design and marketing of all technologies, television included, and privately negotiated relations inscribed in and through the patterns and discourses of everyday life. There is little doubt that the gender relations constructed around the television, in the control of the remote (Morley 1986) or in the competence around the video recorder (Grey 1987, 1992), or indeed in the ownership and use of the computer (Haddon 1988) or the telephone (Moyal 1989) express a gendered division of labor in turn expressive of the dominant gendered structures of modern society (Cockburn 1985) ... A woman's (and also a man's) relationship to the television (Hobson 1982) or to the telephone (Rakow 1988, Mayer 1977, Moyal 1992) is a function of woman's status and role in the household, certainly, but that in itself can only be understood both with regard to the dominant structures in which masculinity and femininity are defined in the public sphere and their particular character within, from the point of view of the household, and its moral economy (Silverstone 1994, 102).

As a clarification for the gendering of VCR, Grey notes that the complexity of this technology is a barrier in that it takes the ability to set off undisturbed time to master it, a more rare commodity for woman than for men (1992, 171–2, 189). This does not, however, seem to be an adequate explanation. *Videotorg* was gendered in spite of the fact that respondents noted it was much easier to use than a standard video machine.[13] Rather, the gendering described in the citations above seems to be the application of generalized gloss of social attributes to a range of technologies, practices or tasks. The gloss directs the attention of the individual and instructs them in the appropriate stance vis-à-vis technology. It implies, in essence, a life long system of attitude and concept development wherein the individual is instructed, cajoled and directed vis-à-vis various social activities.[14]

It is clear that these are broad generalizations. None-the-less, they are generalizations that seem to hold at least some water in the eyes of the respondents. In addition, it seems from the comments presented here that these notions of the gendering of the household are a part of not only the way one carries out their everyday life, but also form the expectations that one has of the other gender.

### 3.2.2 Crystallization of femininity through *Videotorg*

The discussion in this section has, up to now, focused on how the technology was defined as being a portion of one or the other gender's domain. This follows from the sense in the literature that the scripting and gendering of devices goes up and down the production/consumption chain (Cockburn 1992, 41).

There was, however, another dimension of this issue. There was the sense in the interviews that the informants defined not only themselves but

*Gender seems to play an important role in the home's adoption of new technology. Our analysis indicates that men gain an identity via the adoption and use of new technology where perhaps women are more focused on the content into which the technology is placed*

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[13] *For a further discussion of Grey's analysis, see Hellman (1996).*

[14] *For example, the whole gender specific system of doll playing and instruction in nurturance via work as babysitters is one example of the way in which society genders certain tasks. In the same way that young girls are exposed to certain expectations that, later in life, direct their attention away from an interest in technology, with boys one can often see the opposite, ie. the interest in technology.*

also each other vis-à-vis the technology. We observed that the technology was part of the mutual definition process that goes on within the home. Not only was the technology gendered, but also often when a couple was interviewed they defined each other in terms of the technology. This definitional process went in two directions. In broad strokes, the men described their wives or partners as being technically naïve, while the women described their counterparts as being technically fixated.

Turning to the first portion of this equation, several of the men displayed a type of superiority when describing the system. This was in some cases rather directly stated. One informant, for example, used his wife as a reference point for underscoring just how easy it was to operate the system. He said "it is very easy, even my wife can manage to use it, with a little instruction, if you understand." Inherent in the comment is also the sense that he can master both the system and the incompetence of his wife. Another couple played out the same theme.

> Woman: ... even I have the necessary technical insight [into the control of *Videotorg*].
>
> Man: But wait a half ... So when we have friends visiting it is the boys that stand here with the remote control, I don't know, have any of your girl friends tried this while they were here?
>
> Woman: Yeah, a lot.
>
> Man: And it has gone completely ok?
>
> Woman: Jesus! Of course!
>
> Man: Ooooh! I am impressed.

In both of these cases one sees competence in the operation of a technical device, *Videotorg*, as a component in the definition of a partner. There is an implicit suggestion that women do not understand the system and that its operation is the realm of men. Indeed, the men state the claim of female incompetence in literal terms here.

While the women were assumed to be less technically competent, they were seen as having a greater interest in the content of the system. In some cases this took the form of women being described as slaves to various types of programs. In the following series of comments, one can see this theme being played out.

> Man: Yeah, we are sitting here, say that it is a Thursday like today, and there is a lot of rubbish on TV and so this is actually a great alternative to find some films you have not seen. We have actually seen several films that have been shown in *Videotorg*.
>
> Woman: Also, if you want to see a film in the middle of the day, in the morning, or in the middle of the night or God knows when it should be, there is not that much to see on TV, then you also have *Videotorg*.
>
> Man: Here we have soap opera fan number one.
>
> Woman: *Glamour*;[15] no, it is everything from A to Z. I don't watch NRK, I have to say it is the channel I watch the least, with Norwegian theater and different things. No, it is all the channels, TV2, TV3, TV4. And films and different "snacks."[16]
>
> Man: Yeah, there are also the debate programs I like, but she doesn't like them very much.

Thus, one was able to detect two ways in which women were described vis-à-vis *Videotorg*. These included technical naïveté and a fixation on content. These comments also help to define a gendered perspective of the divide between what one might call the object and the content approach to *Videotorg*.

### 3.2.3 Crystallization of masculinity through *Videotorg*

There arose from the interview material a view of men as being interested in the technology and the object status of the system. One often comes across comments wherein the woman suggests that the man is more interested in the physical components and in the status that they provide. The responses from the men, in many cases, seem to support these assertions.

> Woman: I have used it the most because I have been home *but he has used it the most without seeing anything, just to show it off and play* and technical interest. It is clear that he is the most interested on a technical level and thinks that there is a lot of fun with a new system. It is so fascinating, but that doesn't mean anything to me as long as there are no good programs to enjoy. It can be as advanced as you want but as long as it doesn't give me anything then ...

---

[15] *The title of a soap opera, said with an ironic flourish.*

[16] *Og sånn filmer og forskjellige "snacks." This description echoes Grey's (1992) and Morley's (1986) finding that women have a less concentrated style of viewing TV.*

> Man: I think this is a lot of fun ... but it is only a short-lived joy I think, because after a while the neighbor will have one and then it isn't fun anymore. (Emphasis added.)

The lines of the same discussion are also seen in the words of another couple.

> Woman: The things that are on the system today, there is so little and so bad that my willingness to pay is about equal to zero. As long as there is nothing else in there I don't even want the thing.
>
> Man: It is fun to show it off, it really is.

One sees here the enthralment with the technology. These sequences pick up the theme expressed in several of the other interviews, namely the ability of *Videotorg* to bestow status. In four other interviews the male informants brought up the issue in various ways. Most commonly, they (or their wives) reported that their participation in the trial and use of the system was a point of pride for the men. They reported showing it to friends who visited them as seen in the following citations from several different interviews:

> It is actually fun ... [to] show them something that nobody else has.
>
> I think that the menu is very nice, especially with that Telenor logo in the background, very exclusive (*staselig*), there are not many that have something like that.
>
> We are actually a little proud of this here. Because we are ... actually a little group that was chosen to be a part of this trial.

Comments on this theme were also likely to come in unexpected contexts such as here when the interviewer was actually interested in the frequency of viewing. The interviewee, however, used the question as an opportunity to comment on the context in which he used the system.

> Interviewer: Have you used the system regularly?
>
> Man: Yeah, I see films quickly, and it is actually fun to demonstrate it when I get a visit.

Our data shows that men displayed an interest in the system as an object or the system as technology. They were able to use it to attain status from their friends. This can indicate, however, that *Videotorg*, and other technical devices are a part of the rhetoric of male interaction. Part of the rhetoric is status, but ironically, in the establishment of status there is also a type of integration. In the case of the material here the integration in the male peer group uses technology as the common denominator.

## 4 Conclusion

In conclusion, *Videotorg* seemed to both integrate and distance the users in a variety of ways. The fact that it was relatively undefined meant that its social meaning moved in both directions at various moments of its consideration. While on the one hand it brought people together in cozy familial interaction, it also drove them apart via its gendered identity. It integrated men in their common interest in technology but it potentially isolated people and kept them inside, away from social contact.

*Videotorg* provided a forum for integration through the provision for a common event for the family members. It was, along with snacks, discussion and a period of time together, one of the elements that constituted a "video evening." The system allowed the family to discuss the selection of material and its pacing. At a broader level, the system provided a foil for the discussion of the couple's identity. It gave them, or perhaps forced on them, the opportunity to adopt the system and to integrate it into their conception of the home. It was through these discussions in the interview situation that the couples were either able to display their solidarity, to reaffirm their coupledness, or to question it.

When considering the potential for social distancing, the system also brought various issues into focus. At one level, there was a concern that the system would lead to increased social isolation. The fact that more and more institutions are colonized by electronic communication meant, in the minds of some respondents, that one loses physical contact with others. At another level, the technology either played into or even contributed to gendered differences. Since the technology was quickly gendered, it became a short hand for the description of the relations between the two genders. Images of women as naïve and men as techno-fixated were near at hand in several of the interviews.

Thus, the introduction of new technologies that disturb the encrusted routines make obvious issues that have been buried, but not forgotten. The technologies influence our interactions and cause us to reconsider the previously assumed status quo. In the words of Yogi Berra "It is déjà-vu all over again."

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# Interactive broadband services over satellite

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## Introduction

During the past decade much attention has been given to the increasing satellite capacity for Direct to Home (DTH) applications. The driving force for deployment of such capacity is the need to distribute television programmes to the public. With the advent of digital compression techniques for video and audio the bandwidth required to convey a single television programme is considerably reduced. Also, equally important, the flexibility inherent in digital television systems allows a mix of services of widely different nature to be transmitted in the same channel. These systems also allow (at least in theory) that the bandwidth allocated to a particular application be instantaneously adjusted according to the requirements, which in turn may further reduce the transmission costs.

Although the MPEG2/DVB system has been primarily designed for television distribution, much attention has been paid to designing a system which is well suited to also carry data services of a general nature, which may, or may not, be associated with a television or radio programme. The transmission format readily accepts various protocols to suit different types of applications.

The system thus opens for a paradigm shift in the design of television (and radio) programmes. On the other hand the system will also provide for the means to distribute general-purpose data in an efficient and cost effective way to low-cost consumer equipment.

Manufacturers of TV receiving equipment realise this and adopt personal computer type functionality in their design of new equipment.

PC manufacturers likewise see the potential in providing TV reception as standard PC functionality. Software decoding of MPEG2 video consumes a large proportion of the PC computing power. Some manufacturers, therefore, are introducing a dedicated engine in the PC, operating directly on MPEG/DVB protocols, to alleviate the CPU from performing the demanding decoding task.

Altogether the trend is an increasing overlap in the functionality of PCs and television receivers.

In this article the possibilities for interactive services are discussed, with reference to DTH satellite broadcasting according to the ETSI standards for digital television (based on work by MPEG and DVB) [1].

## 1 Terms used

It may be worth-while initially to expand on the terms of the title "Broadband Interactive Services via Satellite".

### 1.1 Satellite broadcasting

The paramount advantage of satellite distribution is the possibility to reach all receiver sites within the satellite coverage area *simultaneously*, regardless of their individual separation, and independent of other telecommunications infrastructure.

Secondly, the bandwidth provided by the satellite transponders allows high capacity services to be supported. This is of advantage to the user only as long as he experiences this large capacity. If the satellite channel is used to carry a large number of separate services the individual user may experience no improvement over a terrestrial low cost link.

A third advantage is the relative ease with which broadband communication using satellite systems can be established. For temporary installations satellite links may be the preferred choice over terrestrial links for cost and time reasons.

### 1.2 Broadband

In general 'Broadband' refers to telecommunication that provides multiple channels of data over a single communications medium. Normally this implies a requirement for large bandwidth. For this discussion, however, the term 'Broadband services' will be used for multiple channel services without regard to the bandwidth requirement. Moreover, it will be seen that for some of the services described the assumption 'single communications medium' is not valid.

### 1.3 Interactivity

In computers, interactivity is "the sensory dialog that occurs between a human being and a computer program". This may take the form of local and remote interaction. In our context local interaction occurs only between the user and his receiver and has no bearing on the transmitted information. Remote interaction, on the other hand, changes the contents of the transmitted signal.

## 2 Satellite channel

In the DVB satellite channel different service components are carried in separate data packet streams in a time division multiplex. Thus service components with differing capacity requirements can easily be mixed. Also components with variable data rate (according to contents) can be supported.

These systems are well suited to support applications requiring 'bandwidth on demand'. That is, access to the transmission channel is granted when the need arises, and only for as long as the actual transmission takes place. In this way multiple users can take advantage of the full transmission capacity, provided that their transmissions do not overlap. As the number of such users increases, however, a transmission time slot for one particular user may not be readily available. This user must wait his turn, and the time to deliver the information increases.

