InterConnect Communications
A Telcordia Technologies Company

Digital Subscriber Loop Technologies

Capabilities and Limitations

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Synopsis

The growth in demand for access to the Internet by business and residential end users has been increasing for a number of years. The content available on the Internet and the applications required to access it have also developed to meet end user demand and become ever more complex and sophisticated and have, in turn, driven demand for greater delivered bandwidths to maximise operational performance.

Forecasts for growth in bandwidth requirements are based upon a number of factors, future demand for services such as "Triple Play" using standard and high definition IP Television is often cited as a driver for the provision of ever increasing bandwidths although there is considerable debate over the dynamics of this market.

This paper assumes that the demand for higher bandwidths will continue to increase, and examines the capabilities and limitations and the current and future roles that Digital Subscriber Loop (DSL) technologies have in delivering ever higher bandwidths to end users to meet demand for access to developing services. It also studies some of the implications of those limitations on end user access in the United Kingdom, not least with regard to the aspirations and objectives set out in the recent Digital Britain *Interim Report.*

Digital Subscriber Loop (DSL) technologies have been used to provide digital transmission connectivity to end users over the copper access network for a number of years. Demand for digital services was initially confined to business end users and Symmetric DSL systems delivering around 2 Megabits per second (Mbps) upstream - from the end user to the exchange - and downstream - from the exchange to the end user - were used to provide digital connectivity over the copper network. The use of DSL systems provided a means of not just for delivering data services whilst the economics of deploying fibre networks were being developed, but also of deferring the high capital expenditure required to in order to overlay the copper network with an optic fibre or hybrid fibre/copper infrastructure.

Early demand for Internet access was met by using dial-up connections over the Public Switched Telephone Network (PSTN) but these calls soon reached volumes that could not be efficiently handled by the switching units. It also became apparent that end users needed faster connections and this could only be provided using digital links. To meet this demand, Integrated Services Digital Network (ISDN) connections were deployed in significant numbers but the bandwidth was still limited to a maximum of 128 kilobits per second (kbps).

The widespread availability of genuinely fast line speeds specifically for Internet connectivity came with the roll-out of services using Asymmetric Digital Subscriber Loop (ADSL) technologies. Recognising the fact that, when end users access the Internet, more data is typically downloaded than uploaded, ADSL restricted available bandwidths upstream (from the end user to the exchange) in order to maximise bandwidths downstream (from the exchange to the end user). With the capability to provide residential end user with bandwidths of up to 8 Mbps downstream and up to 640 kbps upstream, ADSL was ideally suited for Internet access.

This, and other early versions of DSL have come to known as 1st Generation DSL. Other DSL technologies, known as 2nd Generation DSL, have been developed which are theoretically capable of delivering bandwidths of 12 Mbps to 100 Mbps over a copper pair. Due to the fact that broadband services have become synonymous with DSL technologies, the delivered bandwidths have come to be known as 1st and 2nd Generation Broadband services. Table 1 (overleaf) provides a summary of the types of DSL technologies, their operational characteristics and their delivered maximum bandwidths.

In practice, however, these technologies remain reliant upon copper cables in the access network which were originally specified for the transmission of narrowband frequencies used by analogue voice services, these ranging from around 30 kHz to 400 kHz. Broadband services use frequencies that range from 0.1 MHz to 30 MHz and the electrical characteristics that cause the transmitted signal to deteriorate increase with the length of the cable. As a result, the bandwidth that a DSL system can

Technology	Transmission	No. of Pairs	Maximum Bandwidth		
			Upstream	Downstream	
SDSL – Symmetric DSL	Symmetric	1 to 3	2 Mbps	2 Mbps	1st Generation Broadband
HDSL – High Speed DSL	Symmetric	1	2 Mbps	2 Mbps	
ADSL – Asymmetric DSL	Asymmetric	1	640 kbps	8 Mbps	
ADSL 2 – Asymmetric DSL	Asymmetric	1	640 kbps	12 Mbps	2nd Generation Broadband
**ADSL 2+ – Asymmetric DSL	Asymmetric	1	1.2 Mbps	25 Mbps	
VDSL – Very High Speed DSL	Symmetric	1	52 Mbps	52 Mbps	
	Asymmetric	1	16Mbps	52 Mbps	
VDSL2	Symmetric	1	100 Mbps	100 Mbps	
	Asymmetric	1	16 Mbps	100 Mbps	

