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ODTR BRIEFING NOTE SERIES

Potential Applications for Next Generation Networks

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Foreword

This briefing note is a follow up to the Next Generation Networks briefing note[1] that was issued in November 2001. Both are prepared under the Office's Forward Looking Programme. The Next Generation Networks note briefly identified applications of future telecommunications technology as a key driver to the development of next generation networks. It is essential that the potential demand for applications and services is more clearly identified and the need for bandwidth assessed. This note sets out a range of potential changes in technologies and a range of broadband and narrowband applications that could influence the development of next generation networks. Some may be adopted, some may not. Some may be adopted more slowly than others, and some may develop in centralised or de-centralised ways, thereby impacting on the required network configurations and bandwidth. It is important, as we move forward with a variety of methods to increase bandwidth, that we now consider in more detail what benefits we can gain and what uses would be made of further upgrades to our telecommunications infrastructure.

A range of new and potential applications –next generation applications –are emerging in many areas including government, education, entertainment, medicine, and business. In general, video applications are more demanding in terms of bandwidth than audio and voice applications, and so the question as to the degree to which video based applications are developed and taken up will have a key bearing on the bandwidth required. Although many data applications will naturally function at low data rates there are other applications such as Web browsing where users will appreciate the higher speeds afforded by higher bandwidth connections. In many cases next generation applications will involve the transmission of large amounts of information, sometimes more than can be handled by today's telecommunications networks. Therefore further investment may be required to upgrade or reconfigure broadband access networks and core infrastructures.

Some of the applications described in this briefing note are already available in Ireland. However the likelihood of their wider adoption, and the cumulative effects that this could have on telecommunications infrastructure, is something that needs to be highlighted and carefully considered, particularly as we look beyond the realignments and restructuring that are currently taking place in the ICT sector. This paper is intended to develop the debate rather than to outline conclusions and I look forward to receiving comments on this and any other points in this Briefing Note.

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[1] www.odtr.ie/docs/odtr0188.doc . Other briefing notes: Technology Developments in Telecommunications (odtr0159), Wireless Local Area Network (odtr0216), and Optical Access (odtr0229).

The Briefing Note Series is primarily aimed at non-technical readers with some background knowledge of telecommunications technology. The main purpose of the series is to raise awareness of new or developing technologies that could have important implications or present significant opportunities in the telecommunications sector in Ireland.

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Comments on this briefing note

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to arrive on or before 5.30pm on Friday June 7th, 2002.

In submitting comments, respondents are requested to reference the relevant section from this document. Responses to this document will be available for inspection by the public on request. Where elements of any response are deemed confidential, these should be clearly identified and placed in a separate annex to the main document.

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1. Introduction

1.1 Background to Briefing Note

The purpose of this briefing note is to develop the debate about the possible new applications that we might expect to be delivered over next generation networks. Demand for such applications (see Figure 1 below) will help telecommunications operators to make decisions on upgrading networks, to the extent that they can see new market opportunities and increased sources of revenue. There is already a demand for increased bandwidth both from parts of industry and some residential users. Also, if increased bandwidth is made available service providers and researchers will be more inclined to focus on and develop new ICT applications to utilise this bandwidth. Users' experiences of applications deployed over broadband networks will generally be more satisfactory than with lower capacity networks. Some new telecommunications applications have the potential to help increase operational efficiency for businesses while others have the capability of bringing about a wider range of service choices (e.g. medical applications which could cut queues in hospitals) and greater inclusiveness (e.g. in education) for Irish users.

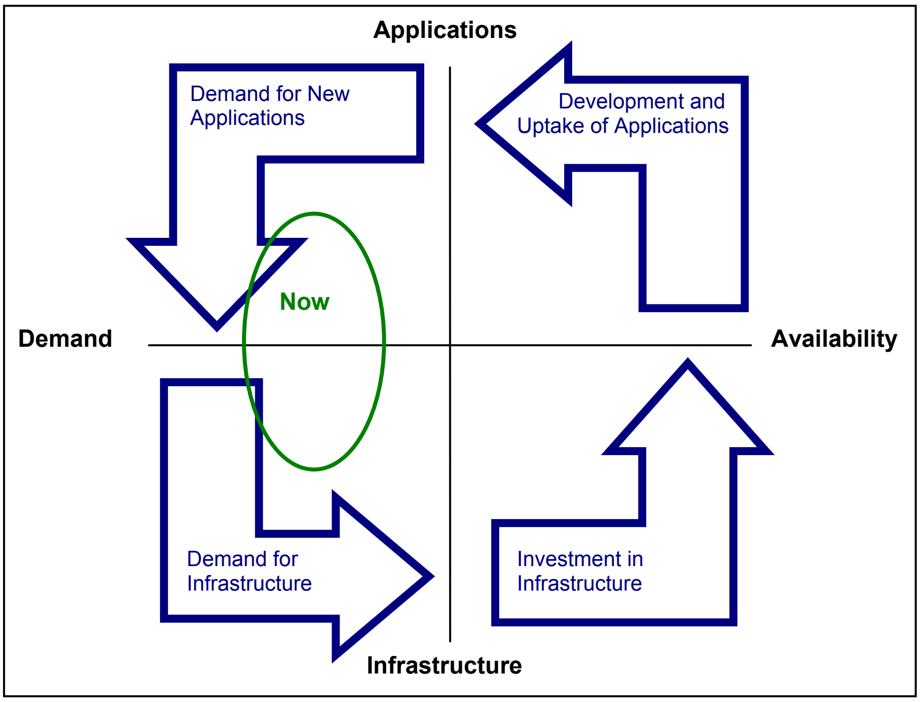

Figure 1. – Applications/network infrastructure dependence relationship.

In some cases commercial versions of these applications are currently under development or have already been implemented to a limited extent using commercially available technologies. Other applications are still at early stages of research and development.

1.2 Application Trends

Telecommunications traffic is continuing to increase[2] despite fluctuations in economic climates. Much of this increase can be attributed to growth in use of the Internet which is forecast to continue growing in capacity[3]. Many telecommunications users are adopting applications that require greater capacities to transfer increasing amounts of information. This is related to the fact that more information is becoming digitised for storage on computers and for efficient distribution through telecommunications networks. For example, some companies and institutions already store 10s and even 100s of Terabytes (1 Million Million bytes)[4]. Widespread deployments of developments in telecommunications access going back even a decade and more (e.g. ISDN) have also helped give rise to new applications (e.g. high speed Web content). These trends are likely to continue or accelerate as the general level of familiarity with technology continues to increase among users. For some applications this is a matter of reaching a certain critical mass so that people are aware of, and are familiar with, new applications[5].

Unanticipated or latent demand can also become visible for applications after they have attained a market presence. This can be because users are often not aware of the benefits of certain applications, and therefore do not generate a demand for them, until after they are launched and their benefits become apparent. Recent growth in the use of mobile short messaging systems is a good example of latent demand.