Alternatively a lower bandwidth can be allocated to each user and several transfers may be run in parallel. The effective data transfer rate is thus reduced and the apparent high capacity data link may eventually become as effective as a low-cost terrestrial link. However, if the information is aimed at many recipients, the advantage in reaching all recipients simultaneously may outweigh the lost speed, see figure 1.

The point made is that care must be taken in introducing services for satellite access, so that the advantages of satellite transmission are preserved.

### 2.1 Error handling

Data communication requiring error free data transfer generally relies on protocols where acknowledgement of the received data is used. If incorrect data are received retransmission of the erroneous data is initiated. Thus, if the transmission link is of low quality (errors are frequently introduced) much time would be used to retransmit previous data. Reduced effective bit rate would result, but in the end the received data would be correct.

In a point-to-multipoint transmission there is little room for the receivers to acknowledge the receipt of correct data. (Each receiver would not experience errors in the same data, and a chaotic situation would occur if potentially thousands of receivers request repeated transmission of different parts of the data contents.) Other means must therefore be used to ensure reception of correct data.

An adequate net bit error rate in a satellite broadcasting system for digital signals is ensured by the use of Forward Error Correction (FEC). This however adds to the complexity of the system and consumes some transmission capacity ('overhead'). Depending on the circumstances different degrees of protection can be provided. The overhead for error correction may in some cases total in excess of 50 % of the transmission capacity.

MPEG coded audio and video signals require an error free signal for correct decoding. On the other hand occurrence of an error is not catastrophic since the signal decoding recovers (resumes normal operation) quickly following an error. For MPEG2 video a noticeable error in the decoded picture on average once an hour is set as the criterion for an operational service. The bit error rate of the bit stream is then less than $10^{-11}$ (also termed Quasi Error Free, QEF). It is the responsibility of the transmission system to provide this bit error rate in the appropriate channel.

Other types of applications may fail completely in the presence of errors. For example, a computer program may not function properly if a single bit error is introduced.

Without the possibility to request data retransmission 100 % error free reception cannot be guaranteed. Any application involving a unidirectional communications link must therefore be designed to handle errors in the incoming data in a controlled way. As will be seen, retransmission of the entire data contents is a frequently used strategy to increase the reliability in such applications.

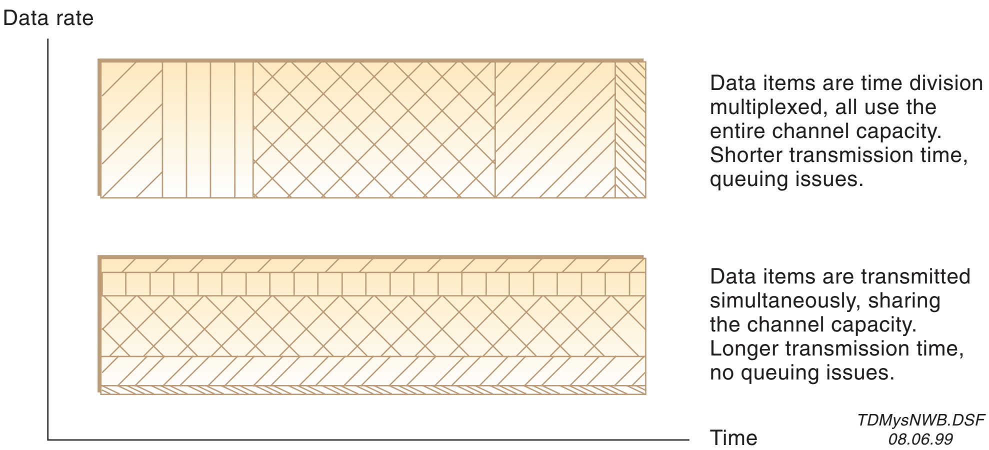



*Figure 1 Using time division multiplexing each data item is transmitted using the full channel capacity. However, some data items may have to wait their turn to be transmitted. When all items share the available capacity the transmission time is longer, but all items arrive simultaneously*

## 2.2 Data transmission protocols

The basic data transport unit in the MPEG2 multiplex is the Transport Stream Packet. In the case of audio and video streams data are first formatted into PES (Packetised Elementary Stream) packets which are then put into Transport Stream packets for transmission.

For transfer of general purpose data, a number of protocols are used to cater for differing application requirements.

Figure 2 shows alternative ways to combine protocols according to application requirements. It represents one implementation of the general protocol map of [2].

Multiprotocol Encapsulation (MPE) provides a mechanism for transporting data network protocols on top of the MPEG2 Transport Streams in DVB networks [3]. It has been optimised for carriage of the Internet Protocol (IP), but can be used for transportation of any other network protocol.

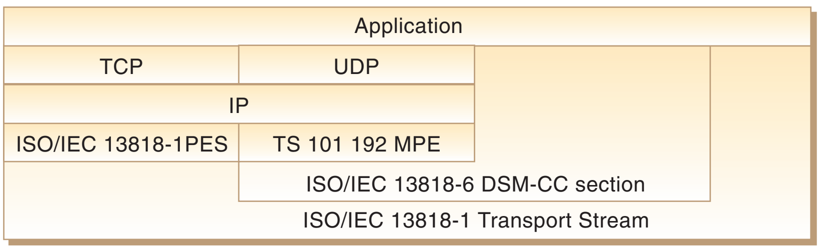
The PES protocol provides a mechanism to transmit datagrams of variable size with a maximum length of 64 kbytes [1]. Additionally it provides the facility to synchronise different data streams accurately (as used in MPEG for synchronisation of Video and Audio). It is therefore suitable for the transmission of synchronous and synchronised data streams. Also asynchronous data streams can be handled.

The DSM-CC protocol for our purpose specifies the full implementation of a data carousel [4]. The specification shall encourage equipment manufacturers to implement a common, non-proprietary solution for this functionality in domestic equipment.

Any combination of the protocols may be used. In the simplest case application data may simply be inserted directly into TS-packets using no other protocols, if appropriate.

In a different scenario an application may receive data from the TCP (Transmission Control Protocol) and IP (Internet Protocol) [8] layers, which has been transported through the Satellite network with the aid of MPE in DSM-CC sections prior to be packaged in Transport Stream (TS) packets. In this protocol stack TCP ensures correctness of the received data, whilst IP provides routing through the network according to the attached address information. MPE represents one way of packaging the TCP/IP data into TS packets (via DSM-CC sections) so that the satellite system can carry the data.

*Figure 2 Data protocol stack*




## 2.3 Round trip delay

TCP is one of many protocols which will provide error free data over the satellite link, on the basis of reception acknowledgements. The data transmission rate available using such a protocol is limited by the round trip delay of the network.

The Round Trip Delay is the time taken from data is sent until the acknowledgement for this data is received by the sender. This delay is an aggregate of (variable) processing and routing delays and fixed time constants within the network. Blocks of data are transmitted and, basically, a new block of data is not transmitted until an acknowledgement for correct reception of the previous block has been received.

A low capacity return will introduce a time delay transmitting the return channel data, and thus increase the round trip delay of an otherwise high speed communications link. This can be alleviated through the use of a higher capacity return link.

In systems including satellite links the path delay introduced by one or more satellite ‘hops’ becomes significant. This delay is constant and cannot be eliminated. For a satellite in a geo-stationary orbit the delay is in the order of 1/4 second.

The protocols provide options to compensate for such factors to some degree. Nevertheless, a large round trip delay is bound to limit the attainable data transfer rate.

UDP may be used in place of TCP if the application does not call for 100 % correct data. As a bonus considerably higher transmission speeds may be obtained. In real applications the transmission protocol should be carefully selected for different data transfers to optimise the overall performance.

# 3 Interactivity

## 3.1 Data carousels

The traditional teletext systems are based on cyclic transmission of information (‘data carousel’), and information items are transmitted in an order governed by the service provider. When the user requests some particular information (generally defined by its Page Number) she must wait for the next transmission of that item before it can be displayed, see figure 3.

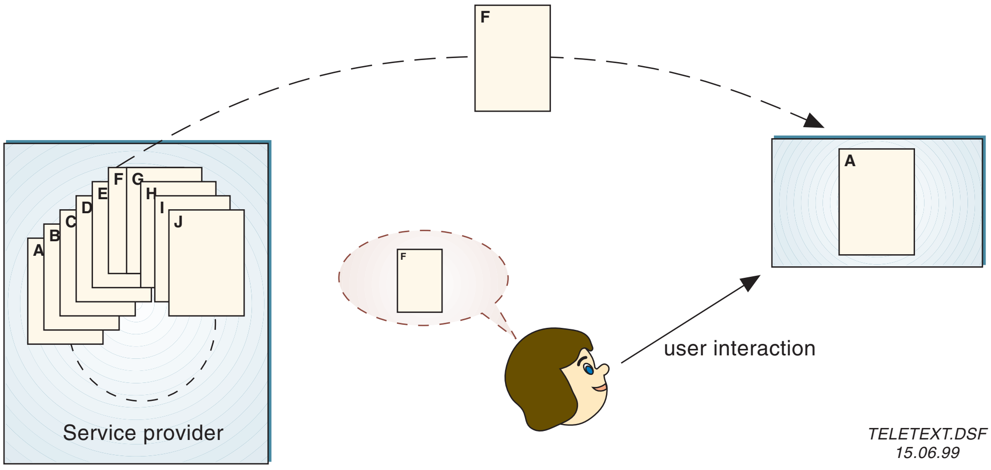



*Figure 3 When the user selects a different page she must wait until it is transmitted*

The waiting time depends on the data transmission rate and the amount of data contained in the carousel (ie. the carousel cycle time). To improve the service quality the service provider may anticipate the user action and arrange the data items in a way that may reduce the waiting time.

However, a more effective way is to equip the receiver with data memory to store the incoming data items. After one carousel cycle all data are stored in the receiver, and the user will experience instant response to her requests, figure 4.

In systems allowing higher data transmission rates than teletext systems similar strategies are used to provide interactive services in a broadcast environment with enhanced functionality.

Selecting a high transmission rate allows the use of carousels of considerable size without the cycle time becoming excessive. In addition there are many ways to enhance the service functionality through different schemes for organising the data transmission sequence and data storage in the receiver.

The choice of transmission rate is an economic question, since in itself repeated transmission of the same information is wasteful. However, in a broadcast situation it must be taken into account that the user is not 'connected' at all times, and that the response time should be acceptable immediately after connection. In addition, updating of the carousel data will also be necessary.

### 3.2 Remote interactivity

To influence the data transmission a return path is required to carry the user commands to the data provider. This path may be referred to by different names; the 'Return Channel', the 'Access Channel, the 'Interaction Channel' or the 'Uplink Channel' are some variants.

In many interactive applications the data transmission capacity required for the return path will be modest, whilst the capacity requirements for the forward channel may be considerable (asymmetric services).

Other applications, however, will require similar transmission capacity in both directions. When the return path requires large capacity more costly links must be provided, which in general also can provide two-way communication. In these cases the advantage of a satellite system over a terrestrial system may become marginal.