Table 1 - DSL Technologies and Their Characteristics

deliver over a copper pair decreases with the length of the pair, so imposing a limit on the bandwidths that the copper network can support. The relationship between DSL technology performance and the length of a copper cable connection is illustrated in the following graph:

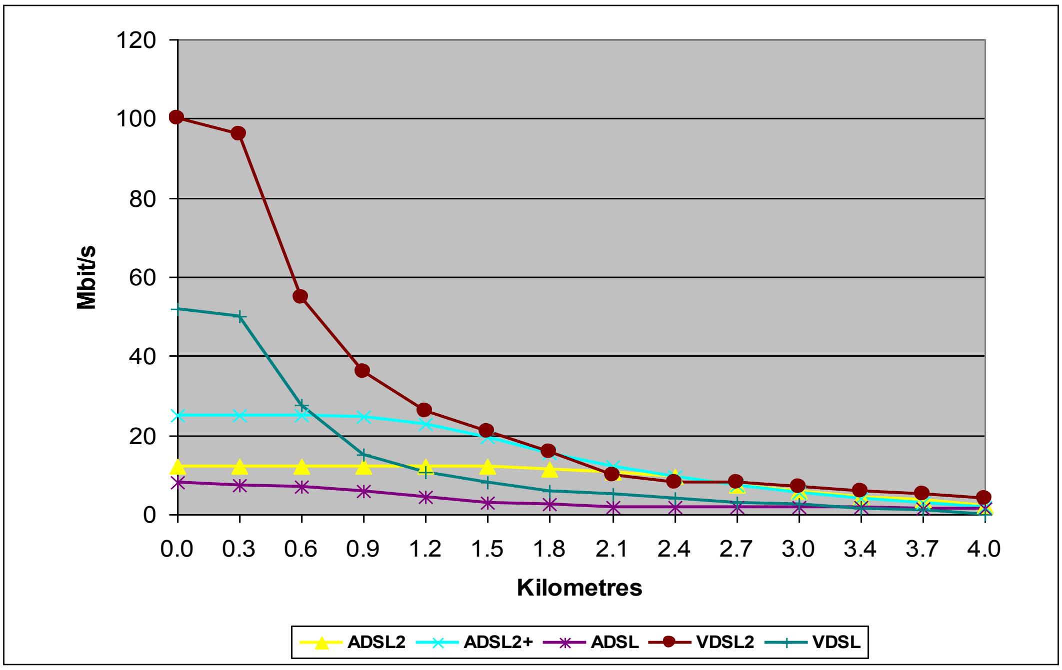

Figure 1 - DSL Technologies and Their Characteristics

Similarly, because copper access cables were never designed to support the high operational frequencies used in DSL transmissions, there is also an effective limit on the number of circuits carrying broadband services that a copper cable can support. Beyond this point, interaction and interference between the DSL systems begins to degrade quality of services being provided on other pairs.

The Consequences of DSL Limitations

In light of the limitations reviewed above, it can be argued that DSL technologies should be considered as – at – best - an interim solution to providing genuinely high bandwidth services.

One of the effects of the intrinsic limitations of DSL over copper is the so-called digital divide, a term first used to describe the fact that most long lines were in rural communities and, as a result, access to high bandwidth broadband services was severely limited within this section of the population. Where the only service required is basic Internet access, the ability of DSL technologies to deliver around 256 kbps on cables in excess of 5 Km in length where the installed infrastructure is of good quality means that relatively few customers are totally unable to get service. The problem of the digital divide becomes more marked where customers, especially business customers, need higher bandwidths to support advanced services to a location connected by long cables.