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[2] Overall traffic growth rates are set to continue at 20-25% annually over the next four years (Probe Research 2001).
[3] See for example Probe Research, 2002 (World Internet Traffic, Volume 1, No. 7) and the Yankee Group report 'The Devil's in the Data: European Bandwidth Demand Assessed', 2002.
[4] e.g. IBM and Seitel Inc. (http://www.computerworld.com/cwi/story/0,1199,NAV47_STO55430_NLTES,00.html), San Diego Super Computer Centre - High Performance Storage System (http://www.sdsc.edu/Storage/statistics/hpss_stats.cgi?1)
[5] The time taken for technologies to reach critical mass can vary significantly, e.g. DVD; ~5 years, wide screen TV; ~10 years.

Generally speaking, people are interested in the benefits and advantages that new applications can bring, rather than in the technology itself[6]. Technology interfaces that are intuitive, easy to configure and unobtrusive (i.e. 'user friendly') help to encourage the widespread adoption of new applications. New approaches to these important aspects of technology[7] are likely to lead to the adoption of new applications.

The following section broadly outlines some of the applications that could be deployed on next generation networks. A more comprehensive listing of developing applications and descriptions of some related technologies can be found in annexes to this briefing note.

[6] Erikki Liikanen, European Commission *"The vision of a mobile Europe"*, Bremen, March 2002
[7] See Annex 1

2. Potential Users of New Applications

In this section the potential adoption of new telecommunications applications is categorised into two broadly defined market segments:

1. Widespread use (mass market) – e.g. residential, Small Office-Home Office (SOHO), SMEs
2. Large business and specialised use – e.g. enterprises and medical, educational and research establishments

With the exception of some next generation broadband entertainment applications (see Section 2.1 below and Annex 3) mass market residential applications will typically operate at lower data rates than many large business applications. However, these two segments overlap in terms of general purpose applications. For example video conferencing technology would be a useful addition to many systems providing person to person communications, although the required quality of service may vary according to use.

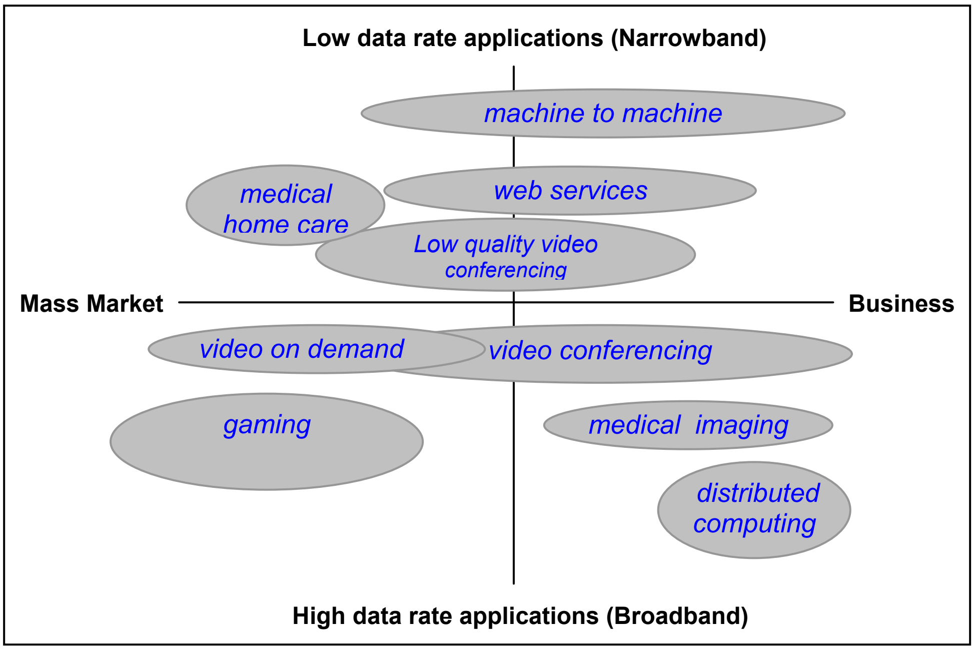

Figure 2. Example applications and their market segments – more broadband applications are likely to develop and extend into the broadband region (lower section) of this diagram.

2.1 Widespread Mass Market Applications

Some of the most demanding applications for the residential sector will most likely be entertainment related. Applications such as good quality video on demand, video telephony and graphically intensive gaming could typically demand data rates of between 2 and 10Mbit/s (and multiples thereof for households running several simultaneous applications). Furthermore, future applications that could utilise three dimensional video (e.g. virtual reality) or holographic displays may require capacities of 100s of Mbit/s or even Gbit/s.

Service	Required Capacity
Voice	6.6kbit/s – 64kbit/s
Audio	32kbit/s – 384kbit/s
Video Conferencing	~100kbit/s – 4Mbit/s[8]
Video Streaming	~1Mbit/s – 10Mbit/s
3D Video	~10Mbit/s – 50Mbit/s+
Web Services	100's kbit/s +
Machine to Machine	kbits/s - 1Mbit/s

Table 1: Some applications that could be carried over next generation networks.

Clearly in the case of entertainment, for example, the costs of providing the higher rate services over networks as opposed to cinemas etc., as well as the cultural issues as to where people want to be entertained, are important factors that need to be considered carefully.

Other applications such as e-learning[9] or tele-education, where users can participate in enhanced educational programmes at home, utilising interactive video tutorials and presentations[10] are likely to become increasingly popular as appropriate access becomes available. Medical home care applications could enable users to consult with doctors using

[8] See Annex 2, Figure A2.1
[9] See www.skoool.ie , www.riverdeep.net
[10] See Annex 3, A3.2

video conferencing and specialised monitoring equipment saving them a trip to the hospital or GP clinic, and in some cases detecting the development of potentially dangerous conditions[11].

Many mass market applications may develop which do not need particularly high capacities. For example many e-government services such as on-line form filling do not typically need capacities greater than a few hundred kbit/s. Similarly, machine to machine communications involving electronic household goods (e.g. washing machines, refrigerators, security systems) would typically only require relatively low speed Internet connectivity[12]. More examples and information on applications in the mass market and residential segment can be found in Annex 3.

2.1.1 The aggregate effect

Although many typical mass market applications such as voice, Internet shopping, basic medical homecare and many web services individually require low data rates (10s to 100s of kbit/s), once aggregated they would require users to have relatively high capacity 'last mile' access to communications networks. Furthermore, the aggregate effect of increased traffic from many users would have significant loading implications for core networks[13].

2.1.2 Falling price points

As new applications are introduced and achieve widespread adoption, technology developments and economies of scale – in manufacturing, distribution and service provision – typically allow consumer costs to fall. In the mass market segment this lowering of price points for communications products and services is likely to expand the potential markets considerably, as costs come within acceptable levels for the majority of consumers.

[11] e.g. www.homehealth-uk.com/medical/healthwatch.htm , see Annex 3, A3.4 for more information on home care applications.
[12] Samsung have begun installing such devices in Korean households; http://www.newsfactor.com/perl/story/13039.html Whirlpool and Intel are other companies developing products for this market. See Annex 3; A3.6, and Annex 2; A2.5
[13] See Scenario 2 in Annex 4

2.2 Large Business Applications

Large corporations, with demanding telecommunications needs, have typically been early adopters of advanced technologies such as video conferencing and virtual private networks. These business users are also likely to be among the first to implement more widespread use of video conferencing giving more employees access to such services from their desks (instead of limited dedicated video conferencing rooms).