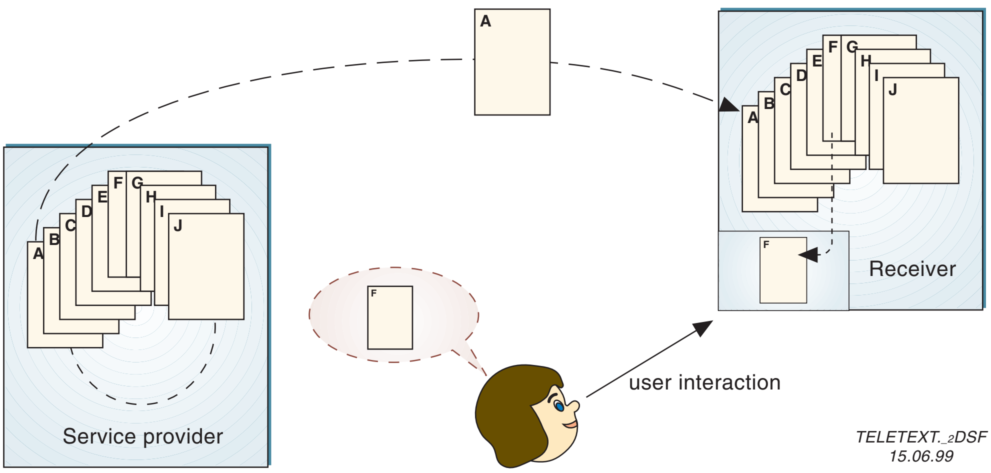
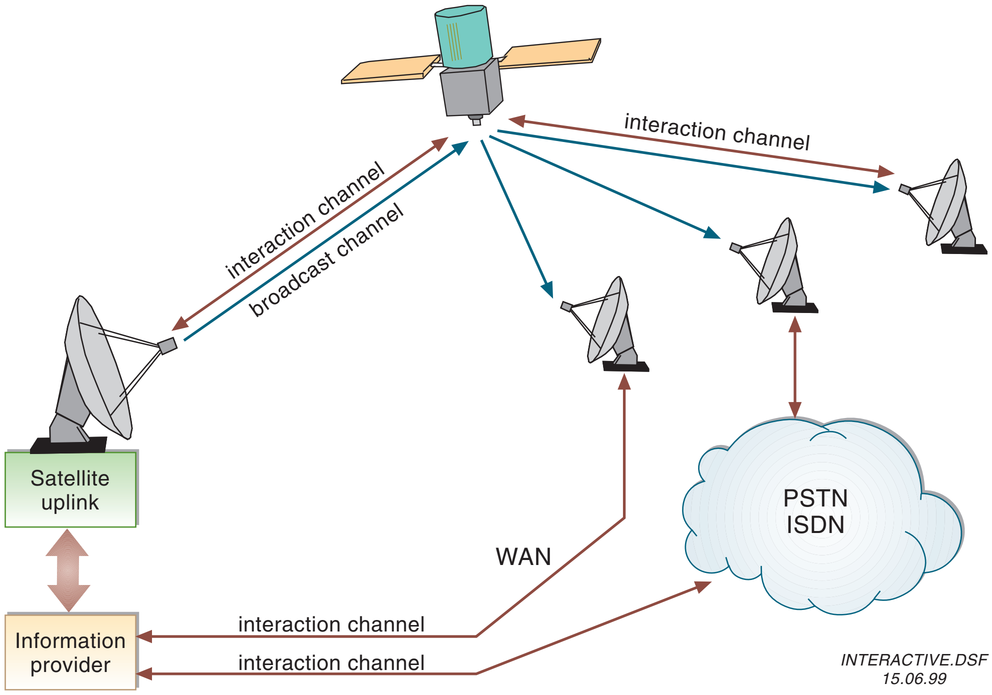



*Figure 4 Storage in the receiver allows instant response to requests*

*Figure 5 Interaction channel alternatives*




In an interactive satellite system any means may be used to establish the return path (figure 5). Which option to choose will be governed by a number of criteria, such as cost, mobility and capacity requirements. Primarily a unidirectional link from the user terminal to the service provider is required in addition to the satellite broadcast channel, but in most cases the return path will be implemented by means of a (narrow band) bi-directional link.

The fixed terrestrial telephone network is an obvious alternative. The available capacity is in the order of 50 kbit/s for analogue lines, and 128 kbit/s for digital lines (ISDN).

A return path may also be provided through the mobile telephone network, in which case the available capacity is reduced to around 8 kbit/s for present day GSM systems. To support future applications specifications are developed to allow higher capacity for data transmission in these systems.

Work is being carried out to standardise equipment and protocols for a satellite interaction channel [5]. The Interaction Channel may be implemented as a unidirectional or bi-directional communications channel, and will allow variable capacity depending on the requirements, in the range from around 100 kbit/s to many Mbit/s.

## 4 Broadcast services

A broadcast service is a so-called 'push' service, implying that the program provider alone decides the contents of the transmitted service. The service may be a mix of any number of audio, video and data components, and user interactivity would allow the user to 'edit' his own program. The editing would involve selecting between the available components, some of which may be available only after required payment has been made.

The user may also indirectly influence the contents of the transmitted program if an interaction channel is available. The service provider may request feedback from the viewers during a program and modify his contents accordingly.

To further describe the mechanisms involved two real applications are discussed. The section on EPG services exemplifies the principles involved in the selection of service components, the Video on Demand section details the operations taking place when acquiring access to a controlled access service.

These principles may be combined to devise more advanced interactive services.

### 4.1 EPG

In the MPEG2/DVB digital TV environment interactivity has been introduced through the inclusion of the Electronic Program Guide (EPG).

The EPG provides an overview of available programs, with scheduled time of transmission for several days ahead. Also more or less comprehensive information for the individual program items may be provided. Closely linked to the EPG is the Navigator, which is a receiver application program presenting the EPG contents and providing functionality to navigate and select amongst perhaps several hundred different services and service components.

The EPG is implemented as a separate information channel, transmitting the information in a cyclic fashion. The capacity allocated to this channel is a trade-off between the amount of data in the carousel and the allowable latency time.

The need to constantly update the EPG contents and the cost of data storage in the receiver are salient factors when implementing an EPG service. The worst case latency time will be the cycle time for the carousel, which is experienced if the information requested by the user at a particular time was just missed in one cycle.

The EPG contains data to index relevant information components, textual information and audio/video information alike. The program provider may choose to transmit several video streams for one program, each of them representing a different camera position. At the viewer's command extra information relating to the ongoing program may be displayed, or a different camera angle may be selected. Other (simple) uses of this feature include the opportunity to select the spoken language or subtitle language in a program.

The introduction of such systems requires appropriate software in the receiver, and of course specially adapted program generation. The interaction involves the user and the receiver only.

Proprietary systems exist offering this type of functionality to the end user.

#### 4.1.1 CustomTV

CustomTV is a project within the EU ACTS (Advanced Communication Technologies and Services) program with focus on TV applications along the lines described above, only developing the ideas much further. New coding standards (MPEG4) are introduced to reduce the required bandwidth for the information, and standardised ways of organising and indexing the information are developed (MPEG7). These standards can be used to build totally new services or they can be used to enhance already existing television services. Demonstrators are developed to visualise the functionality and motivate the industry to support these functions in future products [6].

### 4.2 Video on demand

The possibility to provide large bandwidth terrestrial communication links to the home has nourished the idea of providing video services on demand to the individual user. Direct to home satellite transmission opens new ways to obtain the same.

The end user (via his access channel) would request a particular program to be delivered and, ideally, the program will start shortly after. At first, this may seem almost trivial to implement. In reality it is a rather complex scenario involving exchange of messages across many interfaces, see figure 6.

Firstly, in a Video on Demand service, payment of the received program must be ensured. Therefore, when the user requests to purchase a program and prior to program delivery, the Subscriber Management System (SMS) must negotiate with the user's smart card to establish whether there is sufficient credit. If that is not the case actions may be taken to transfer credits from the user's bank account to his smart card.

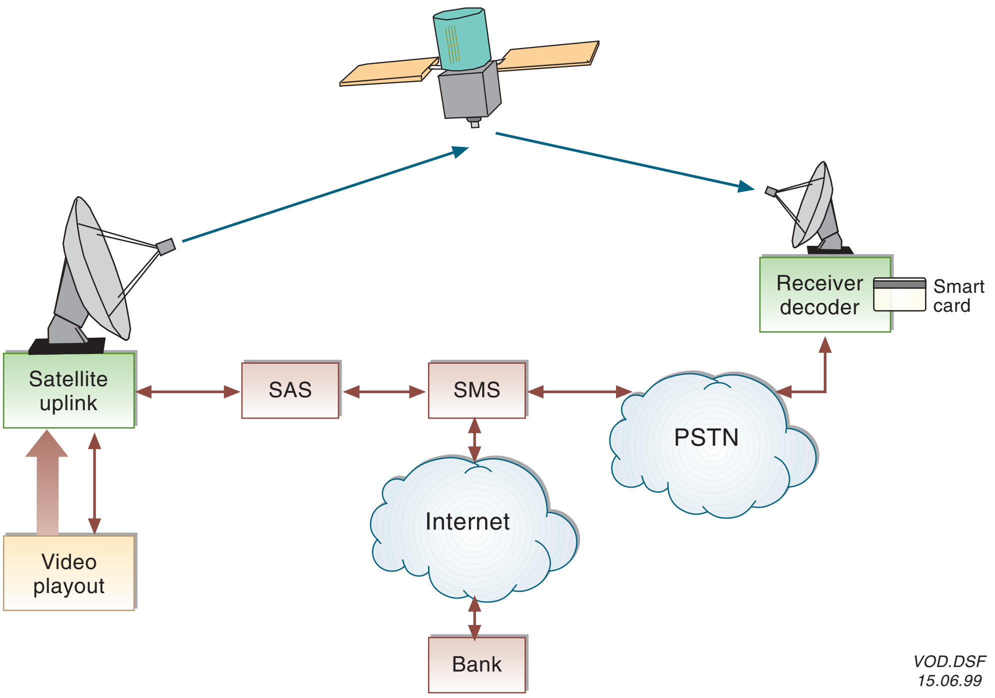



*Figure 6 Video on Demand*

When this is in order, and the user confirms the purchase of the program, the Subscriber Authorisation System (SAS) will issue the necessary messages to authorise and enable program reception, and arrange for scrambling of the desired program.

Only then the actual play-out of the program can start, the reception of which has been automatically set up in the end user's receiver with the aid of the EPG and the navigator functionality.

Whilst this is a perfectly viable scenario the economics of such a single subscriber transmission would be unfavourable unless satellite capacity could be acquired at extremely low cost. To overcome this limitation modifications are intr duced resulting in Near Video on Demand (NVOD) services.

In NVOD services the degree of freedom for the user is reduced as follows:

1. The number of programs to choose from is reduced;
2. The program play-out cannot be started at random times.

A typical system may transmit 12 program streams in one satellite channel. Within each stream the same program (movie) is transmitted cyclically, restarting every 2 hours. The start interval between two successive plays of the same movie can be reduced if more streams carry the same program with offset start times, ie. 2 streams carrying the same movie provides the possibility to start viewing the movie on every hour. Thus this NVOD service provides a choice between 6 movies which all may be started with one-hour intervals.

The challenge for the program provider will be to offer attractive programming and to ensure that the start times for each program is acceptable to a sufficiently large number of viewers. Thus exploiting the point-to-multipoint advantage of satellite transmission.

## 5 High speed Internet

Many Internet users experience a slow response to their requests. This can be attributed to two factors:

1. Limited data transfer rate available for the local communication with the Internet Service Provider (ISP);

2. Limited capacity in the Internet backbone network in periods of high traffic.

For the average consumer the communications link to the ISP is established via an analogue modem or an ISDN connection. Signalling rates up to 128 kbit/s can be achieved with ISDN, whilst 56 kbit/s presently is the highest rate that can be obtained for an analogue link at reasonable cost. Depending on the line quality the effective data transfer rate may be considerably less than this, as explained in section 2.1.

In a general Internet session the data flow is highly asymmetrical. Data *from* the user (uplink) mainly represent small data items, whilst data *to* the user (down-link) may be of large volume. If the down-link data was delivered on a high speed connection the limitation on the ISP communication would be substantially eliminated. This is the primary motivation for introducing satellite Internet access (figure 7).