Recent developments in the UK appear to have solved the basic problem of broadband availability. BT has reduced its costs for wholesale broadband products, made a commitment to install Digital Subscriber Loop Access Multiplexer (DSLAM) equipment in over 90% of UK telephone exchanges and removed limits imposed on the distance that broadband can be supplied over a copper cable. The first two initiatives were undoubtedly good news but the third relies on broadband being supplied on rate-adaptive technologies. These, as the name suggests, automatically adapt the supplied bandwidth to the capabilities of the copper cable. In practice this still means that the further an end user is from the local exchange, the lower the bandwidth that can be supplied. This is because the copper network was specified and built to provide narrowband voice services and has inherent performance limitations when used for any other purpose. It would be well to note that copper network infrastructure is still being installed to these same narrowband voice specifications and standards.

The result is that the requirement for greater bandwidth to support ever more sophisticated service platforms has now expanded the digital divide to include suburban areas where cables have to follow roads and streets and so can have lengths greater than 2.5 Km in length.

Past research carried out by broadband industry analysts Point Topic[1] to quantify the relationship between the UK population and line length has indicated that only 30% of the UK population enjoy connections of 2.5 Km or less. Given known technological limitations, this implies that some 70% of the UK population will only be able to access a maximum delivered bandwidth of 8 Mbps, regardless of the type of DSL technology used.

1 http://www.point-topic.com

On this basis, it is possible to estimate the practical availability of various levels of bandwidth across the UK population. The following graph shows the maximum delivered bandwidth of ADSL technologies with regard to the length of end user connections and estimates the percentage of population that can receive specific levels of bandwidth:

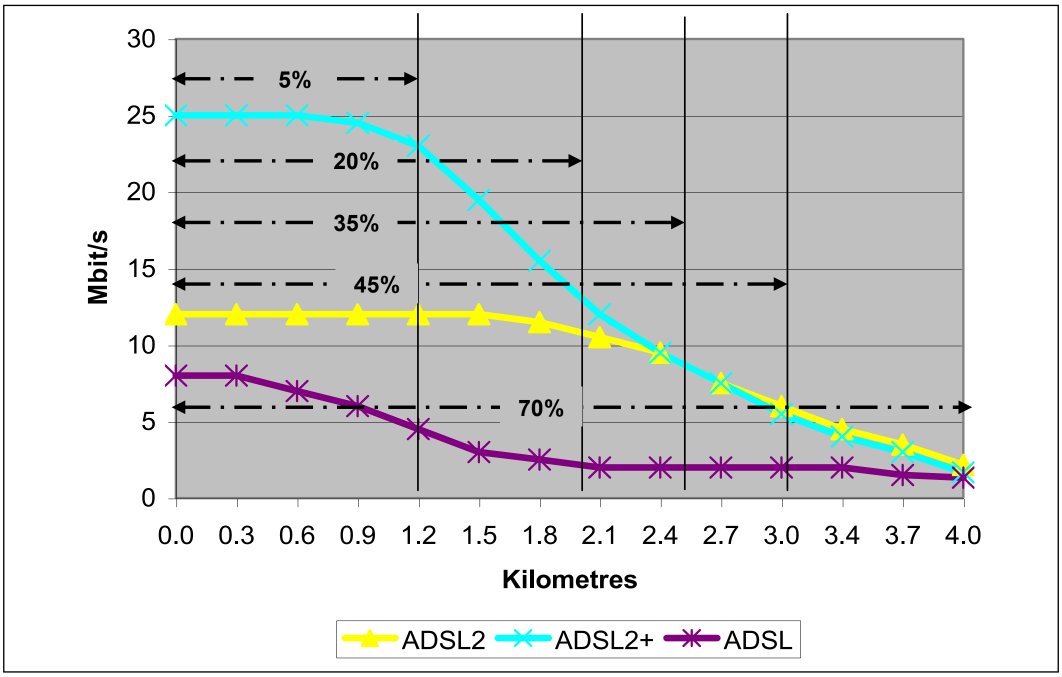

Figure 2 - ADSL Theoretical Performance and Percentage Population Coverage

The situation for the theoretically-faster VDSL technologies is not much better when deployed over copper loops, with typical maximum bandwidths of 4 Mbps and 8 Mbps for VDSL and VDSL2 respectively over a 2.5 Km connection:

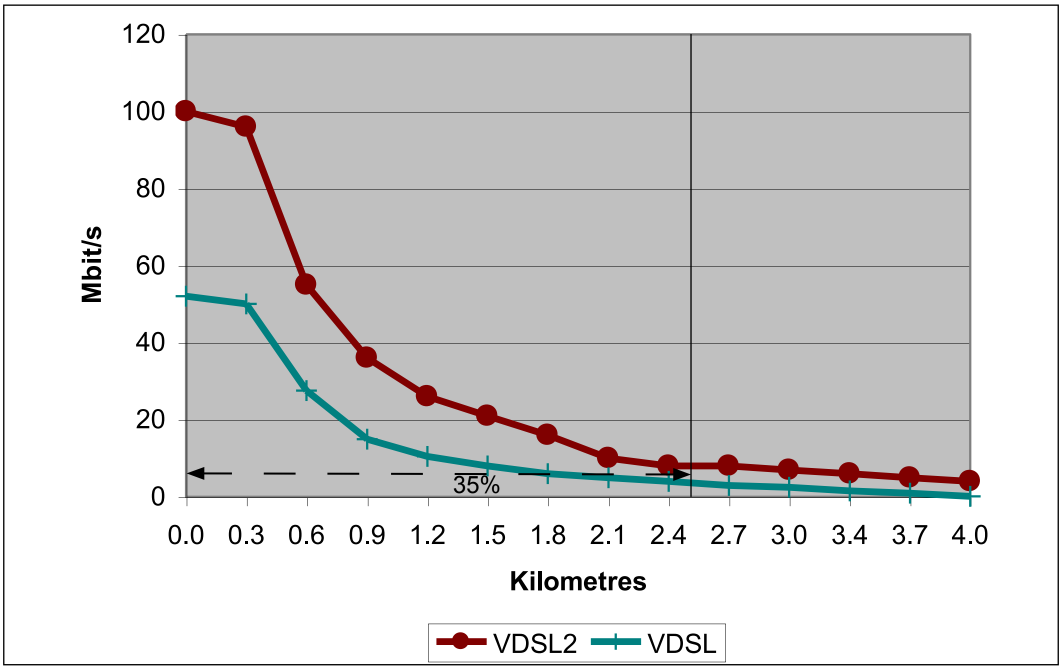

Figure 3 - VDSL Theoretical Performance

The following table provides a summary of the data shown in the above graphs:

% UK Population and Average Loop Length	Theoretical Maximum Delivered Bandwidth		
	ADSL	**ADSL2**	**ADSL2+**
5% - 1.2 Km Loop	~4.5 Mbps	~12.0 Mbps	~23.0 Mbps
20% - 2.0 Km Loop	~2.0 Mbps	~11.0 Mbps	~12.5 Mbps
35% - 2.5 Km Loop	~2.0 Mbps	~8.0 Mbps	~8.0 Mbps
45% - 3.0 Km Loop	~1.5 Mbps	~6.0 Mbps	~6.0 Mbps
70% - 4.0 Km Loop	~1.0 Mbps	~2.0 Mbps	~2.0 Mbps
	VDSL	**VDSL2**	
<5% - 300 m Loop	~50.0 Mbps	~96.0 Mbps	
5% - 1.2 Km Loop	~10.5 Mbps	~26.0 Mbps	
20% - 2.0 Km Loop	~6.0 Mbps	~11.0 Mbps	
35% - 2.5 Km Loop	~4.0 Mbps	~8.0 Mbps	
45% - 3.0 Km Loop	~2.5 Mbps	~7.0 Mbps	
70% - 4.0 Km Loop	~512 kbps	~4.0 Mbps	
NB: *It should be noted that, in order to maximise the potentially high delivered bandwidths, VDSL technologies would only be used to provide broadband services on short copper loops with a maximum length of around 500 metres. This would require the VDSL DSLAM to be located deep in the access network as close to end users as possible. The VDSL DSLAM would need mains power and an optic fibre backhaul and these technologies are often referred to as "deep fibre" technologies.*			

Table 2 - ADSL/VDSL Theoretical Performance and Percentage Population Coverage

The most significant fact that this exercise highlights is that, using DSL technologies to deliver broadband services on the copper access network, less than 5% of the UK population will be able to receive the maximum available bandwidth offered by specific technologies.