Other applications are developing to serve the collaborative needs of business users in areas such as multi-site software development and product design. The use of three dimensional interactive displays and user interfaces could be important to users in working on collaborative designs (e.g. component design in the automotive industry)[14].

The medical sector is another potential adopter of high capacity telecommunications applications. As use of electronic records management (ERM), digital imaging and teleconferencing systems increases in hospitals more capacity will be needed from telecommunications networks to facilitate inter-hospital communication. Advanced display technology, including three dimensional video systems, have enabled surgeons to perform surgical procedures remotely (telesurgery), with the aid of robotic instruments. Surgeons can be located at great distances from their patients using telecommunications technology[15].

High capacity applications such as distributed computing are already being used by education and research institutions to help solve computationally intense problems (e.g. high energy physics). Distributed computing can carry out complex calculations by allowing portions of a problem to be calculated on different computers, often situated at different locations (see Annex 3, A3.8).

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[14] See Annex 1, A1.1

[15] A surgeon in New York performed surgery on a woman in Strasbourg France, via a 10Mbit/s link, in September 2001 (See Next Generation Networks briefing note). See also the European Institute for Telesurgery (www.eits.org) where surgeons are being trained to operate telesurgical systems.

Expanded use of lower capacity new applications and services such as web-services[16] can be expected from large businesses, to help them integrate separate systems and improve efficiency through increased automation (e.g. supply chain management). Customer facing applications such as customer relationship management (CRM) are also likely to see increasing use. The aggregate effect of widespread adoption of these services is likely to increase traffic on core telecommunications networks significantly. Further information on emerging applications for business, education, medical, and research and scientific uses can be found in Annex 3.

It is important to note that the applications described in the sections above are not intended to be a comprehensive listing, and more examples can be found in Annex 3. Furthermore, some of these applications could also be applied in other areas not mentioned here. Although in certain cases some of these applications have already been deployed to a limited extent, over time we can expect to see more widespread deployment, including among new groups of users (e.g. video conferencing).

[16] Irish companies such as Iona, Epionet, Bind Systems and Vordel are developing web-services products. See Annex 2; A2.4 and Annex 3; A3.1.4 for an explanation and examples of web-services.

3. Implications for Telecommunication Networks

3.1 Characteristics of Applications for Next Generation Networks

Some of the new telecommunications applications will be developed for widespread adoption. In which case, irrespective of the technology used, they should have the following characteristics:

- Usability - Devices should be easy to use (e.g. have intuitive interfaces).
- Configurability - Simple or automatic configuration of new applications and devices is important for their widespread adoption. If telecommunications technology is to penetrate beyond early adopters or high tech enthusiasts the applications must be easily accessible and easy to use.
- Flexibility - Applications should be flexible and adaptable to enable their operation in numerous user scenarios.

Other new applications (e.g. business and R&D applications) will serve narrower, more specialised markets. Hence the emphasis here is more likely to be on very high data rates.

3.2 Network Characteristics Required by New Applications

While some applications will be catered for by existing networks many new applications if adopted on a widespread basis will impose heavy demands on next generation networks. Further expansion of core telecommunication network infrastructures would be needed in due course to cope with the aggregate traffic arising as a result of the increasing availability of high capacity 'last mile' networks. To the extent that these types of applications are adopted, the main network characteristics that will be required are:

- High Capacity - The aggregate effect of many users of high capacity applications–and also lower capacity applications such as machine to machine communications–will clearly require high capacity next generation networks. Furthermore, new applications requiring even greater individual capacities are likely to continue emerging, despite the development of more efficient compression techniques[17].

- Delay Tolerance - Real-time applications such as video conferencing services will have a low tolerance for delays, possibly requiring that some sort of connection or dedicated capacity be guaranteed at the beginning of a communication. Other applications such as archiving of data may be more tolerant of delays.
- Security & Reliability - As individuals become more reliant on telecommunications technology and increasingly use them for private matters (e.g. banking, medical services) higher levels of security will come to be expected of telecommunications services. Furthermore, increased dependence on telecommunications will heighten the importance of reliable systems.

For more details of the characteristics of next generation networks see the next generation networks briefing note[18].

Many of the applications described in this briefing note depend on the deployment of broadband 'last mile' access networks so that services can be provided to individual businesses, homes and users (see Annex 2; A2.7). Other applications, although not individually large consumers of network capacity, will contribute to the requirement to up-grade core telecommunications networks to cope with aggregate traffic levels resulting from widespread use (e.g. web-services). Some applications will also be dependent on packet based network architectures, and others will call for guaranteed levels of service (see Next Generation Networks briefing note).

[17] Compression techniques use computer processing to reduce the amount of data needed to communicate information.
[18] www.odtr.ie/docs/odtr0188.doc

4. Market Development

4.1 Economic Development

Ireland has a substantial track record in developing its IT sector identifying the trends and attracting companies to invest in Ireland. This sector has played a vital role in Ireland's economic success in recent years.

New telecommunications applications will continue to emerge that can be of significant benefit to Irish users. Furthermore, people will gradually come to expect these new applications as the norm, both at home and at work. Implementation and adoption of these new applications can help move Ireland up the ICT sector value chain. Economic growth is likely to come about from the emergence of interest in new applications which people will want to use. However, it will take manufacturers and service providers time to identify, develop and deploy some of the new applications. To some extent, the rate at which this happens will influence and be influenced by the availability of appropriate telecommunications infrastructure.

4.2 Convergence

The emergence and uptake of new applications will probably reinforce the trend towards convergence in the telecommunications market. Some operators who traditionally only offered a single type of telecommunications service (e.g. telephony or cable TV), may in some cases find it appropriate to offer a wider selection of services and applications in future[19]. Network technologies which on their own are less able to facilitate multiple services and applications might form the heart of a hybrid solution in combination with other network technologies. For example, some companies are exploring the possibility of complementing 3G mobile services with wireless LAN based services. In so doing they would potentially be combining the

[19] The combined provision of voice, video and data (e.g. Internet) over a single network or from a single service provider is often referred to as 'triple play'.

high mobility and coverage capabilities of 3G technology with the higher data rate capabilities of wireless LAN technology, which tends to offer portability rather than full mobility.

4.3 Restructuring and New Business Models

On the other hand, rather than promote convergence, some new applications may in some cases lead to separation of business activities. For example, alternative business models may emerge whereby content and application service providers increasingly operate separately from network operators, enabling the various businesses to focus on core competencies. There may also be opportunities for new entrant and incumbent network providers to develop and deploy new backbone and access infrastructure topologies that may be needed to carry some of the new applications e.g. for some new machine to machine communications.

4.4 Government Initiatives

There have been a number of government initiatives under the National Development Plan to help facilitate, develop and encourage the use of telecommunications services. In March, the Department of Public Enterprise (DPE) announced a programme to invest €160 million in providing high capacity fibre optic networks around Irish towns[20]. The DPE also launched a programme in February to encourage the use of telecommunications applications in Irish communities. Approximately €3 million in funding is allocated for the Community Application of Information Technology initiative[21].

The Department of Health and Children published a draft consultation document in July 2001, 'A national health information strategy – 2002 to 2009'[22] in which the

[20] http://www.irlgov.ie/tec/press02/March8th2002.htm
[21] http://www.irlgov.ie/tec/cait/
[22] www.doh.ie/hstrat/nhis/consult.pdf , see also a report from the Consultative Forum on E-Heath (National Health Strategy): www.doh.ie/hstrat/repeh.pdf

application of telecommunications technology within health services is a main objective.