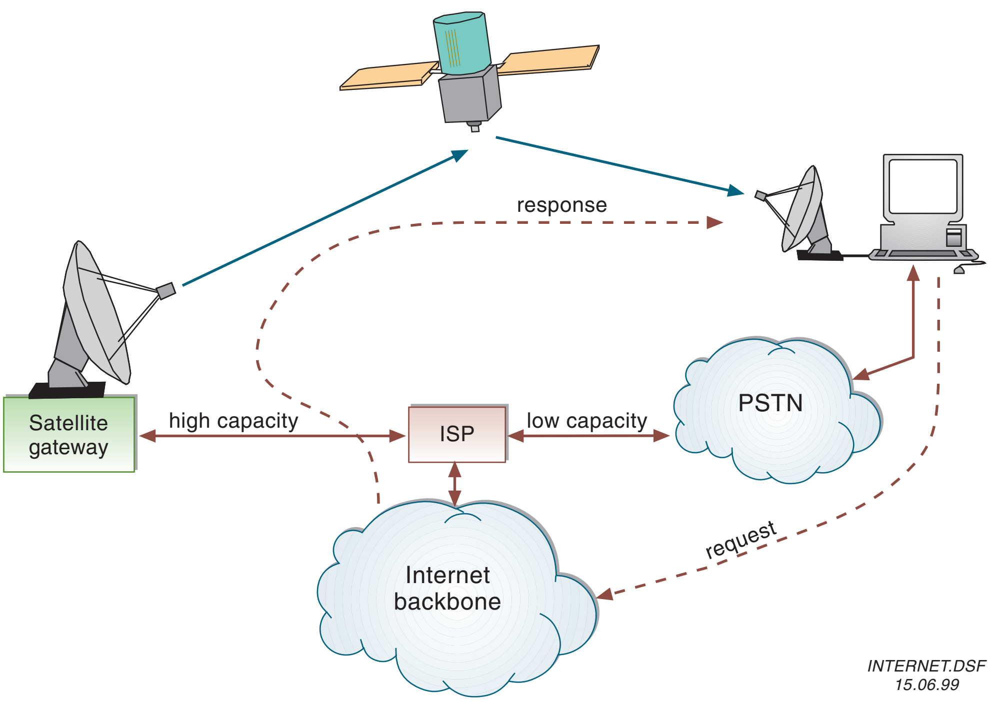



*Figure 7 Satellite Internet Access*

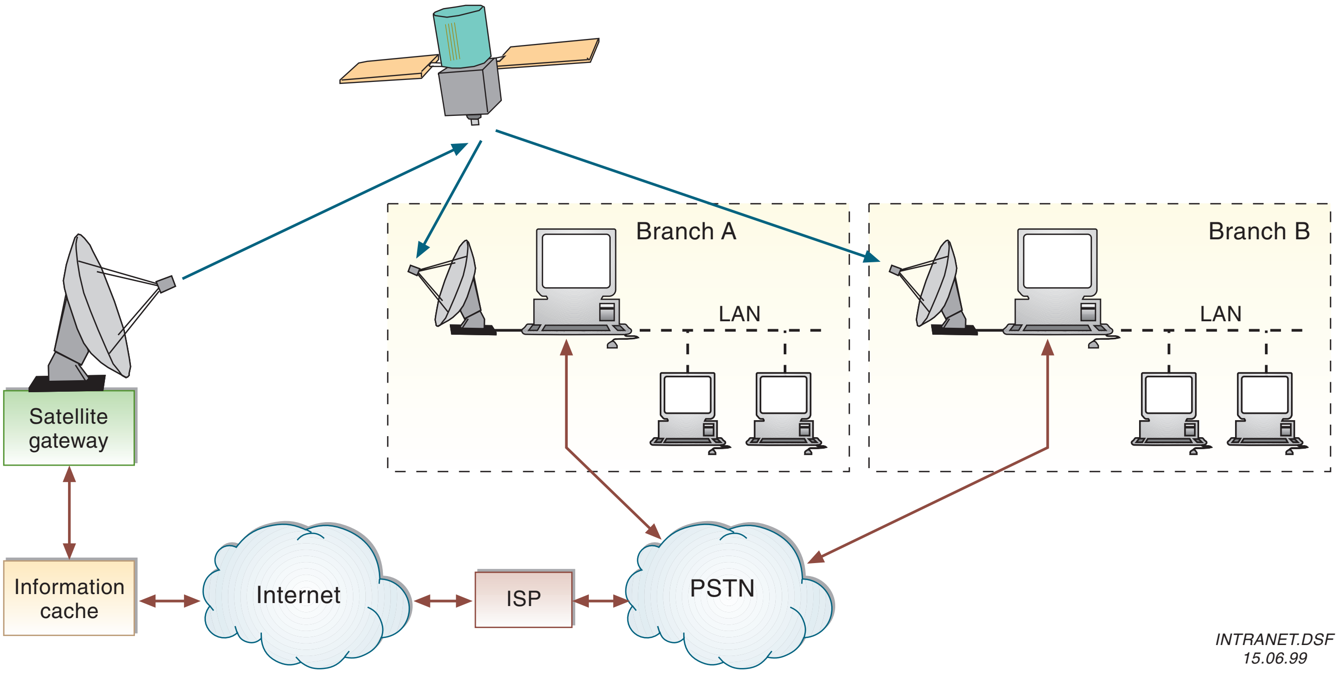



*Figure 8 Corporate Intranet*

Internet access is a typical point-to-point bandwidth-on-demand service and the same considerations as described in section 2 apply.

Congestion in the Internet backbone cannot really be overcome by other means than increasing the backbone capacity. However, some improvement in service quality may be achieved by local information caching. A cache stores frequently requested information in the anticipation that this information will be requested again. Thus, the information can be provided locally avoiding having to connect to distant servers through congested lines. The drawback is that the cached information may not be up-to-date with the original information at all times.

Another application based on information storage near the up-link is the satellite *intranet* solution for corporate business (figure 8). In each of a number of branches of a company a satellite receiver forms the gateway between the satellite network and the branch Local Area Network (LAN). Corporate information may be stored in a server with a high capacity connection to the satellite up-link, and requests for such information from any terminal in any of the corporate LANs may be delivered fast via satellite eliminating the need for high capacity terrestrial links to all branches.

Multicasting is a feature that allows single transmission of information destined for multiple users in IP networks. Multicasting is ideally suited for satellite broadcast systems, whilst it is supported only to a limited extent on the Internet. It is primarily suited for push-services; ie. the user connects to a multicast group expecting that the contents provided will be of interest. In these cases the UDP rather than the TCP protocol is used which does not provide assurance of data integrity. It is expected that IP multicasting will become more widespread in the future.

## 6 Distance education

There is a great potential in using satellite systems for distance education. Much work is being done in designing solutions that are satisfactory for the users and also economically viable. Depending on actual requirements scenarios of different complexity are considered.

In general there will be a requirement for a high capacity connection to all students to bring the ‘classroom’ to the student. Although there are other alternatives this is easily provided by a satellite link. For different situations there will be differing needs for the return link from the student to the ‘classroom’, with different capacity requirements and implementation options.

A simple scenario would call for a voice and/or text based return connection to the classroom. For more demanding applications an audio/video/data return connection may be required to create a virtual classroom. In this case the student would have a display of the lecturer(s) and the other students, thus enhancing the collaboration and intercommunication within the class [7].

The greatest challenge in forming an attractive distance education set-up is the integration of all the different means for information interchange into a unified ‘package’. Many actors should join efforts in multilateral projects to meet this challenge [9].

## 7 Electronic commerce

Electronic Commerce (EC) is the buying and selling of goods and services on the Internet. In itself the bandwidth requirements to accomplish such transactions are limited, and naturally it represents point-to-point communication. Only when this is coupled to larger bandwidth applications can it be considered a broadband service. The economic transactions take place via the interaction channel, whilst presentations are delivered via satellite (in much the same way as described for Video on Demand). Security in the money transfer and authentication of the users are highly important issues in such applications.

## Conclusion

The broadband capability of DTH satellites lends itself to a wide range of applications. Together with a return path, which can be selected from many alternatives, a multitude of interactive services can be designed.

In many of the applications described the interactivity may be regarded as an add-on to the high capacity service provided via satellite, often carried by separate networks. This is immaterial as long as the user experiences an enhanced service. Moreover, it is important that the most appropriate communications links be used in each particular case to ensure economic operation.

So far only applications of modest complexity and fairly low functionality are commercially available. This can be accredited to several factors:

- *Receiving equipment with limited functionality.* Support of specific applications requires dedicated software in the receiver. Although retrofitting software into receivers is relatively simple, the application must first be designed. And to design an application either a specification must exist (preferably) or an agreement on a proprietary solution must exist between service providers and receiving equipment manufacturers.

- *Uncertainty with respect to economics.* The introduction of any service involves an economic risk. And in the end the consumer must be willing to pay. The challenge is therefore to device services that are attractive at an acceptable cost.

- *Technical limitations.* The services described represent a mixture of already implemented and future functionality. In principle the more advanced functionality may seem straightforward to implement. There are, however, many issues that must be addressed when bringing different technologies together to build new services.

In order to overcome these limitations a decision to implement a certain application must be made first of all. This requires a common understanding by program providers, receiver manufacturers and network operators. All parties concerned must be willing to take the economic risks involved, which in turn depends on their common belief that the application will ‘sell’. The lack of an obvious ‘killer application’ is one reason why interactive services via satellite are having a slow start.

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# Introduction

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Wireless and personal communications technologies had a huge growth in the last decade of the 20$^{th}$ century. We believe that further developments, both evolutionary and revolutionary, in this field will mark the new century. It started with the automatic mobile telephones in the early 1980s and in 1999, the Internet became available on the mobile terminal. The term 'WAP' was suddenly known all over.

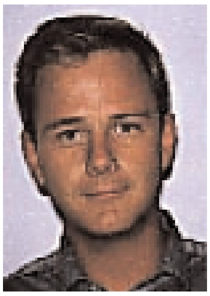
In this issue of Telektronikk's Status section, we try to go behind the buzzword and find out what it is all about. Erik Aslaksen presents an overview of *WAP – Wireless Application Protocol*, one of the new value added service technologies specially made for the wireless environment. Another technology in the same area, but not much heard of yet, is *MExE – Mobile station Execution Environment*. MExE is even more powerful than WAP in providing advanced data applications to the mobile device. In the same article together with WAP, MExE is explained. Both MExE and WAP are standardised by ETSI SMG and 3GPP.

New communications technologies also open the possibilities of advanced fraud, eavesdropping and other security threats. Early, analogue mobile phones, like NMT, did not have much in the way of security, neither with authentication nor 'data' protection. In GSM, this was greatly enhanced; however, there are several security breaches even here. In the second paper in this issue, Geir Køien describes the *security for UMTS release 99*, which is much more consistent, and which is based on the OSI Security Architecture.

| | |
|---|---|
| 3GPP | 3rd Generation Partnership Project |
| ETSI | European Telecommunications Standards Institute |
| MExE | Mobile station Execution Environment |
| NMT | Nordic Mobile Telephone |
| OSI | Open Systems Interconnection |
| SMG | Special Mobile Group |
| WAP | Wireless Application Protocol |

# MExE and WAP overview

ERIK ASLAKSEN



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**This article presents the value added service technologies MExE and WAP – how they work and how they relate to each other. There are already far more mobile subscribers than Internet users in the world. The standards reviewed in this article are believed to be very important in the context of how the customers' relations to Internet services in a mobile environment evolve.**

## 1 Introduction

MExE (Mobil station Execution Environment) is an ETSI SMG and 3GPP standard that specifies the application environment in mobile phones, allowing applications to run in a browser environment or as a stand-alone application in the mobile terminal.

MExE is divided into two classmarks. For classmark 1 the MExE standard is referencing the WAP (Wireless Application Protocol) specifications made by the WAP Forum. So a MExE classmark 1 terminal is basically a WAP enabled terminal.

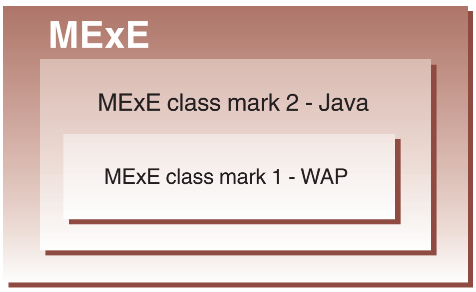


*Figure 1 Relationship between MExE and WAP*

MExE classmark 2 is a Java enabled terminal, but it also includes support for WAP.

The rest of this article will elaborate on the MExE and WAP technology and give some indications of the near future for this technology.

## 2 WAP

The group behind the WAP specifications, the WAP Forum, is an industry group of over 200 member companies covering the major part of the telecom and computer industry. The forum is dedicated to the goal of enabling sophisticated information and telephony services on handheld wireless devices. These devices include mobile telephones, pagers, personal digital assistants (PDAs) and other wireless terminals.

Recognising the value and utility of the World Wide Web architecture, the WAP Forum has chosen to align its technology closely with the Internet and the Web. The WAP specification extends and leverages existing technologies, such as digital data networking standards, and Internet technologies, such as IP, HTTP, XML, SSL, URLs, scripting and other content formats.

The WAP specifications cope with the limitations of the existing wireless network when accessing Internet services. It is expected that the WAP Forum will continue to work on mobile specific issues of Internet standards and hopefully bring the WAP specifications to a convergence with the IETF and W3C specifications.

WAP v1.1 was approved June 1999. This version is used for the product coming to the market in the first half of 2000. In November 1999 the WAP v1.2 was approved. This version includes features like Push, User Agent Profile, WIM and WML Script Crypto library.

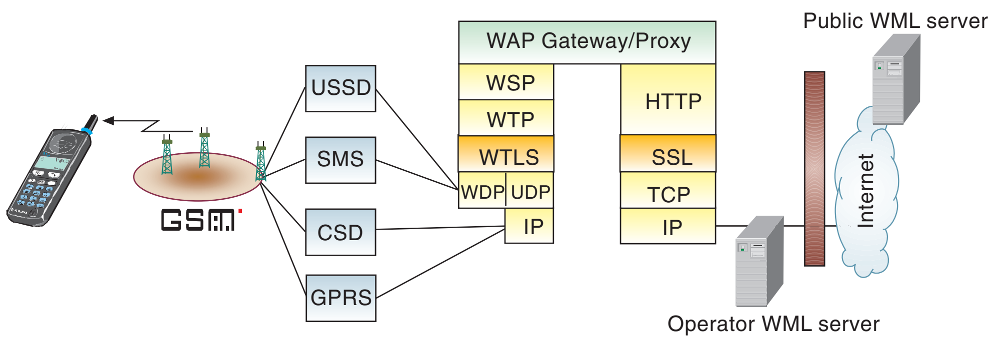


*Figure 2 The WAP basic architecture for the browsing model*

## 2.1 Why WAP?

Mobile terminals have limited screen size, processing power, memory, keyboard and data transmission rates. The intention is for the WAP technology to consider these limitations. Even though the future will give new systems providing higher data rates and better screens, the mobile terminal will always be limited compared to a stationary terminal. It is therefore believed that the need for mobile adaptation will still exist when UMTS emerges.