These limitations are determined by the nature of the transmissions generated by the DSL technologies and the electrical characteristics of the copper network. Given that the Point Topic data represents an average across the UK of the percentage of population unable to access high bandwidths, it is unlikely to be representative of all areas. In a largely rural region, for instance, the proportion of end users unable to access high bandwidth services is likely to increase above the average. Likewise, whilst the proportion of users unable to access high bandwidths in densely populated regions has historically been below national averages, the increasing tendency of developing service demands to outstrip system capacities may mean that this situation is likely to prevail only where the provision of new infrastructure is financially and technically viable.

The practical effect of this will be that, as services are developed with increasing bandwidth requirements, the percentage of the UK population capable of accessing these services may actually decrease, becoming confined to city centres and other dense urban areas. In contrast to its historical status as a largely rural problem, the negative effects of the digital divide are likely to be found increasingly prevalent in low-density built environments, such as suburban housing areas and possibly even small towns. As time goes on and the use of high-bandwidth applications becomes increasingly universal, the inability of domestic and business end users in such areas to access high-bandwidth services on an affordable basis may well result in increased levels of social exclusion and economic disadvantage.

The deployment of Next Generation Networks (NGNs) has frequently been highlighted as a solution to such problems, by making access to affordable high-bandwidth services a universal reality. For example, BT's 21st Century NGN - "21CN" - will use ADSL2+ technology to make bandwidths of up to 25 Mbps available at the end user line card. Like many NGN projects in other countries, however, the BT 21CN deployment is a core network upgrade and will not improve copper network infrastructure at a local access level. The analysis of the data produced by comparing estimated line lengths to the performance of DSL technologies suggests that only around 5% of the UK population will have access to bandwidths of 25 Mbps and above. Therefore the availability of 25 Mbps provided by NGN equipment at the exchange will, if anything, only serve to exaggerate the deficiencies of the copper network after Core Network uplift programmes such as the 21CN have been completed. This is because, in reality, the copper access network will not be affected by the BT 21CN deployment and the availability of broadband delivered using ADSL2+ will only increase bandwidths to end users with a copper connection that has a cable length of 2.0 Km or less.

This fact has been reiterated by Point Topic in its comments on Lord Carter's *Digital Britain* Interim Report[2] where it also highlights concerns that there are implications for the stated aim of the Interim Report to make access to 2Mbps broadband a universal service[3]. On the basis of Point Topic data on available bandwidth it is estimated that around 30% of the UK population will not be able to access 2Mbps broadband. In addition, around 65% will experience an effective 8Mbps broadband 'ceiling', irrespective of which DSL technology is used.

In order to envision the likely impact of this on the rollout and take-up of new-generation services, it is instructive to set out in graphical form the upper and lower operational bandwidths required to deliver specific ICT services and applications such as:

- Voice Call;
- Audio Streaming;
- Web Browsing;
- Virtual Worlds;
- Video Conferencing;
- Internet Protocol TV;
- Video on Demand;
- Online Games; and
- High Definition TV.

2 See http://www.culture.gov.uk/what_we_do/broadcasting/5631.aspx
3 See http://news.bbc.co.uk/1/hi/technology/7910679.stm