In the area of e-government, Ireland has taken the opportunity to introduce a number of new applications to encourage the adoption of telecommunications technology aimed at improving the quality of service for citizens[23]. For example, the Reach initiative (www.reach.ie) offers users a gateway to on-line government services. Irish government web sites were rated best of the EU government web sites in 2001 by the Internet Intelligence study[24].

Science Foundation Ireland (SFI)[25] was established in 2000 to administer Ireland's Technology Foresight Fund which totals more than €635 million. SFI provides awards to support scientists and engineers in undertaking far-reaching, high impact research. SFI is focusing on the fields underpinning two broad areas: information and communications technology development, and biology and biotechnology. A significant part of the ICT funding will go towards research and development of new applications and devices.

4.5 Impact on Choice and Quality

The arrival of new applications to the market will create new choices for consumers and users of telecommunications services. As more worthwhile applications become available to carry out new functions users will be able to choose alternative telecommunications solutions over traditional methods. For example, video conferencing can in many cases reduce the need for people to travel (e.g. business meetings, seminars, training sessions and even medical procedures –see Annex 3; A3.1.1).

[23] See Annex 3, A3.7 for more detail on e-government.
[24] Survey conducted by PoliticsOnline, Inc. and Amsterdam-Maastricht Summer University: www.politicsonline.com/specialreports/010803/eusurvey2001.asp
[25] www.sfi.ie

The deployment of next generation networks, needed to facilitate widespread adoption of new applications, will also benefit current applications through the enhancement of characteristics such as high capacity, security and reliability.

Conclusions

There is a clear global trend in growth for information and communication services over the medium and long term, notwithstanding the realignments and restructuring that are taking place in the telecommunications and related industries. A multitude of applications are being researched and developed and over time some will be deployed in markets around the world. Widespread implementation of high capacity applications will in some cases require broadband telecommunications networks with greater information carrying capacities than are commonly available in today's networks, particularly in the 'last mile' portion of networks. Different approaches to other network characteristics such as network topology may also be needed. Therefore, some of the applications outlined in this briefing note may require significant prior investment in next generation network infrastructures if they are to be adopted on a widespread basis. This will pose significant technical and investment challenges to telecommunications operators and service providers. However, such investments would in some instances enable operators to save on operational costs and create new revenues from new applications in the medium term[26].

[26] Refer to the Next Generation Networks briefing note for further information: www.odtr.ie/docs/odtr0188.doc

Annex 1 – Human/Technology Interactions

Changes in the way in which users interact with computers and other electronic devices will help create more useful applications. More useful applications in turn lead to more widespread adoption, which in turn will require investment in telecommunications networks to accommodate the increased volume and other requirements (e.g. security – see Section 3) associated with new traffic.

Developments in interactive voice systems will allow users to access information by speaking commands and asking questions[27].

Advances in computer outputs will also help new more useful applications to develop. Flexible displays that can be integrated into every-day objects (e.g. table tops, walls), and three dimensional displays (spatial imaging) requiring high capacity access (e.g. 100's of Mbit/s) will enhance our viewing experiences (see Section A1.2).

A1.1 Displays and Haptic Inputs

Head-worn displays for example mounted on glasses to project images directly onto viewers' eyes will allow users to access information without having to look at a screen (see Section A1.3). Users will then see the projected information along with their normal vision, in a similar manner to the display of subtitles on TV programmes. Such displays are already commercially available with products such as 'Nomad' from Microvision, and the 'Wearable Internet Appliance' from Xybernaut & Hitachi[28].

Incorporating the sense of touch via haptic[29] interfaces into computer systems can enhance a number of interactive activities, which would require higher capacity networks. One example is in the manufacturing industry where designers of

[27] Voice XML is one of the technologies enabling voice interaction with the Internet through voice browsers and gateways (www.voicexml.org)

[28] www.hitachi.co.jp/Prod/vims/wia/eng/main.html

[29] The term 'haptic' relates to the sense of touch.

machined parts could gain extra insight into the pieces that they form through interfaces that give haptic feedback related to the stiffness of the material being worked on[30].

A1.2 Ambient Intelligence (AmI)

Ambient intelligence (AmI) is the concept of integrating small computers into everyday objects such as work tops, doors and windows. Examples of ambient intelligence could be lights that brighten when sensors detect someone reading and dim when a computer display is being viewed. Other applications could re-direct music or computer displays to follow users as they move through a building, leaving nearby consoles ready for interaction with a current application. Various types of sensors can also be used to collect and interpret physical movements (e.g. hand or eye movements) to passively control an on-screen cursor instead of using a mouse. See European Commission ISTAG (IST Advisory Group): www.cordis.lu/ist/istag.htm and the MIT pervasive computing lab: http://oxygen.lcs.mit.edu/ for examples of applications currently under research.

A1.3 Wearable computers & Personal Area Networks

As computers become smaller they can be integrated into items of clothing, eliminating the need to carry specific devices around with us. Wearable computers are already being adopted in situations where conventional computers would be too cumbersome (e.g. Fedex[31] - aircraft maintenance technicians, using WLANs). Other interfaces could be integrated into jewellery (e.g. ear rings that are speakers). Multiple wearable devices can be networked forming a personal area network (PAN). Typically this could be achieved using short range wireless technologies such as Bluetooth or through conducting wires woven into the fabric of clothes (Levi/Philips ICD+ Jackets). Broadband mobile access infrastructures (e.g. 3G, WLAN) would

[30] A Virtual Lathe is being developed at the MIT Medialab: www.media.mit.edu/groups/spi/HHlathe.htm

[31] The Fedex system was provided by Xybernaut. Xybernaut, in association with Hitachi has recently released affordable ($2000) wearable computers targeted at consumer markets: www.hitachi.co.jp/Prod/vims/wia/eng/main.html

greatly enhance the viability of wearable computers enabling users to avail of broadband services.

Annex 2 – Communications Technologies

A2.1 Voice & Audio

Digital fixed line voice communications have typically operated at 64kbit/s. Through the use of compression (i.e. prior knowledge of the type of information being sent) much lower data rates could achieve good quality voice communications, e.g. mobile (RPE-LTP[32]: GSM). The ITU has recently ratified a standard for high quality voice communications which can also operate at relatively low data rates (6.6 – 23.85kbit/s) (G722.2 – Adaptive Multi-Rate Wideband: AMR-WB).

In addition to encoding and compression, the set-up and control of a voice call and any additional services (e.g. caller line identity number, call waiting) must be controlled. Protocols such as SIP (Session Initiation Protocol) are important here.

Audio compression protocols such as MP3 (MPEG[33]1 layer 3) can allow for transmission (including streaming and multi-casting) of music and other forms of audio communications, typically at data rates between 32 and 384kbit/s.