## 2.2 The basics of WAP

WAP is based on a browser model like we know it from the Web today with for example Internet Explorer and Netscape Communicator.

### 2.2.1 Efficiency

To address the limitations of the mobile technology, WAP uses the following techniques:

| HTTP/TCP/IP | WSP/WTP/UDP |
|---|---|
| • → TCP SYN | • → **Data Request** |
| • ← TCP SYN, ACK of SYN | • ← ACK, **Reply** |
| • → ACK of SYN, **Data Request** | • → ACK, **Data Request** |
| • ← ACK of Data, **Reply** | • ← ACK, **Reply** |
| • → ACK of Reply, **Data Request** | • → ACK, **Data Request** |
| • ← ACK of Data, **Reply** | • ← ACK, **Reply** |
| • → ACK of Reply, **Data Request** | • → ACK |
| • ← ACK of Data, **Reply** | |
| • → ACK of Reply, TCP FIN | |
| • ← TCP FIN, ACK of FIN | |
| • → ACK of FIN | |

*Figure 3 Wireless Application Protocol efficiency*

- A protocol stack over the air interface that is designed for bearers with low bit rate and high latency.
  ⇒ Gives better performance than TCP/IP in mobile networks (illustrated in figure 3).

- Long lived session relationship between the terminal and WAP Gateway.
  ⇒ Reduces the number of roundtrips and packet overhead when re-establishing connection to the WAP Gateway.

- A gateway architecture that allows the WAP stack to be converted to well known Internet protocols on the services side.
  ⇒ Allows services to reside on normal Web-servers using existing service design procedures.
  ⇒ Allows compression of the WAP content types over the air interface.

- Content types that are designed for terminals with limited screen, keyboard and telephony capabilities.

A comparison of the Internet protocols and WAP carrying Web content is illustrated in figure 3. This shows a typical session with 3 requests and responses. Packets in bold represent packets with payload, and the non-bold packets represent overhead. The Internet stack illustrated shows a representative behaviour of implementations found in operating systems like Linux and MS Windows. In terms of packets (or actually round trips) the Internet stack has an overhead of 45 % compared to 14 % with the WAP stack. This does not take into account roundtrips and packets for things like DNS, SSL, Authentication or Cookies, which for the WAP case can be handled by the WAP Gateway and therefore do not affect the air interface efficiency. In wireless networks the number of roundtrips is a very important number because of the very high latency in these networks.

The throughput in wireless networks tends to vary a lot since the radio conditions and network capacity vary in time and space. TCP has often problems with these frequent variations in throughput. WAP, on the other hand, is designed to cope with such variations and should therefore also be an important protocol stack for GPRS which will give higher data rates but possibly also very varying in time and space.

The application layer is also optimised in WAP. The WAP content (eg. WML) is compressed by using binary encoding of tags. To reduce roundtrips several pages can be downloaded like a pack of cards. It is then possible to navigate between pages (cards) without accessing the network.

### 2.2.2 Network independence

WAP can be transported over all existing GSM bearers and bearers in several other network technologies like IS-136, CDMA, PDC and TETRA. So WAP is basically network independent. WAP services that are hosted on ordinary Web servers (called public WML server in figure 2) can therefore be accessed by mobile customers from all over the world without the service providers having to worry about the capabilities of the different networks. All adaptation between the Internet and the mobile network is the responsibility of the WAP Gateway. The only thing the service developer has to learn in order to develop a WAP service or to convert Internet is WML and WML Script. WML is an XML based language which is very easy to learn for a developer that is already familiar with HTML. WML Script should also be easy to

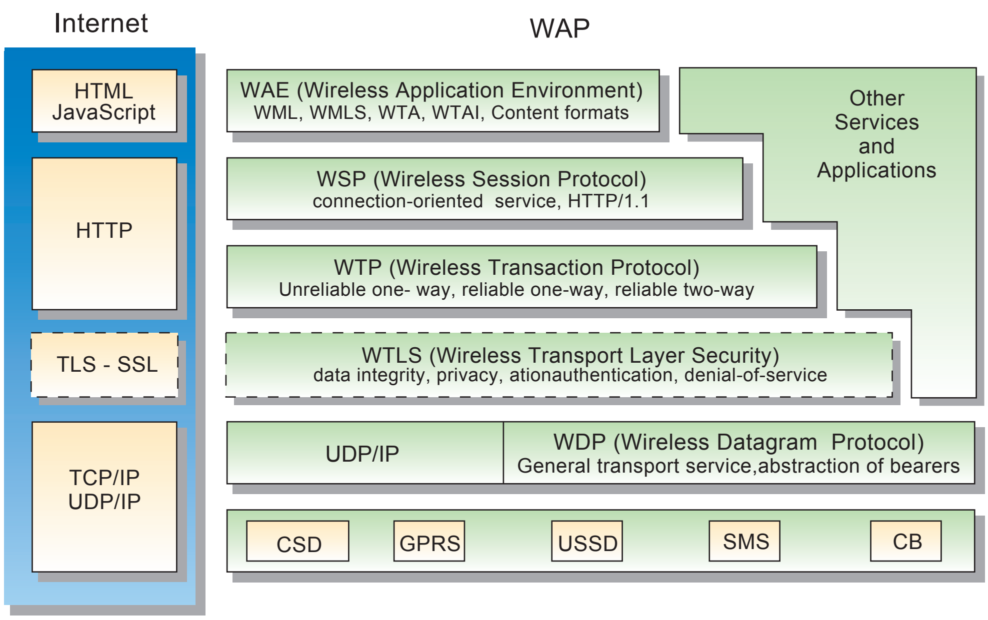


*Figure 4 The WAP Protocol stack compared to the Internet protocol stack. At the application layer, WML and WML Script is directly comparable to (X)HTML and Java/ECMA-Script. The WSP layer uses the same semantics as HTTP/1.1. WSP can therefore be directly mapped to HTTP/1.1 by the WAP Gateway. WTLS is comparable with TLS/SSL. For the rest of the protocol stack it is difficult to identify the corresponding Internet layers because the semantics and responsibilities of the WAP layers are different than the remaining layers in Internet*

learn. It can be considered as a subset of Java/ECMA-script.

### 2.2.3 Security

The security functions in WAP v1.1 are provided by WTLS. WTLS offers secure transfer of content, to allow for applications needing:

- Privacy – using encryption;
- Integrity – using MACs;
- Public key based handshake with server authentication – using server certificate and private key;
- Client authentication – using client certificate and private key

at the transport level. The protocol is based on SSL and TLS from the Internet community, but modified for a wireless environment by eg. supporting very long-lived sessions. This reduces the need for frequent and time consuming handshakes.

As illustrated in figure 2, the WTLS-protocol only stretches between the terminal and the WAP Gateway. To provide security further out, SSL/TSL can be used between the WAP Gateway and the content server. The security chain is in this case not end-to-end, and the WAP Gateway operator has to be a trusted party. In future releases of WAP, end-to-end transport level security will be addressed.

As the first step on the way towards application level security WAP v1.2 supports a limited WML Script Crypto API. By using this to sign

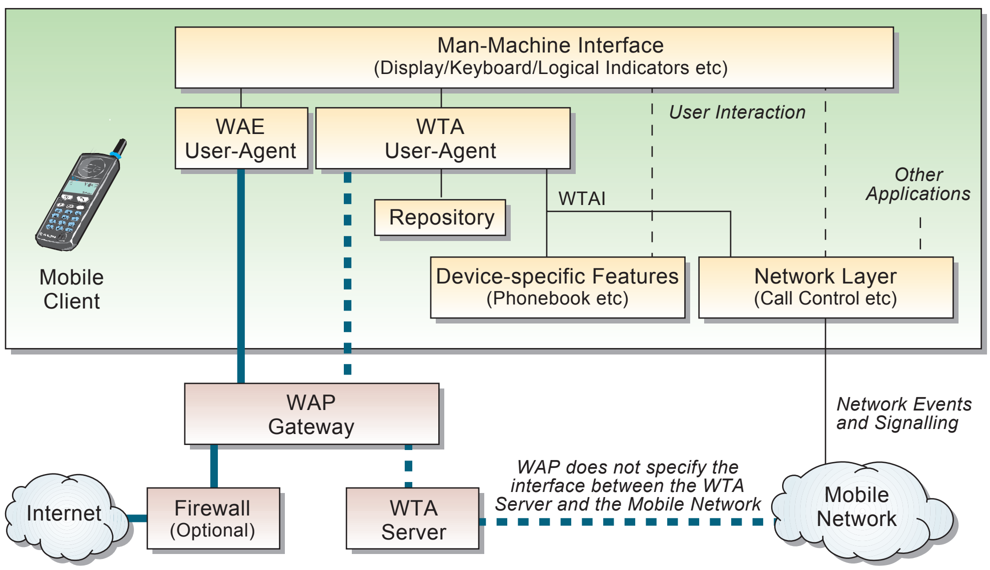


*Figure 5 WTA architecture*

application data, the user and transaction can be authenticated. The Crypto API can eg. be used to achieve non-repudiation in connection with electronic transactions. Since this API is executed on application level data, the data can be signed end-to-end between the terminal and the application server.

For storage of private keys, trusted CA certificates and data for long lived sessions, a tamper proof module is desirable. In WAP v1.2 this functionality is provided by the WIM. By supporting generic operations like digital signature and private key decryption, the private data should never have to leave the WIM. In GSM the WIM would typically be implemented in SIM.

## 2.3 WTA

In addition to basic browsing, provided by WAE User Agent, the WAP specifications include WTA (Wireless Telephony Application) support. WTA gives the service provider a framework to exploit the telephony capabilities in the terminal to make new advanced telephony services or more user friendly interfaces to existing services. It is not expected that WTA will be implemented in the first WAP terminals entering the market.

In figure 5 the WTA User Agent is depicted as a logical user agent separate from the WAE User Agent used for normal public browsing. The separation is done to provide security according to the sand box principle. The WTA User Agent will have a separate secure connection with a trusted WTA server which will typically be controlled by the telephony service provider. The secure WTLS session allows the WTA server to be authenticated.

The WTA User Agent interacts with the telephony features in the terminal and in the network trough an API (WTAI). WTAI includes functionality like setup call, call reject, send text (SMS), incoming call indication, send USSD, etc.

To be able to replace the MMI for real-time applications like incoming calls, the WTA framework has a repository where recourses (WML decks and WML Scripts) can be persistently stored. So when an incoming call indication occurs, a menu for incoming calls can be fetched from the repository and presented to the user in real-time. Resources can be added and removed by the WTA service provider over the air.