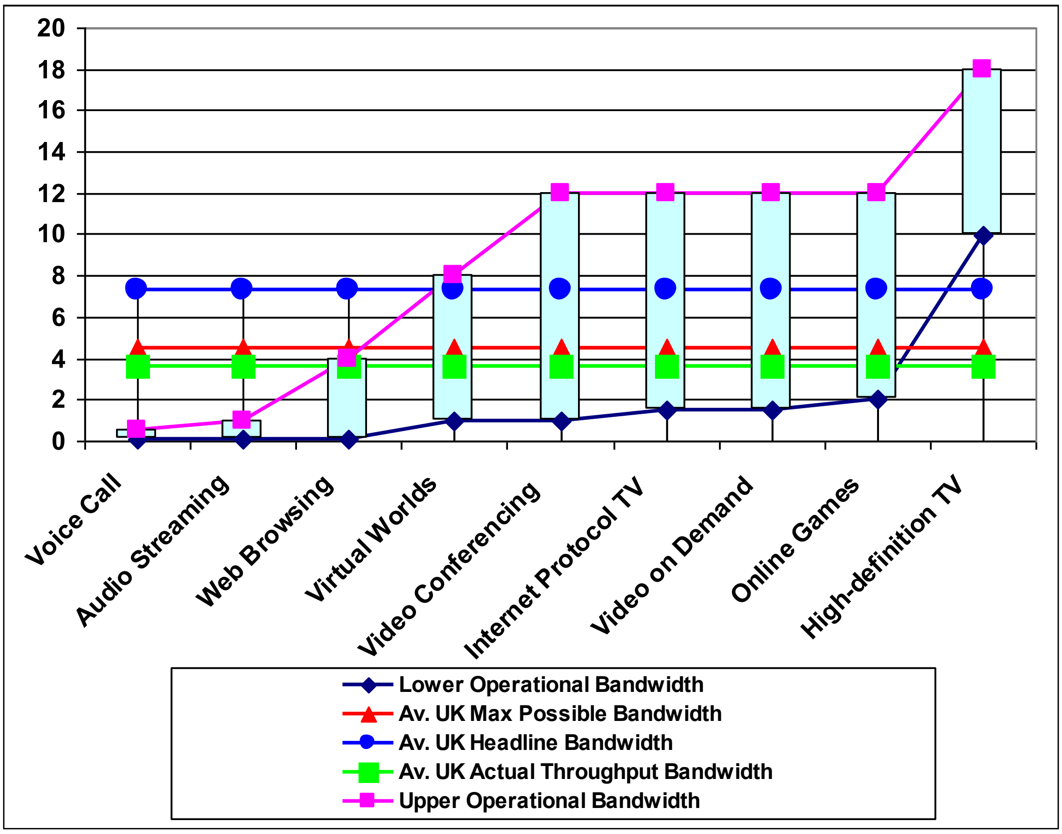

Figure 4 - Typical Application Bandwidth Requirements Relative to UK Operational Parameters

These services and applications and their associated operational bandwidths are as defined by the OECD in their report *Information Technology Outlook 2008*. The figures provided and shown in the above graph appear reasonably conservative, especially those given for High Definition IPTV, with some analysts estimating that bandwidths in the region of 40Mbps will be required to enable simultaneous viewing of multiple channels.

The graph also shows three operational parameters specific to the UK broadband market:

1) The average UK maximum possible bandwidth;
2) The average UK headline bandwidth; and
3) The average UK actual throughput bandwidth.

These parameters have been identified by the UK National Regulatory Authority, OFCOM, in their research report *UK Broadband Speeds 2008*. They are defined in the report as:

- **Maximum line speed** - The highest download speed that a broadband connection is capable of delivering. Also known as the access line speed. As it is a characteristic of DSL broadband that speeds degrade with distance from the exchange, the maximum line speed varies, and, for ADSL1 connections, only those users who have a line length of less than 1km typically achieve maximum speeds of close to a headline speed of 8Mbit/s;

- **Headline speed** - The speed at which a broadband service is marketed, usually expressed as ‘up to’ (for example, in January 2009 all of BT’s nationally available broadband services are advertised as “up to 8Mbit/s”). Typically, the headline speed represents the theoretical maximum download data speed that can be achieved by any consumer on this package. A number of factors, such as the quality and length of the physical line from the exchange to the customer, mean that a customer may never experience this headline speed in practice;
- **Throughput speed** - The actual speeds delivered to consumers over a broadband connection, usually measured in Megabits per second, and generally referring to the download speed.

It should be noted that the values for the parameters used in the OFCOM report and shown in the graph have been nationally averaged for the UK network. However, given that the most significant factor that limits the line speed of a DSL connection is the length of the line, an average maximum line speed of 4.5Mbps indicates that the average length of copper lines in the UK is around 3.5 Km. This figure accords with Point Topic’s analysis that around 45% of the UK population is connected by lines with a length of 3.5 Km or more.