A2.2 Video

The video compression standard MPEG2 is capable of compressing video streams to data rates typically between 300kbit/s and 9Mbit/s. Data rates in excess of 50Mbit/s can be required for high quality (e.g. broadcast/studio quality) video signals, typically used within studios for editing and production purposes. However, it may not be practical to deliver services over telecommunications networks at such data rates due to various commercial, economic and technical constraints. MPEG4 is a more advanced video compression standard that allows further reductions in data rates (at the price of increased computational/processing power). MPEG4 also has a number of additional features which could be used in next

[32] RPE LTP: Regular Pulse Excitation – Long Term Prediction (operates at 13kbit/s or 6.5kbit/sec)
[33] MPEG: Motion Picture Experts Group

generation video applications, such as information about individual items or objects in a video image (including copyright information). MPEG4 treats individual objects in a video image as separate entities greatly increasing image manipulation capabilities, and also allowing for the future incorporation of three dimensional features (see Virtual Reality section below). MPEG4 video typically operates at data rates up to 10Mbit/s and is still an emerging technology. MPEG and ITU members are working together in the Joint Video Team (JVT) to produce MPEG4 part 10, which will incorporate elements of both MPEG4 and ITU H.26L[34].

Other advanced display technologies (e.g. video holography) that could require substantially higher data rates –possibly of the order of Gbit/s –are being developed in research centres (e.g. the Spatial Imaging Group at the MIT Media Lab, www.media.mit.edu/groups/spi/index.html).

A2.3 Virtual Reality

Virtual reality systems can operate using technologies such as VRML (Virtual Reality Modelling Language) and X3D (extensible 3D). The development of networked virtual reality is still in its early stages[35]. X3D is expected to be integrated with the MPEG4 standard, providing it with three dimensional capabilities. These technologies are also being adopted for use on mobile devices (e.g. Parallel Graphics – mobile VRML browser). Data rates of over 500Mbit/s could be required for graphically intensive virtual reality video systems. However, transmitting these high capacity services across telecommunications networks may not be practical for the time being, and will depend to a large extent on various commercial, economic and technical constraints.

A2.4 Web-Services

Web-services used to facilitate the interaction and re-use of applications across the Internet require open technologies and protocols to be successful. Some common protocols are XML

[34] H.26L is an ITU standard for video coding.
[35] See www.web3D.org for more information.

(extensible mark-up language), SOAP (Simple Object Access Protocol) and WSDL (Web Services Definition Language). These protocols specify formats and procedures for communication between applications using the Internet.

A2.5 Machine to Machine

As intelligence is embedded into more and more devices and everyday objects which are capable of communicating with one another, without human intervention, the concept of machine to machine (M2M) communications becomes more important. Even though these communications are typically narrowband the aggregate effect of multiple devices communicating could place significant loads on telecommunications networks. An example of a machine to machine application could be a wake-up alarm that would wake individuals earlier if it received reports through the Internet of traffic congestion or delays on the user's planned journey. It is estimated that in time the number of devices capable of communication will be comparable to, and could possibly exceed, the number of people who use telecommunications services[36].

A2.6 Peer to Peer

Peer to peer networking allows users to access and download data from other users' computers. In return for this the users usually grant others access to their computer archives. This technology could be used to share any kind of information (e.g. audio, video, and data), thereby granting users access to vast amounts of information. Freely available peer to peer networking programmes such as BearShare[37] and Swaptor[38] could conceivably increase traffic loads on telecommunications networks dramatically, as was the case with Napster[39],[40]. However, there are many copyright issues associated with peer to peer networking technologies since they can make it

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[36] Deloitte Research, 'Machine to machine E-Business, Information systems meet electrical systems', Nokia: http://nds1.nokia.com/press/pdfs/m2m_whitepaper.pdf
[37] www.bearshare.com
[38] www.swaptor.com
[39] www.napster.com
[40] Some US networks saw a doubling of traffic during Napster's peak popularity.

possible for users to re-distribute media. This also has the effect of increasing the amount of traffic that flows from users to the network, rather than just from the network to users. Thus symmetrical access networks are needed.

A2.7 Typical Access Technologies

Below are some of the access technologies that are currently being used to carry various types of new applications.

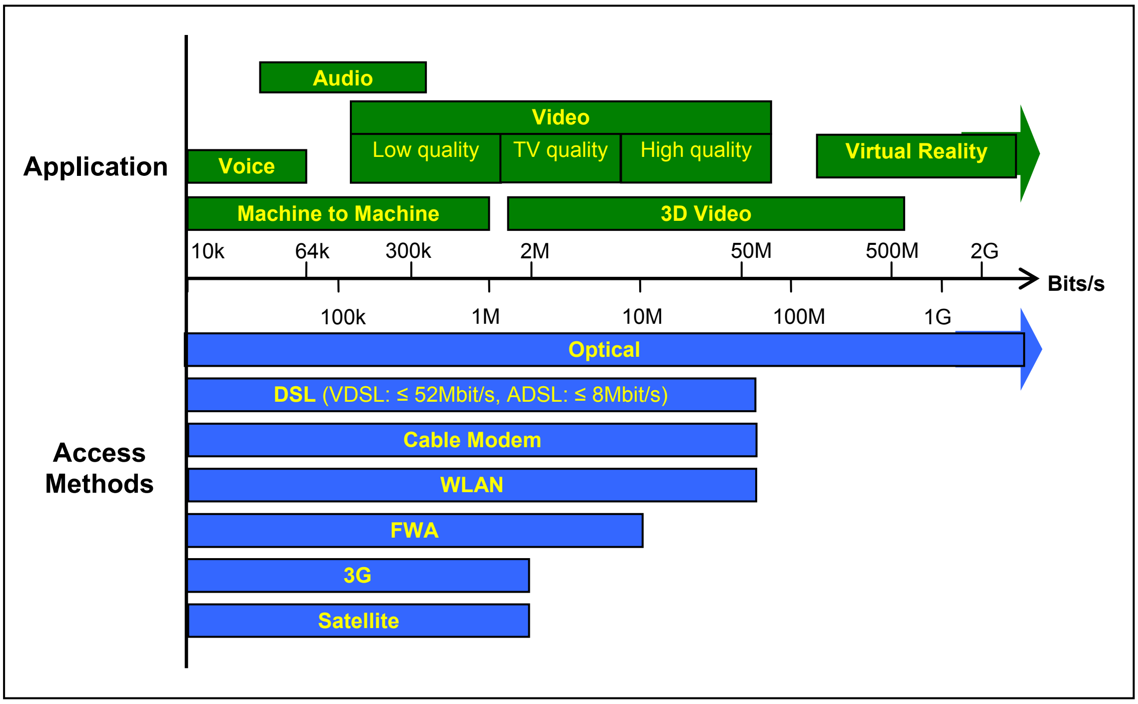

Figure A2.1. Approximate capacities of some applications and access methods

The diagram above illustrates the range of access technologies capable of carrying a variety of applications. It is apparent that optical access technologies are most appropriate for applications that will require more than 50Mbit/s[41], either individually or in aggregate.

[41] See the 'Optical Access' briefing note for more information on optical access: www.odtr.ie/docs/odtr0229.doc

A2.8 Relative transfer speeds of access technologies

Table 2 below illustrates the approximate amount of time that it would take to download a large 7GByte file using various access technologies. This is the size of a typical feature length film using the MPEG2 standard.