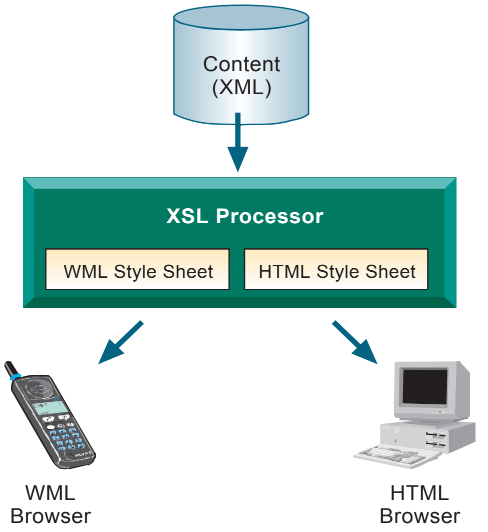


*Figure 6 Automatic content shaping*

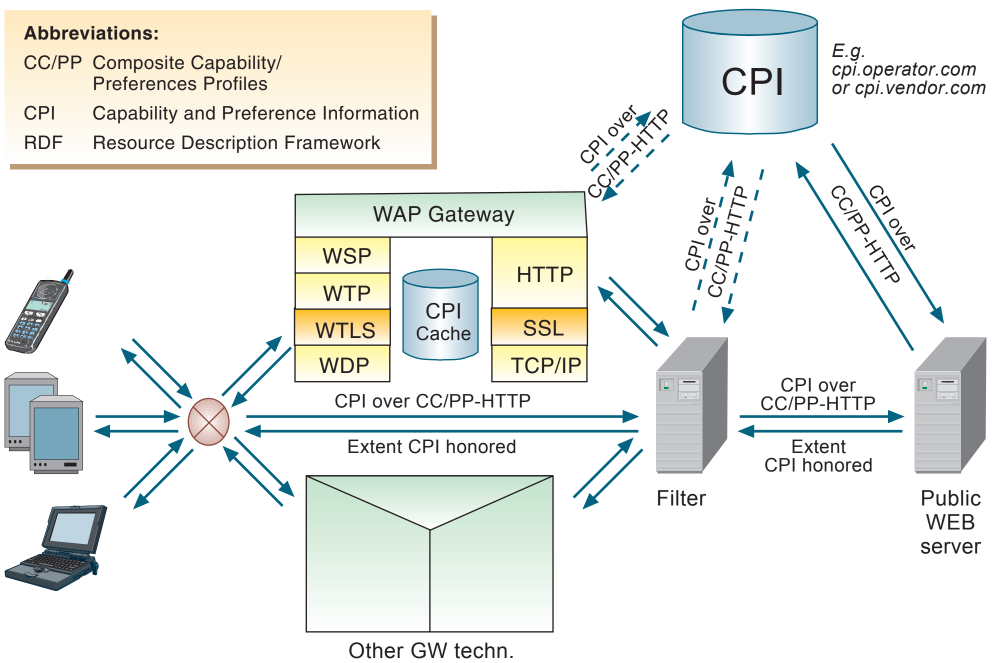


*Figure 7 The UAProf framework*

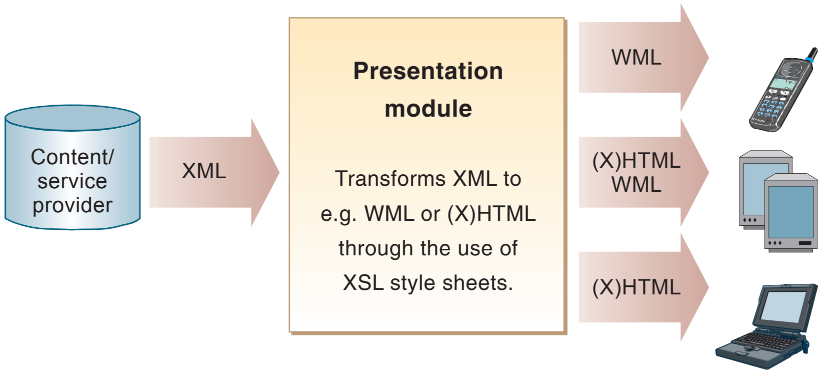


*Figure 8 Content shaping using XSL*

The WTA framework does not add new signalling for example between the PLMN and the terminal, it only provides APIs to existing signalling.

## 2.4 User Agent Profile

On the Web today most services are written for screens with 800x600 pixels. With mobile terminals this situation will change. There will be a huge diversity of terminals with different screen size/resolution, keyboard or input device, memory, etc. In the future service production it will be very important to be able to offer the same services to terminals with different capabilities.

Because WML is based on XML, it is well suited for the future service production with automatic content shaping. The idea is, within a very short time, to make generic services that automatically adapt to the terminal capabilities by the use of XSL (eXstensible Style Language).

To provide capability information about the terminal to the server hosting the service, WAP Forum has specified the UAProf (User Agent Profile) in close co-operation with the W3C and 3GPP-MExE. The UAProf is used also for MExE classmark 2 to convey the Java terminal capabilities to the server.

The UAProf framework is illustrated in figure 7. Capabilities of a user agent (eg. the WAP browser) and the user's preferences (eg. colors on/off, sound on/off, etc.) are called CPI. The CPI can be described according to CC/PP in RDF. To transport the CPI from the client to the server, the CC/PP Extension Framework is used over WSP in the WAP domain and over HTTP 1.1 in the Internet domain. The filter depicted in figure 7 does not need to be provided and can of course be bypassed. The UAProf framework is designed in co-operation with W3C to be utilised for ordinary browsing using HTPP over TCP/IP as well. The CPI is in that case not cached, unless this feature is provided by some intermediate proxy.

When a WAP client is establishing a long-lived session with the WAP Gateway, the whole CPI describing every little detail of the client is not transferred over the air. The client will typically only send a URL as a reference to the static CPI describing the terminal and/or user agent. In addition it will send the differences between the static CPI and the current setting of the client. The static CPI can be stored in a database eg. operated by the terminal vendor or the operator.

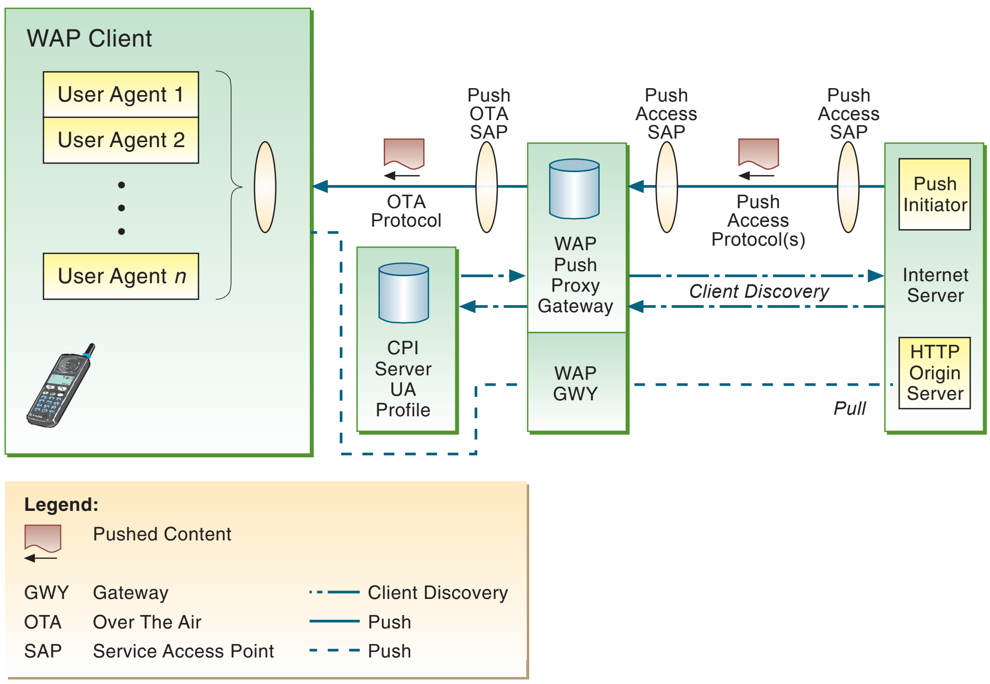


*Figure 9 Push Architecture*

The WAP Gateway may resolve the URL reference for the static CPI and cache it together with the non-static CPI about the client. All nodes on the way to the server may resolve the static CPI reference and add information to the CPI. So a network node may add information about the bearer used, the position of the client, etc.

During the session, the client may at any time make changes to its CPI by sending 'Profile-Diff' headers in the requests.

At the content server the CPI can be used to form an XSL, describing the presentation of the content. The content described in XML can then be fed into the presentation module together with the XSL and produce presentations for clients with different capabilities as illustrated in figure 8. The extent of how the CPI was honoured by the service logic is signalled back to the client as illustrated in figure 7.

### 2.5 Push

Push provides the means by which trusted application servers can send information directly to the application environment on the terminal for processing. Applications generating events, such as telephony applications, emergency services, telematics and countless others can benefit from using Push technology.

The WAP Push concept is very similar to SMS, but enhanced significantly when it comes to content capabilities (eg. size of content is NOT limited to 160 characters only).

The WAP Push framework (see figure 9) provides functionality like:

- Store and forward of messages;
- The Push initiator can be notified when the message is delivered to the terminal;
- The Push initiator can request the status of a submitted message;
- The Push initiator can modify messages stored in the PPG pending delivery;
- The Push initiator can address different applications on the terminal with different content;
- The Push initiator can ask for the terminal capabilities before formatting and submitting the message;
- The push message can be delivered over any available bearer.

The Push Proxy Gateway (PPG – see figure 8) is the entity that does most of the work in the Push architecture. Its responsibilities include acting as an access point for content pushes from the Internet to the mobile network, and everything associated therewith (authentication, security, client control, etc.). As the PPG is the entry point to a mobile network, it is the owner of this gateway that decides the policies about who is able to gain access to the WAP network, who is able to push content and who is not, and under which circumstances and parameters, etc. It should be noted that the PPG functionality may be built into the (pull) WAP gateway; this would give the benefit of shared resources and shared sessions over-the-air.

The PPG accepts pushed content from the Internet using the Push Access Protocol. The PAP uses HTTP/1.1 POST to carry an XML entity between the Push initiator and PPG and vice versa.

This XML entity is divided into several sections using a multipart/related content type, where the first part contains information for the PPG itself and the other parts are content for the client. Information for the PPG includes recipient information, time-outs, call-back requests, and similar pieces of information. The PPG will acknowledge successful (or report unsuccessful) parsing of this control information, and may in addition report debug information about the content itself. It may also do a call-back to the pushing server when the final status of the push submission (delivered, cancelled, expired, etc.) has been reached, if the push initiator so requests. To be able to receive this asynchronous information from the PPG, the pushing server has to be configured as a Web-server to accept HTTP POST.

## 3 MExE

This chapter will describe MExE classmark 2, which is a Java based terminal. The MExE specifications do not describe classmark 1 in detail at all – it only refers to the WAP Specifications.

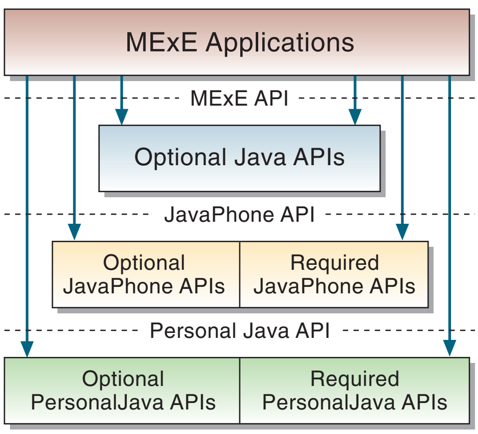


*Figure 10 Overview of APIs used by MExE class mark 2*

For MExE classmark 2 the Personal Java application environment is described in more detail.

To ensure backward compatibility, MExE classmark 2 terminal is mandated to also support WAP.

The introduction of MExE can change roles of players in the telecom business completely. It is no longer only the network operator that can download applications providing advanced telephony services like it is with SAT and WTA. With MExE classmark 2 any certified party (typically certified by the telephony service provider) can provide applications able to access advanced and security related functionality in the terminal.

### 3.1 Java

MExE classmark 2 is based on Personal Java Virtual Machine from Sun.

Enhanced Java functionality in a MExE device is achieved through MExE APIs which allow access to functionality which is specific to a mobile station, like SMS management (send and receive SMS), mobility handling (eg. network selection) etc., illustrated in figure 10). The additional Java APIs in the Wireless Profile of the JavaPhone are defined by the JavaPhone Expert Group.

### 3.2 Security

In order to manage the MExE and prevent attacks from unfriendly sources or transferred applications unintentionally damaging the MExE devices a security framework is defined.

The basis of MExE security is:

- A hierarchy of permissions which define the permissions the transferred MExE executables have within the MExE MS;

- The secure storage of these permissions and permission types;

- Conditions within the execution environment that ensure that MExE executables can only perform actions for which they have permission.

The MExE security domains are defined as follows:

*MExE Security Level 1*
*(used by the HPLMN operator)*
MExE applications, applets and content designated at this security level have been authorised by the network operator (ie. HPLMN), with access to GSM security areas and functions.

*MExE Security Level 2*
*(system applications, applets and content)*
MExE applications, applets and content designated at this security level have access authorisation on the ME or smart card, to enhance the MExE MS's capabilities (ie. upgrade the MExE MS software/firmware). This level of authorisation is normally ascribed to the MExE MS manufacturer.

*MExE Security Level 3*
*(trusted applications, applets and content)*
MExE applications, applets and content designated at this security level have been authorised to perform functions (such as create files, or read files) on the MExE MS, and have access rights to the MExE MS's capabilities as defined by this level of user-authorised certification. The user may determine the applications', applets' and content's access rights associated with the certification.

*MExE Security Level 4*
*(untrusted applications, applets and content)*
MExE applications, applets and content designated at this security level have restricted access authorisation on the ME or SIM, and do not have certification permitting access to the MExE MS's capabilities. The applications', applets' and content's access rights have not been supplied with an associated certification determined by the user, or the certification has not been successfully verified.