Similarly, based upon technology performance characteristics, the limiting factor of line length on bandwidths of broadband services delivered using DSL technologies on copper connections means that, at 2.5 Km, the highest maximum bandwidth available to end users is 8Mbps regardless of which DSL technology is used. It is estimated that around 30% of the UK population have connections with line lengths of 2.5 Km or less.

In light of this, a fundamental question must be “what is ‘sufficient’ bandwidth” and is the requirement for ever faster delivery speeds driven by customer expectation or by the real demands for bandwidth generated by the technical necessities of ICT services and applications to maximise performance?

As noted previously, the *Digital Britain* Interim Report proposes making access to 2Mbps broadband a component of the universal service obligation. Given the issues illustrated above, however, and current forecasts for bandwidth growth to meet the performance requirements of new and emerging services, not even access to 2Mbps will allow a significant number of UK end users to access these new services. This increases the danger of providing a solution to one digital divide whilst simultaneously creating another.

Indeed, it is already recognised that many UK regions have areas where sections of the population cannot access broadband services with bandwidths of 2Mbps. One recent analysis of the areas and the proportion of population identified as being unable to access these services is as follows:

UK Region	Percentage of Population Presently Unable to Access Broadband Services with a Minimum Speed of 2Mbps or More
Northern Ireland	32.2%
Wales	26.9%
South West	19.9%
Yorkshire/Humberside	16.1%
North East	15.8%
Scotland	15.6%
East Midlands	15.2%
East of England	15%
South East	13.5%
North West	10.8%
West Midlands	10.4%
London	1.2%
Data Source: *Point Topic as reported on BBC News website, http://news.bbc.co.uk/1/hi/technology/7910679.stm*	

Table 3 - Existing Prevalance of Broadband 'Notspots' (2Mbps service and above)

It must be appreciated that the locations of population without access to 2Mbps broadband will be spread across the regions and each so called 'not-spot' will need to be addressed by providing technology solutions on an individual basis. Even so, the relative disparities in broadband access outside metropolitan areas can clearly be seen, with even the relatively prosperous South East of England having some 13% of its population unable to access 2Mbps broadband.

By contrast, most of the new-generation ICT services and applications identified by the OECD have a bandwidth spread up to a maximum of 12Mbps which is required to allow optimal performance. As has been shown, the continued use of DSL technologies on the copper network to deliver broadband services simply cannot provide sufficient bandwidth for significant proportions of the UK population to access many of these new applications and services. Access to new and emerging services will also be limited to end users connected by short copper lines.

The decision that now has to made is whether to attempt to upgrade existing copper network infrastructure or to begin the deployment of Next Generation Access (NGA) networks using hybrid fibre / copper or all fibre network architectures. These would complement the capabilities of the enhanced services and facilities offered by the provision of NGN equipment, and permit the delivery of bandwidths of 50 Mbps and above to end users. Even so, in the case of hybrid networks using copper loops to provide the end user connection, the effect of limitations inherent in the copper cables will mean that there is a maximum bandwidth that can be supported. All-fibre networks, by contrast, have a theoretically limitless bandwidth capability and there is a strong case for using these networks as they future proof the installed network infrastructure.

Conclusions

The development of Digital Subscriber Loop technologies has enabled the delivery of high bandwidth broadband services to end users connected to the copper access network.

However, the intrinsic limitations of the copper cables impose a finite limit on the maximum bandwidth that can be delivered to end users. Given that forecasts for bandwidth demand indicate a continuous increase, DSL technologies seem to offer - at best - an interim solution to the problem of providing genuinely fast broadband services.

Although end user demand for standard and high density IP Television is often hailed as a major driver for the provision of high-bandwidth networks, the continuing slow take-up of IPTV offerings in the UK would seem to make it unlikely that this sector will be sufficient to drive a significant increase in bandwidth in the UK. Instead, it is the ever-greater requirements for bandwidth to access more sophisticated content and to efficiently run the applications needed to exploit them which is likely to make the ubiquitous provision of high-bandwidth services a necessity, for both business and domestic users across a range of urban, rural and suburban environments.