Access Method	Time Taken
Dial-up Modem (56kbit/s)	~ 12 Days
ISDN (128kbit/s)	5 ½ Days
E1 Leased Line (2Mbit/s)	8 Hours
ADSL (8 Mbit/s)[42]	2 Hours
Cable Modem (10Mbit/s)[43]	1.6 Hours
MMDS (24Mbit/s)	39 Minutes
Optical Access (100Mbit/s)	9.6 Minutes
Optical Access (1Gbit/s)	1 Minute

Table 2: Relative access download rates for a 7GByte file.

[42] Actual achievable data rates may be lower (e.g. 2Mbit/s) in many instances depending on a variety of factors such as the distance between the customer and the service provider, and the quality of the installed copper cable.
[43] Actual available data rates may start from 56kbit/s depending on the cable network.

Annex 3 – Some Applications of Next Generation Networks

In this section some leading edge and developing applications of telecommunications technologies are outlined, highlighting the importance of new applications across a broad range of sections. The applications are divided into eight categories;

- Business
- Education
- Medical
- Home Care
- Entertainment
- Domestic and Retail Markets
- Government
- Scientific research

A3.1 Business

A3.1.1 Person to Person Business Communications

New features that enhance the function of voice telephones in business applications are beginning to emerge. Some of these additional features include an interactive screen for retrieval of directory information, a sketch pad to allow users to draw diagrams for one another, and integration with personal diaries or organisers (e.g. AT&T Broadband Phone System – www.uk.research.att.com/bphone , Avaya, Mitel)[44].

Business to business video conferencing is already a key application. This allows participants to communicate without having to meet in person, saving on time and costs associated with travelling to meetings. Currently users pre-arrange a video conferencing session, in the same way that a meeting might be arranged, and then make use of dedicated

[44] These features are typically being incorporated in IP telephony systems which place stringent requirements on current IP networks such as guaranteed capacity and limited end to end delay.

video conferencing facilities (including dedicated network capacity). If video conferencing were to become more pervasive it could be adopted as a replacement for some voice only telephone terminals (either dedicated, or integrated with PCs) on users' desktops. Such use would require businesses to scale up their telecommunications connectivity and at the top end the costs could be very substantial (e.g. 10 simultaneous video conferencing sessions could require up to 20Mbit/s in each direction). Demand for videoconferencing increased markedly following the tragic events in the US on September 11th 2001, as business users sought alternatives to air travel[45].

Unified messaging applications will facilitate co-ordination of different types of media such as voice and e-mail, so that a user can access and manage their messages from a single terminal and through a single media type (e.g. e-mail messages can be listened to and written using text to speech conversions). These services would need greater inter-working between different communications.

A3.1.2 Collaboration

Advancements on current collaborative applications where users located separately can actively contribute to a single project will continue to reduce costs in the design and manufacturing industries for instance. Collaborative applications are also important in scientific research and the arts[46] (see Section A3.8).

Integrated customer relationship management (CRM) systems place high demands on data storage (i.e. Terabytes of data) and communications. For example, these systems help businesses retain customers by collecting customer information and tailoring product and service offerings accordingly.

Electronic supply chain management (SCM) systems enable businesses to operate more closely to a supply on demand system, reducing the cost of retaining excess stock and at the same time avoiding product shortages.

45 Source: Probe Research, U.S. Competitive Service Markets: Established Carriers, Feb. 2002
46 e.g. The SMARTlab centre; http://www.smartlabcentre.com/

A3.1.3 Marketing and Sales

The use of three dimensional graphics and interactive presentations can assist in marketing and sales of new products and services[47]. Such presentations can then be efficiently distributed to potential customers through the Internet.

A3.1.4 E-Commerce

Increasing use of business to business electronic commerce applications will place increasing demands on overall network capacity, security and reliability.

Web-services are potential enablers of widespread e-commerce adoption. Web-services allow users to access services on the Internet instead of just information. These services consist of re-usable programmes that can be applied in various situations[48]. Web-services will allow more complex business transactions to take place on the Internet, involving multiple parties. For example, a person buying fragile materials on the Internet, might need to arrange transportation and insurance for the goods from separate parties. Web-services allow each of these businesses to interact before completing the transaction. In general the application of this technology means increased usage and development of the Internet.

A3.1.5 Storage Area Networks

Storage area networks (SANs) allow companies with reasonably large storage requirements (i.e. typically more than 1 Tera byte) to build scalable, fault tolerant storage systems. Typical users are content and media providers who need to store large numbers of media rich files (e.g. video, graphics, etc.). SANs enable high speed access to stored information at a single user site, but can also be extended to incorporate multiple locations by operating over wide area networks.

[47] Parallel Graphics produce three dimensional display software for use in areas such as real estate and furniture marketing, and to aid architects when working with clients (www.parallelgraphics.com).
[48] Web-services are commonly being used to reduce the costs of internal system integration for businesses.

A3.1.6 Mobile and Portable

As higher mobile data rates become available from new GPRS and 3G networks, new mobile data applications for business users (e.g. mobile Intranets) are likely to emerge. Furthermore, mobile networks with increased capacities are moving toward some form of video conferencing capabilities (see Annex 2). The addition of more broadband features requires mobile networks with greater access and backhaul capacities. WLANs[49] are currently capable of providing users with up to 10Mbit/s, with 50-100Mbit/s expected soon.

Location based services are particularly applicable to mobile users. For example, these services will present users with local information on products and services as they travel, thus enhancing the quality of the information given (e.g. a user could find out the address of and directions to a local cinema). Such services will increase traffic on mobile networks.

A3.2 Education[50]

As well as increasing the reach of educational and training programmes to more diverse sections of society (distance learning), telecommunications services can be used to provide more efficient personalised education to individuals. Specific, tailor-made courses can be delivered based on a particular user's needs, who can participate at their own pace and at convenient locations and times (e.g. at home in the evenings)[51]. Lectures and tutors could deliver presentations over video links which could also be enhanced with interactive features so that students can ask questions and submit material for assessment (e.g. the Blueprint for interactive Classrooms (BiC)[52] is currently testing systems in European universities including University College Dublin). Furthermore, on-line educational institutions will need sophisticated video and content distribution and storage systems to serve students on a more individual basis.

[49] WLAN: Wireless Local Area Network. See WLAN briefing note: www.odtr.ie/docs/odtr0216.doc
[50] A recent report from Sage research ranks education as potentially the most profitable on-line consumer service: *"Customers at the Gate: Mounting Demand for Broadband-enabled Services",* Sage Research, Feb. 2002.
[51] Skoool.ie (www.skoool.ie) and Riverdeep (www.riverdeep.net) are two Irish providers of on-line education services.
[52] http://www.avd.kuleuven.ac.be/bic/products/classrooms/classrooms.html

Mobile education applications could also be of great benefit to users wanting to learn in a particular environment, for example a horticultural student could receive course materials while conducting fieldwork (e.g. HP Wireless Mobile Classroom[53]). High speed mobile networks such as 3G are needed to deliver media such as text and images at 100's of Kbit/s. Broadband wireless networks (i.e. greater than 2Mbit/s) would be needed for video content.