The authorisation of the MExE applications is achieved by the use of PKI (Public Key Infrastructure) and certificates provided along with the application.

## 4 Abbreviations

| | |
|---|---|
| 3GPP | 3rd Generation Partnership Project |
| API | Application Programming Interface |
| CA | Certification Authority |
| CC/PP | Composite Capability / Preference Profile |
| CB | Cell Broadcast |
| CPI | Composite Preference Information |
| CSD | Circuit Switched Data |
| DNS | Domain Name Server |
| ETSI | European Telecommunications Standards Institute |
| GPRS | General Packet Radio Service |
| HTTP | Hyper-Text Transfer Protocol |
| HTML | Hyper-Text Mark-up Language |
| IETF | Internet Engineering Task Force |
| IP | Internet Protocol |
| MAC | Message Authentication Code |
| ME | Mobile Equipment |
| MExE | Mobil station Execution Environment |
| MMI | Man Machine Interface |

| | |
|---|---|
| MS | Mobile Station |
| PLMN | Public Land Mobile Network |
| PPG | Push Proxy Gateway |
| PKI | Public Key Infrastructure |
| XML | Extensible Mark-up Language |
| RDF | Resource Description Framework |
| SAT | SIM Application Toolkit |
| SIM | Subscriber Identity Module |
| SMS | Short Message Service |
| SSL | Secure Socket Layer |
| TCP | Transaction Control Protocol |
| TLS | Transport Layer Security |
| UAProf | User Agent Profile |
| UMTS | Universal Mobile Telecommunications System |
| URL | Uniform Resource Locator |
| USSD | Unstructured Supplementary Services Data |
| W3C | World Wide Web Consortium |
| WAE | Wireless Application Environment |
| WAP | Wireless Application Protocol |
| WIM | Wireless Identity Module |
| WML | Wireless Mark-up Language |
| WSP | Wireless Session Protocol |
| WTA | Wireless Telephony Application |
| WTLS | Wireless Transport Layer Security |

## 5 Further reading

ETSI. *MExE Stage 1 Description.* Sophia Antipolis, 1999. (3G TS 22.057 V3.0.1.)

ETSI. *MExE Functional Description Stage 2.* Sophia Antipolis, 1999. (3G TS 23.057 V3.0.0.)

WAP Forum. *Wireless Application Protocol Specification Suite (version 1.1).* Mountain View, CA, 1999.

WAP Forum. *Wireless Application Protocol Specification Suite (version 1.2).* Mountain View, CA, 1999.

*WAP Forum Specifications.* (2000, 02, 29) [online]. – URL: http://www.wapforum.org/what/technical.htm

# Overview of UMTS security for Release 99

GEIR KØIEN

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## 1 Introduction

In the old days of cellular systems security was not a major issue. For example, in the NMT system all communication was in clear and there were virtually no attempts at providing confidentiality, integrity checking or authentication. In fact, about the only early attempts at security in NMT was the 3 digit 'password' $K_1K_2K_3$ which was actually transmitted in clear. Quite early on the lack of a secured password was exploited. Attackers simply recorded valid password/subscriber number combinations off the air and used these with a slightly modified mobile station. Later on NMT got the SIS [2,3] function which provided authentication of the user, and thus made the above fraud impossible. Data privacy on the other hand cannot easily be provided in NMT since the connections are analogue and not digital.

When GSM was designed one already knew about subscription fraud and authentication of the user was designed into the system from the start. Furthermore, since GSM provided digital connections it made sense to provide encryption of the connection over air. Since GSM provides both data link encryption and authentication of the user it is often perceived to be a 'secure' system. This is far from the truth. The security provided by GSM is limited in scope and even incomplete in the areas that it attempts to secure.

The problem with security in GSM is that it is designed without a consistent and complete view of what the threats and risks for the system are. This can clearly be seen today, for instance when it comes to authentication. While it certainly was necessary to provide authentication of the user, the lack of mechanisms for the user to authenticate the network is today a glaring omission. This combined with the fact that the user is never given any indication whether or not encryption is applied and that only the network that can initiate encryption means that the user may be lulled into a false sense of security. It is fully possible to set up a 'false basestation' and mimic a valid network. Users attached to such a false basestation can easily be eavesdropped. The connections can also be actively manipulated, for instance to send false short messages to the users.

So while security in cellular systems have improved over the years, so has the sophistication of the attackers. It is reasonably clear that the security model behind NMT and GSM is both incomplete and inconsistent.

For UMTS it has therefore been a design goal to provide a pervasive, consistent and complete security architecture. The background for security in UMTS is largely based on the OSI Security Architecture [1].

When developing the Security Architecture for UMTS one wanted to be methodical and systematic. The work was therefore started by defining the high-level security goals, principles and objectives. The next step was to define the threats and risks to the UMTS system, before the abstract security services required were specified. From that base the actual UMTS Security Architecture was subsequently developed.

The work on the UMTS Security Architecture started within ETSI, but as the UMTS standardisation now is carried out by 3GPP, the UMTS Security Architecture is now developed by the 3GPP Technical Specification Group for security (SA3). The following is a description of some of the main features of the UMTS Security Architecture for release 1999.

This article takes basic knowledge of the UMTS architecture largely for granted. Since the UMTS architecture is complex the reader may want to consult with [6] for a survey of the UMTS Release 1999 specification set and with [7] for a closer look at the standard UMTS vocabulary.

## 2 The core UMTS security specifications

Security is a system property and as such all UMTS specifications can be viewed as security related. The number of specifications can be narrowed down to those that 3GPP Technical Specification Group SA3 (Security) are responsible for. Even within that subset it is useful to define a core set of UMTS security specifications – table 1.

## 3 Security principles and objectives

It is a sound principle to know the goals and objectives of the task at hand before proceeding to develop the actual security architecture. The specification TS 33.120 "Security Principles and Objectives" attempts to define the guiding principles and objectives. Amongst the more important points are:

- **Existing GSM security features that are *needed* and *robust* shall be kept**
  In most cases the features will be significantly improved. Examples are authentication of subscribers before being granted access to services, encryption over the air interface and using a tamper resistant subscriber identity module.

- **UMTS security shall improve on GSM security in areas where GSM have real or perceived security problems**
  UMTS systems must among other things be able to protect against "false basestations" (achieved by mutual authentication), protect cipher and authentication keys which today are transmitted in clear in the core network, provide explicit mechanisms for integrity and authentication which are independent of encryption.

- **UMTS shall offer security for completely new services and under a new set of security assumptions**
  The growth and importance of non-voice services like for instance e-commerce will make security more important, and it will make active attacks on subscriptions and systems more likely.

One very important security issue in UMTS is the backward compatibility with GSM and GPRS. Obviously one wants to provide the best possible security, but what exactly constitutes the best possible security in an environment where GSM and GPRS is seamlessly integrated into UMTS? The answer is not straightforward and it will depend on compatibility between both user and system equipment, which may be compliant with several different releases of GSM, GPRS and UMTS. The guiding principle is nevertheless that the system shall try to provide the highest possible level of security.

## 4 Security threats, risks and requirements

The specification TS 21.133 gives a good overview of what kind of security threats against UMTS that have been identified. It then proceeds with a risk assessment before it specifies the security requirements for UMTS. Although the specification is rather brief it is the key to understanding the rationale behind the measures and mechanisms defined in TS 33.102 UMTS Security Architecture.

There are basically three areas that have been identified:
- The air interface;
- The network (both access network and core network);
- The terminal and the smartcard/UMTS Subscriber Identity Module(USIM).

| | |
|---|---|
| TS 21.133 | Security Threats and Requirements |
| TS 33.102 | Security Architecture |
| TS 33.103 | Security Integration Guidelines |
| TS 33.105 | Cryptographic Algorithm Requirements |
| TS 33.106 | Lawful interception requirements |
| TS 33.107 | Law interception Architecture and Functions |
| TS 33.120 | Security Principles and Objectives |
| TR 33.900 | Guide to 3G security |
| TR 33.901 | Criteria for cryptographic Algorithm design process |
| TR 33.902 | Formal Analysis of the 3G Authentication Protocol |

*Table 1 A core set of UMTS security specifications and reports*

### 4.1 The radio interface

The radio interface between the terminal equipment and the serving network represents a significant point of attack in UMTS. Among the threats identified are:
- Unauthorised access to data/services;
- Threats to integrity;
- Denial of service attacks.

### 4.2 The network

Attacks against access network, the core network entities and the operation and maintenance interfaces represent a significant threat. Without proper security measures it will be technically feasible to set up entire false networks.
- Unauthorised access to data/services;
- Threats to integrity;
- Denial of service attacks;
- Repudiation (of charging in particular).

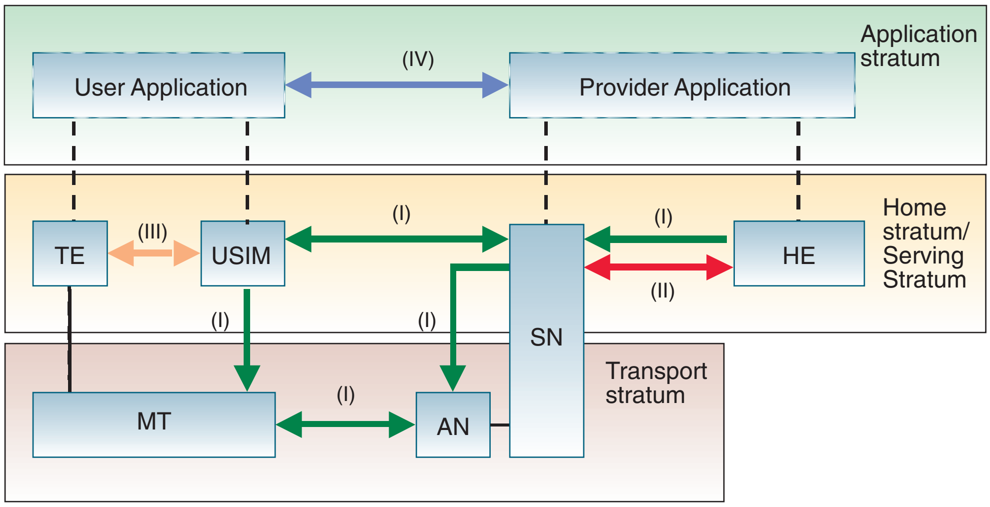
### 4.3 The terminal and smartcard/USIM

In UMTS there will be a large number of different types of terminals. To a large extent these terminals will also be configurable through services provided for instance by the Mobile Execution Environment (MExE). The smartcard, called UMTS Integrated Circuit Card (UICC), will be a computing platform in its own right. The main application to run on the UICC will be the UMTS Subscriber Identity Module (USIM).

There is a number of threats towards the terminal, the UICC and the USIM:
- Use of a stolen or borrowed terminal and UICC;
- Use of a stolen terminal;
- Manipulation of terminal identity (IMEI);
- Integrity of data on a terminal through modifications to the terminal;
- Integrity of data on USIM (incl. SAT applications);

Figure 1 Overview of the security architecture (from TS 33.102)

SN – Serving Network
AN – Access Network
HE – Home Environment
TE – Terminal Equipment
USIM – UMTS Subscriber Identity Module




- Eavesdropping on the UICC-terminal interface;
- Masquerading as the intended recipient of data on the UICC-terminal interface;
- Manipulation of data on the UICC-terminal interface;
- Loss of confidentiality of secured data on UICC/USIM (private telephone books, etc.);
- Loss of confidentiality of security data on UICC/USIM (authentication keys, etc.).

### 4.3.1 The security requirements

The list of security requirements found in TS 21.133 is rather long and no attempt to classify the relative importance of the requirements will be made. However, as a general rule the requirements are all related to one or more of the following security services from [1]:

- Confidentiality (locations privacy and data confidentiality);
- Integrity;
- Authentication (mutual);
- Authorisation/access control to services/applications;
- Non-repudiation (for charging purposes);
- Denial of service (to an admittedly very limited extent).

## 4.4 Overview of the security architecture

TS 33.102 is for all practical purposes the most important security specification in UMTS and it defines the security architecture. That is, TS 33.102 defines the security features and the security mechanisms for UMTS.

**A security feature** is a service capability that meets one or more security requirements. The complete set of security features addresses the security requirements as they are defined in TS 21.133 "Threats and Requirements".

**A security mechanism** is an element that is used to realise a security feature. All security features and security mechanisms taken together form the security architecture.

An example of a security feature is user data confidentiality. A security mechanism that may be used to implement that feature is a stream cipher using a derived cipher key.