As requirements for universal Internet access combined with greater bandwidth increase, and the associated problems with providing high bandwidths over legacy copper access networks threaten to expand the phenomenon of the digital divide to include not just remote rural areas but populous suburbs as well, so increased attention will need to be devoted to the underlying issues of broadband access.

As already discussed, one obvious solution lies in the construction of Next Generation Access networks using both hybrid copper/fibre networks and all-fibre networks to deliver bandwidths of 50 Mbps and above to large numbers of end users. Negative aspects, however, include the substantial levels of investment by network operators or public/private partnerships required to make this a reality, and the degree of disruption inherent in laying new infrastructure by trenching in existing built environments. Solutions to the latter exist in the possibility of running fibre circuits through sewers, or in carrying them on overhead rights-of-way, but both suffer from drawbacks in terms of the vulnerability to damage of the circuits and the potential difficulty of making in-field repairs. Concerns are also likely to be expressed over the visual impact of any extensive new overhead infrastructure, especially in urban environments or areas of outstanding beauty.

Another possible means of increasing the availability of broadband is through the use of wireless or satellite technologies. This may have special relevance to ‘gap-filling’ between existing areas of provision, especially in remote or sparsely-populated rural areas. Key shortcomings, however, include capacity restrictions and unacceptable levels of latency which can undermine the provision of applications such as IP VPN. In addition, whilst costs of initial provision may well be lower than with a hybrid or all-fibre network, operating costs are likely to be higher, which poses questions over the affordability of service to economically disadvantaged users.

Whilst it is obvious that continued inability or failure to address the challenge of providing high bandwidth broadband services is likely to carry with it substantial economic and social costs, it is equally obvious that there are no easy answers. At present, most if not of all the available options have significant negative aspects, ranging from limitations on utility through to high costs of provision and/or operation. Neither is the current economic situation propitious for investment from a commercial point of view, despite the undoubted arguments in favour of increasing the availability of high bandwidth services from a wider economic and social perspective. Without some initiative for forward progress, however, it is difficult to see how the aim of widening high bandwidth broadband access will become any more than that. Logically, therefore, the first step in reconciling this dichotomy is in determining just what quantities of bandwidth will actually be necessary for underpinning future development on the part of domestic and small business end-users, then tailoring provision strategies to match.

The Author

Steve Morgan joined InterConnect in October 2000 as a Senior Consultant advising on Access Tactical Planning and Local Access Networks. For the previous 32 years he worked for British Telecom spending fourteen years as a network field engineer and eighteen years in Access Network Planning covering a variety of posts including Planning Engineer, Planning Manager, Technical Support Manager, Network Performance Analysis Manager, Tactical Access Network Planning Manager and Customer Network Design Manager.

Since joining InterConnect, Steve has worked on a wide variety of projects in the UK, Europe, the Middle East and Far East involving the planning and operations of telecommunications networks. Work areas of projects undertaken include the provision of xDSL technologies, network and customer infrastructure strategic and detailed planning, technical due diligence assessments, strategic deployment and management of operator-independent open access networks, the impact of telecommunications on economic regeneration, development of processes and procedures, network planning / operational performance and Quality of Service, Local Loop Unbundling network operation and collocation / distant location issues. He is also a regular presenter at InterConnect's Telecommunications Regulatory Master Class (TRMC) courses.

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InterConnect Communications

InterConnect Communications is a wholly-owned subsidiary of Telcordia Technologies Inc., based in the United Kingdom, and a leading provider of consultancy services on network access, interconnection and the use of information and communications technologies (ICTs) as a tool for supporting economic development and regeneration initiatives.

InterConnect has extensive experience in the design, development and implementation of ICT networks, for both public and private sector players. Our regulatory expertise covering all aspects of ICT activity is of international scope and reputation, whilst strong working linkages with leading specialists in economic regeneration allow us to offer an end-to-end service covering all aspects of regional regeneration policies and strategies.

For more details of InterConnect's services in this sphere, please visit http://www.icc-uk.com/ict-development.php

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