A3.3 Medical

Many hospitals are beginning to adopt electronic means of storing medical information on patients, so that details can be more efficiently stored, transferred and retrieved. Medical images such as x-rays are now often stored electronically[54]. As this technology progresses, hospitals and doctors' surgeries will be able to instantly transfer medical records between one another helping to ensure that a patient receives the most informed diagnosis. Digital images such as X-rays are very capacity intensive and would typically involve data rates of several Mbytes per second. Other systems where patients carry smart cards containing all their relevant medical details could, if adopted on a widespread basis[55], require high capacity secure core networks.

Transferring electronic medical details through telecommunications networks could also be beneficial to ambulance crews on the scene of an accident. Vital information concerning a patient's medical condition can be transmitted ahead, using mobile networks (e.g. GPRS, 3G, satellite), to brief hospital staff waiting to receive the patient. This type of application is already being used in Sweden[56] and other countries. Furthermore, ambulance crews could be given instructions on how best to carry out medical procedures while at the scene of an accident, and could be directed to the appropriate hospital for specialised treatments[57]. Secure, reliable and timely delivery of this information is essential for these services. Therefore mobile networks with large coverage areas such as 3G and mobile satellite will be

[53] http://government.hp.com/pdf/mobile_datasheet.pdf
[54] Typically several Mbytes each
[55] Cardlink Portable Emergency Card has been successfully trialled in Ireland among other European countries
[56] http://www.symbol.com/solutions/healthcare/healthcare_ambulance.html
[57] e.g. TNAC mobile computers: www.tnacorp.com/publicsafety.asp

suited for applications here. Applications such as medical imaging could require higher data rates in excess of 10s or even 100s of Mbit/s (e.g. three dimensional digital imaging). Advanced display technology, including three dimensional video systems are already enabling surgeons to perform surgical procedures remotely (telesurgery), with the aid of robotic instruments[58]. The levels of reliability and security needed for such applications are not widely available on current telecommunications networks and can be costly.

A3.4 Home Care

Telecommunications technology is already allowing some patients to be cared for remotely, for example reducing the time they spend in hospitals during recovery. Home care systems can also reduce the numbers of visits needed between patients and doctors. In some cases a patient's heart and breathing rates, for example, can be monitored, using a wearable device that can trigger an alarm at a monitoring station if a patient required attention[59]. Other devices could be used to collect test data from patients in their own homes. The data could then be transmitted to another location (e.g. hospital, GP clinic) for processing and analysis via the Internet[60].

Home care systems can also be used to lengthen the amount of time that elderly people can live un-assisted, and can enable some terminally ill patients to live at home instead of in hospices. There are issues for the public and for medical practitioners. Would a pattern emerge where patients consult their local doctors who in turn might use high capacity links to hospital specialists? Or would there be many users at home consulting with doctors via video conferencing links, enabling a diagnosis in certain circumstances to take place remotely from the patient? High quality video conferencing would often be needed for doctors and patients to communicate effectively requiring broadband access for both doctors and patients. Such services could typically involve data rates between 2 and 10Mbits/s.

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[58] A surgeon in New York performed surgery on a woman in Strasbourg France, via a 10Mbit/s link, in September 2001. See Next Generation Networks briefing note.
[59] e.g. www.homehealth-uk.com/medical/healthwatch.htm
[60] www.smartsensortelemed.com

A3.5 Entertainment

Audio on demand and personalised listener profiles have the potential to provide users with the type of music, discussion, drama and information, whenever they want it. Current peer to peer technologies (see Annex 2) are capable of providing these types of services over today's telecommunications networks. However, real time audio services would in many cases require access networks to be upgraded (e.g. typically up to 400kbit/s). Also, an increased availability of such services could attract enough users to overload current networks (e.g. Napster caused traffic on some US networks to double at peak times, thereby causing congestion).

Similarly, video-on-demand could place significant loads on telecommunications networks (2-10Mbit/s per user) if it was widely adopted, since users who previously shared broadcast capacity[61] would now require individual broadband access. This would enable viewers to download movies or other programmes of their choice at convenient times[62]. Peer to peer networking of video would also require broadband access to telecommunications networks to reduce download times (e.g. a feature length DVD movie would take approximately 1 minute to download at 1Gbit/s compared to approximately 12 days using a 56kbit/s dial-up modem[63]). Users' perceptions of acceptable download times will probably be an important factor in determining demand for capacity. For example, an acceptable download rate may be somewhere in the region of 5-10 minutes.

Multi-player gaming over the Internet is already a popular application in areas with higher levels of broadband penetration. For example, in South Korea 70% of broadband users visit games sites[64]. These applications allow users to compete with other users through the Internet. The extent to which users can interact is determined by the capacity of the networks connecting them and gaming applications will develop to consume whatever capacity is available for the foreseeable future. Game console developers are currently incorporating

[61] Approximately 30MBit/s is used for between 5 and 10 channels for broadcast Digital Terrestrial TV (DTT)
[62] Video on demand services have been implement by Kingston Telecommunications in the UK, providing services such as a 'virtual video store', http://www.kcom.com/news93.html
[63] See Annex 2
[64] Source: NetValue survey – September 2000

Internet capabilities into their products (e.g. Sony- PlayStation2, Microsoft- x-Box), bringing networked gaming to widespread markets (although typically aimed at users with broadband access, i.e. 2Mbit/s+). Mobile gaming is also a growing application[65].

Virtual reality (VR), already used in specialist applications (e.g. pilot training and simulation of hazardous environments), might be incorporated into future gaming and entertainment systems providing a greater sense of immersion for the user. However, advanced three dimensional visual displays would require large amounts of information to be transmitted (e.g. 100's of Mbit/s). The sense of touch can also be incorporated into virtual reality systems creating further realism and interactivity. Future fully immersive VR systems would require data rates of multi Gbit/s, which are presently achievable only through optical technologies.

A3.6 Domestic and Retail Markets

A possible application of video conferencing technology would be in the residential market as an augmentation to telephony, for example enhancing communication between distant family members. For video conferencing systems to operate with sufficient quality for home users data rates between 100 and 400kbit/s are required. This is currently beyond the capacity achievable using commonly available dial-up modems (i.e. 56kbit/s).

Home security systems, including video cameras, could be adapted to allow users to remotely monitor their homes[66].

As the number of devices capable of communications in our homes increases, the trend towards interconnecting them is likely to continue (e.g. smoke alarms and video cameras connected to security alarms). Furthermore, multiple domestic devices will mostly likely need to share a single or a few Internet access connections, making it necessary for them to connect to an external gateway device. A home area network (HAN) can interconnect domestic devices throughout a home (i.e. independent of telecommunications service

[65] Ericsson, Motorola, Nokia and Siemens formed the Mobile Games Interoperability Forum (MIGF) in 2001 to help develop mobile gaming; http://www.mgif.org/index.html
[66] http://www.digi-watcher.com/

providers). This allows multiple devices to gain access to the Internet. Domestic appliances such as refrigerators, microwave ovens and washing machines could be connected to the Internet (using current technology), so that supplies, detailed recipes and replacement parts could be re-ordered automatically when needed[67]. HANs can be implemented using cabled networks, or with wireless technologies (e.g. WLAN). Data rates of up to 10Mbit/s would typically be needed to transfer video signals around a HAN.