Five security feature groups have been identified. For each of the security groups there is a defined set of threats and corresponding security requirements (see figure 1):

**I) Network access security**
The set of security features that provide users with secure access to 3G services. This group covers the radio interface.

**II) Network domain security**
The set of security features that enable nodes in the provider domain to securely exchange signalling data, and protect against attacks on the transport network

**III) User domain security**
The set of security features that secure access to mobile stations. To some extent this also covers access to UICC/USIM. The borderline between *user domain security* and *application domain security* for UICC/USIM is based on functionality and not physical entities.

**IV) Application domain security**
The set of security features that enable applications in the user domain and in the provider domain to securely exchange messages. To some extent this also covers UICC/USIM enabled functionality.

**V) Visibility and configurability of security**
The set of features that enable the user to inform him/her whether a security features is in operation or not and whether the use and provision of services should depend on the security feature. In UMTS the terminal is required to be able to give such indication

## 4.5 Confidentiality

This section covers confidentiality over the air interface. Specifically it covers confidentiality of user and signalling data over the air.

UMTS also defines two other aspects of confidentiality:

- **Enhanced User Identity Confidentiality (EUIC)**
  EUIC is a set of mechanisms to ensure that the user identity is never passed in clear over any UMTS link. The EUIC requirements are troublesome to meet, and it is not yet clear to what extent EUIC will be provided in UMTS release 1999.

- **Network-wide encryption**
  Network-wide encryption is scheduled for implementation in UMTS release 2000, but a number of preparatory steps have been taken in release 1999.

### 4.5.1 Ciphering algorithm

The UMTS encryption algorithm (UEA) is implemented in both the MS and the RNC. The UEA shall produce one output as a sequence of keystream bits referred to as a Key Stream Segment (KSS). A KSS of length $n$ shall be produced to encrypt a given segment of plaintext of length $n$.

The current UEA is based on an algorithm called KASUMI. The KASUMI algorithm, which is expected to be released in public, is derived from Mitsubishi's MISTY [8,9] algorithm. UMTS is not limited to the KASUMI encryption algorithm, an encryption algorithm identity field consisting of 4-bits allows for new algorithms in the future.

## 4.6 Authentication in UMTS

Authentication and Key Agreement (AKA) is one of the fundamental security functions in UMTS. Authentication in UMTS is mutual as opposed to one-way as in GSM today. By having mutual authentication a number of threats can be effectively prevented. The method is a challenge/response mechanism. UMTS extends the GSM subscriber authentication and key establishment protocol [5] by adding a sequence number-based one-pass protocol for network authentication derived from the ISO standard ISO/IEC 9798-4 (section 5.1.1).

The authenticating parties are the Authentication Centre (AuC) of the user's Home Environment (HE/AuC) and the USIM in the user's mobile station. That is, the parties engaged in the actual challenge-response exchange will be the Serving Network (SN) and the MS. This implies trust between the HE and SN and it requires a protected means of signalling between SN and HE. One should be aware of the implied trust model since it is fundamental that the HE and SN trust each other in UMTS. Furthermore, a "protected means of signalling" really implies that the MAP protocol must be secured. The UMTS security group (SA3) has proposed to provide confidentiality, integrity and entity authentication for MAP, but due to time pressure and implementation complexity it will be March 2000 before it will be finally decided whether or not MAP security will make it into UMTS release 1999.

Keys for encryption and integrity (CK and IK) are produced during the execution of the authentication mechanism.

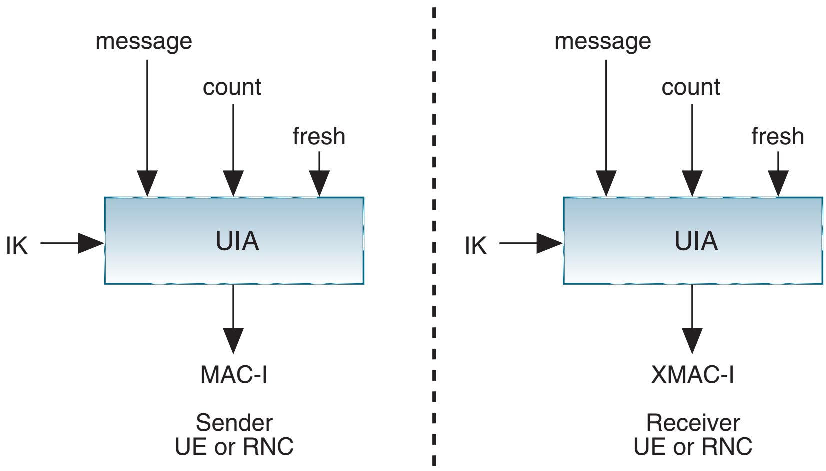
## 4.7 Integrity procedures and functions

Many signalling information elements are considered sensitive and must be integrity protected independent of whether the messages are encrypted or not. A message authentication function shall be applied on most signalling information elements transmitted between the MS and the SN. The UMTS Integrity Algorithm (UIA) shall be used with an Integrity Key (IK) to compute a message authentication code (MAC) for a given message (figure 2). The MAC is 4 octets long and adds considerably to the message overhead.

### 4.7.1 Integrity algorithm

The UMTS integrity algorithm shall be implemented in the UE and in the RNC.

*Figure 2 Derivation of MAC-I (or XMAC-I) on a signalling message (from TS 33.102)*



The input parameters to the algorithm are the Integrity Key (IK), a time dependent input, a random value generated by the network side, the direction bit and the signalling data. Based on these input parameters the user computes the message authentication code for data integrity using the UMTS Integrity Algorithm. The MAC-I is then appended to the message when sent over the radio access link. The receiver computes XMAC-I on the message received in the same way as the sender computed MAC-I on the message sent and verifies the data integrity of the message by comparing it to the received MAC-I. The counter parameter protects against replay during a connection. It is a value incremented by one for each integrity-protected message. The input parameter FRESH protects the network from replay of signalling messages by the user. At connection set-up the network generates a random value FRESH and sends it to the user. This mechanism assures the network that the user is not replaying any old MAC-Is. The current integrity algorithm is based on KASUMI, but UMTS is not limited to KASUMI. An integrity algorithm identity field consisting of 4-bits allows for new algorithms in the future.

## 5 What has been achieved in release 1999

Figure 3 gives an overview of where UMTS will provide security. Inter-system security aspects have deliberately been excluded from the figure.

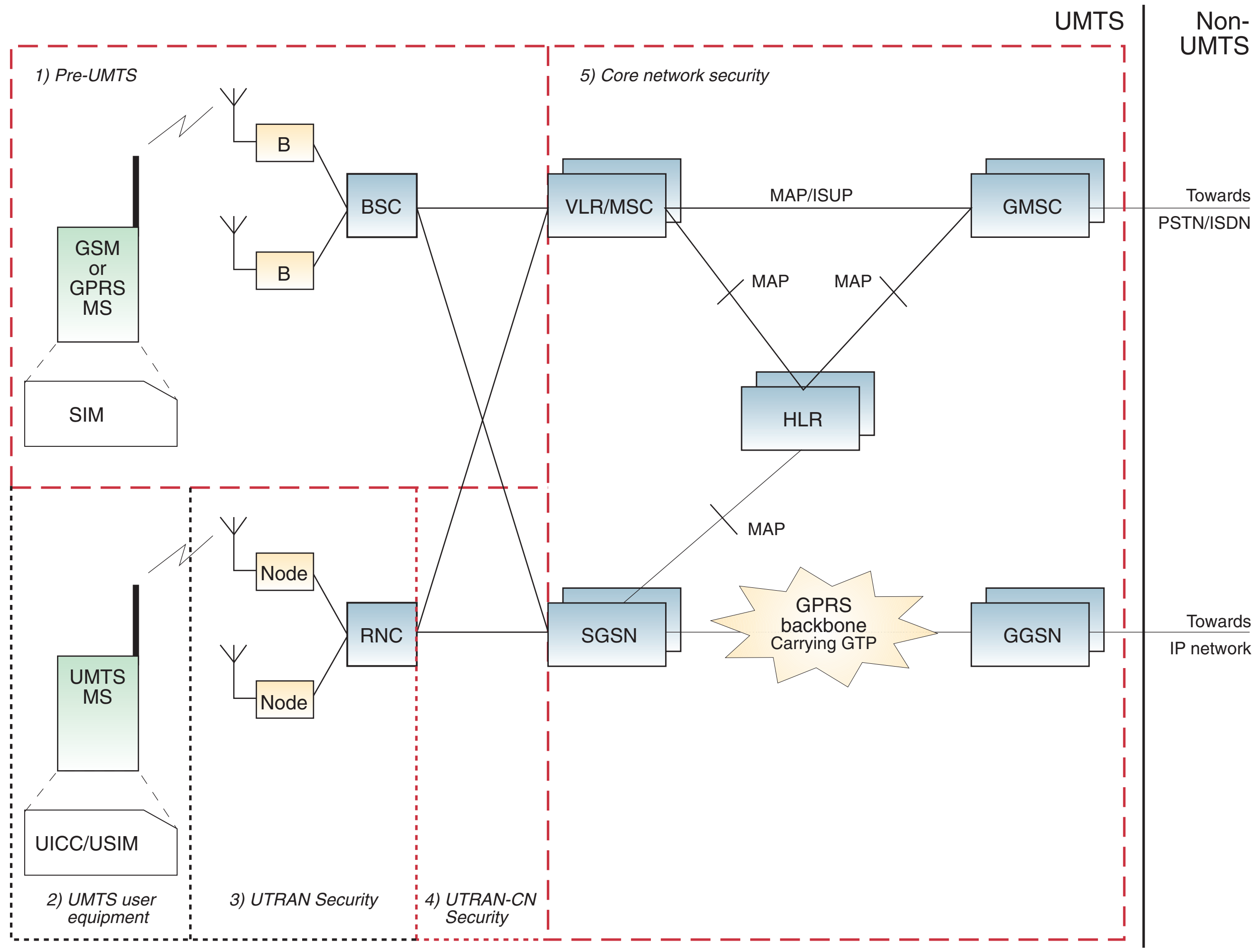
From the figure we have that:

1) **Pre-UMTS nodes and equipment**
In some instances pre-UMTS nodes and equipment may transparently support full UMTS security, but in many instances only GSM or GPRS level of security can be accommodated.

2) **UMTS user equipment**
UMTS will provide improved security for the terminal and the UICC/USIM. However, added functionality in MExE and SAT may effectively negate that advantage. The security provided by MExE in particular, may be somewhat limited.

3) **UTRAN security**
For the access network the security will be much improved compared to GSM/GPRS. This includes integrity checking of signalling

*Figure 3 Simplified UMTS system architecture*



messages as well as greatly improved encryption of user and control data.

**4) UTRAN – SGSN, VLR/MSC**
The security between the UTRAN and the network nodes SGSN and VLR/MSC will be improved, but in general there will be no user data encryption here.

**5) The core network**
The security group SA3 has planned and implemented security for the MAP protocol in the core network in the security architecture. However, the MAP specification itself still remains to be updated accordingly, and it is not clear whether this will happen for release 1999.

Other protocols that should be protected in the core network are the GPRS Tunnelling Protocol (GTP) and the CAMEL/IN protocols (CAP/INAP). Possibly, one should also provide some security for ISUP. Release 1999 does not provide any security services for GTP and CAP/INAP and has in this respect fallen short of the goals in TS 33.120 *Security Principles and Objectives*. Further work in this area is scheduled for release 2000, including coverage for the all-IP and Mobile IP options.

**6) Roaming and inter-system issues**
Release 1999 provides essentially very little in the area of roaming and inter-system security. Work in this area is scheduled for release 2000.

## 6 References and further reading


1 ISO. *ISO 7498-2 Information processing systems – Open systems interconnection - Basic Reference Model – Part 2: Security Architecture.*

2 *SPECIFICATION FOR NMT-SIS KEY MANAGEMENT IN NMT-900 (1988-07-01).* The Post and Telegraph Administrations of Denmark, Finland, Norway and Sweden.

3 *NMT-SIS, AUTHENTICATION REGISTER, Functional specification of an Authentication Register for NMT-900.* The Post and Telegraph Administrations of Denmark, Finland, Norway and Sweden.

4 ETSI. *GSM 02.09 Security Aspects.*

5 ETSI. *GSM 03.20 Security Related Network Functions.*

6 3GPP. *UMTS TS 21.101 Release 1999 Specifications.*

7 3GPP. *UMTS TS 21.905 3G Vocabulary.*

8 The Mitsubishi MISTY homepage, http://www.mitsubishi.com/ghp_japan/misty/.

9 Matsui, M. New Block Encryption Algorithm MISTY. *(The 4th) Fast Software Encryption Workshop,* Jan. 1997.