Electronic devices and telecommunications technology are being developed to help users carry out everyday shopping. Smart cards, possibly incorporated into mobile devices (e.g. easyPay, speedpass[68]), allow users to purchase items without using cash or credit cards, simply by swiping their smart card. Widespread adoption of these applications would result in increased traffic on fixed and mobile networks. Smart cards would contain credit information about the customer. Such electronic transfers would save time for both the customer and the retailer. Also, electronic identification tags may be implemented in product packaging eliminating the need for a check out (RFID[69]). Further penetration of the Internet is also likely to encourage a higher level of on-line purchasing.

Information services such as on-line counselling and legal or medical advice, possibly requiring video conferencing facilities, are other examples of residential applications that are expected to develop.

A3.7 Government

Government departments and public bodies are helping encourage the use and development of electronic services by adopting new applications for their own use. The European Commission has asked for countries to support e-government systems in order to encourage an 'information society'. Typically this has been implemented through publishing information on the Internet such as official forms. In Ireland the Reach agency has been set

[67] Samsung have begun installing such devices in Korean households; http://www.newsfactor.com/perl/story/13039.html . Whirlpool and Intel are other companies developing products for this market.

[68] www.speedpass.com/index.jsp

[69] Radio Frequency IDentification.

up to develop this concept[70]. The Revenue Commission[71] for example, have an effective on-line service which works well using narrowband (i.e. dial-up Internet) connections. However, there are a wide range of potential public service applications which could require larger capacity connections, such as those referred to in relation to education an health. Future advancements on e-government could allow for more efficient distribution of election campaign and policy information. Electronic voting greatly reduces the resources needed to carry out elections and referenda, allowing results to be determined almost instantly. In Ireland, electronic voting is being trialled in three constituencies (North Dublin, West Dublin, Meath) in the forthcoming general election with a view to implementing a nationwide system in 2004. This trial requires that computers located in each of the voting stations be physically brought to a centralised counting point. Future systems could utilise the telecommunications infrastructure to transfer this information, but would require investment in both security and reliability to ensure the integrity of the ballot.

A3.8 Scientific Research

Universities and research organisations typically have requirements for high capacity telecommunications services. A major scientific research application is distributed computing[72], used to solve computationally intense problems (e.g. high energy physics, using 100's of Mbit/s). Other scientific applications that require telecommunications services are collaborative applications where data needs to be collected from numerous locations. Examples of this are advanced weather systems where readings are taken from multiple global sources, and global arrays of astronomy telescopes (Very Large Baseline Interferometry). Virtual reality and other advanced visualisation applications can help researchers working on abstract problems (e.g. – Astrophysical virtual lab – ESA).

[70] www.reach.ie
[71] http://www.revenue.ie/
[72] This is where a large problem is divided up for computation on a number of separate computers which could be located in research institutions or universities anywhere in the world.

Annex 4 – Implementation Examples

Example 1: Business Scenario

Consider a hypothetical business park with five medium-sized companies approximately five years from now. The five businesses consist of a call centre (80 employees), a software localisation facility (50 employees), a high tech. research and design facility (50 employees), a financial software provider and support centre (110 employees), and an office supply warehouse (30 employees). The software localisation facility needs to avail of occasional high capacity while downloading and submitting large pieces of software code (in excess of 1Gbit/s). At other times their bandwidth requirement is substantially lower (100s Mbit/s). The research and design facility regularly needs to transfer large data files to other company locations as well as participating in collaborative simulations using high resolution 3D graphics (100's Mbit/s). The financial software company has a sophisticated CRM system enabling them to monitor customer needs through interfaces with customers' systems (100 Mbit/s total). The office supply warehouse has an advanced stock tracking and control system, linked into a database of customer requirements. The total supply of capacity to the business park may need to be between **300Mbit/s** and **2Gbit/s** to accommodate peak demands. The level of capacity required would depend on many factors such as the level of adoption of video conferencing.

Example 2: Residential Scenario

Consider a hypothetical row of 5 family homes at some time say five years from now. Potential next generation applications are:

- Video telephony (from 400kbit/s to 4Mbit/s)

- High quality real time video on demand (from 2Mbit/s to 10Mbit/s)[73]
- Networked gaming (from 500kbit/s to 10Mbit/s),
- Distance learning (from 400kbit/s to 10Mbit/s), and
- Audio on demand (400kbit/s).

What would be the potential demand? It depends on the capacity required by the individual applications and their level of use. Assume three of the homes are watching video on demand for movies and other programmes. Three of the homes have networked video games running (including one home with two). Two home use video conferencing and two have an active video tutorial running as part of a distance learning programme. Four out of the five homes would be receiving audio on demand services. Other miscellaneous lower data rate applications could also be operating such as home care monitoring, file downloads and on-line banking. In order to provide sufficient capacity for each of these applications, and to allow some headroom to avoid congestion in peak times (i.e. allow this sample use to be say 60% of total capacity), the telecommunications service provider would need to be capable of delivering a range of between **22Mbit/s** and **170Mbit/s** in total to the five houses (i.e. between 4.5 and 35Mbit/s per house), depending on the level of service required by each application.

These are illustrations rather than forecasts, an effort to set out potential applications and the aggregation of demand. They are presented to assist the debate as to the potential requirements for the future.

[73] If downloading of video services increased dramatically (e.g. peer to peer), users' expectations of download times may reduce, requiring high capacity networks: see Annex 2, A2.8.

Annex 5 – Links to Web Sites for Further Information

Company/ Organisation	Web-Site
Alcatel	www.home.alcatel.com/pkits/pdf/gsmwc01.pdf
Avaya	http://www.research.avayalabs.com/department/collapps/
BT Exact	http://www.btexact.com
Ericsson	http://www.ericsson.com/about/publications/review/2001_02/article133.shtml
European Commission	http://www.cordis.lu/ist/
Heinrich Hertz Institute	http://www.hhi.de/engl-HHI/engl-hhi.html http://imwww.hhi.de/blick/3-D_Display/3-d_display.html
Hitachi	http://www.hitachi.co.jp/Prod/vims/wia/eng/main.html
HP	http://www.cooltown.hp.com/cooltownhome/index.asp
IBM	http://www.research.ibm.com/thinkresearch/pervasive.shtml
Information Society Technologies Programme (IST)	http://www.cordis.lu/ist/istag.htm
Information Age Town, Ennis	http://www.ennis.ie/cgi-bin/eiat.cgi?page=information_age_town.htm
Internet2	http://www.internet2.edu/html/advancedapps.html
Microsoft	http://research.microsoft.com/ui/
MIT Media Lab & Media Lab Europe	http://gonzo.media.mit.edu/public/web/ http://www.medialabeurope.org
Motorola	http://www.motorola-labs.com/
National Institute of Standards and Technology (NIST)	http://www.nist.gov/smartspace/smartSpaces/
National Tele-immersion initiative	http://www.advanced.org/teleimmersion.html
Next Wave Technologies and Markets – UK DTI	http://www.nwtm.org/index.phtml
Nokia	http://www.nokia.com/mobilecity/index.html
Philips	http://www.research.philips.com/generalinfo/shaping/humanware.html
Siemens	http://www.siemens.com/pof
The Digital Hub	http://www.thedigitalhub.com/index.htm
World Wireless Research Forum (Alcatel, Ericsson, Motorola, Nokia and Siemens)	http://www.wireless-world-research.org/

Table 3: Some further reading relating to applications for next generation networks can be found on the example web sites above.