The Challenges of Broadband

By Keith G Knightson

1 Introduction

The Internet has become an integral part of the functioning of society. However, the increasing use of the Internet places new demands on the requirement to deliver high speed services to both small commercial and residential end users. This article examines the challenges of bringing high speed services to all users, and a number of issues related to the provision of such services.

2 What is Broadband?

2.1 According to the FCC

Section 706 (b) of the US Telecom 1996 Act defines "advanced telecommunications" capability as "high-speed, switched, broadband telecommunications capability that enables users to originate and receive high-quality voice, data, graphics, and video telecommunications using any technology."

In the *First Report*[1], the FCC defined "broadband" and, in effect, advanced telecommunications capability and advanced services as -- "having the capability of supporting, in both the provider-to-customer (downstream) and the customer-to-provider (upstream) directions, a speed (in technical terms, 'bandwidth') in excess of 200 kilobits per second (kbit/s) in the last mile." The *Second Report*[2] reaffirmed this definition.

This definition is derived from considering ISDN, where the basic rate access (BRA) service of 128 kbit/s is considered to be "narrowband" and anything higher considered to be broadband. This definition, however, is not very realistic in the face of the requirements of practical web-based applications.

It is interesting to speculate if the definition of "universal service" will be revised to include broadband rates at some point in the future.

2.2 According to Application Requirements

Like beauty, speed is in the eye of the beholder or, in this case, the user and the application. However, from a brief examination of typical usage, the anthropomorphic requirements, and specific applications, a more useful classification may be made.

Several studies have concluded that there is a pent-up demand in the e-retail area and other areas where web-based applications are used. These studies indicate that the potential for introduction and adoption of the Internet to replace existing business or social practices is severely hampered a)

---

1 Deployment of Advanced Telecomunications Capability, First Report, Federal Communications Commission FCC 98-146, February 1999.

2 Deployment of Advanced Telecomunications Capability, Second Report, Federal Communications Commission FCC 00-290, August 2000.

by the lack of adequate speed of access networks. The mathematics is not difficult, the requirements for bandwidth can easily be calculated. For example, Web pages can require 1-5 Mbytes of information. In the case of regular telephone line usage, a single page can take from 20 – 200 seconds to download, due to the speed bottleneck created at the access. No matter how good the server and the backbone are, this delay cannot be reduced if regular telephone lines are used. This range of delay is extremely unfriendly to the use of e-retail applications. A transaction involving 10 such pages can take as much as 30 minutes at 56 kbit/s.

The table in figure 1 shows best possible transfer times for three different file sizes, and four different access rates.

Web Page or File Size	Access Rate			
	50 Kbit/s	100 Kbit/s	500 kbit/s	1 Mbit/s
100 kbytes	20 seconds	10 seconds	2 seconds	1 second
1 Mbytes	200 seconds	100 seconds	20 seconds	10 seconds
5 Mbytes	16 minutes	8 minutes	100 seconds	50 seconds

Figure 1 - Transfer times

It has been estimated, from various human factors studies, that for the comfort of the user, a new page should appear within 1 second of the request for it. This translates into required access speeds of 1 Mbit/s or above. Therefore, one can only conclude that the success and growth of e-retail, and Web activities of a similar nature, is dependent on having universal access speeds of at least 1 Mbit/s and preferably higher, say, 5 Mbit/s per desk-top.

The International Electrotechnical Council (IEC) “Survey of Telecommunications Scenarios” by the IEC Future Watch Working Group [2] provides a good basis for summarizing the need and range of Broadband access requirements, as shown in Figure 2.

It should also be noted that Study Group 15 of the International Telecommunications Union (ITU-T) has declared bit rates above 2 Mbit/s to be Broadband and rates below 2 Mbit/s to be Narrowband.

It should also be noted that provision of telephone service over the Internet is not so bandwidth demanding. Access rates of 56 kbit/s per call are quite adequate, and indeed significantly lower values may suffice. Short and relatively constant transit delay times of the order of 100 ms are essential, however.

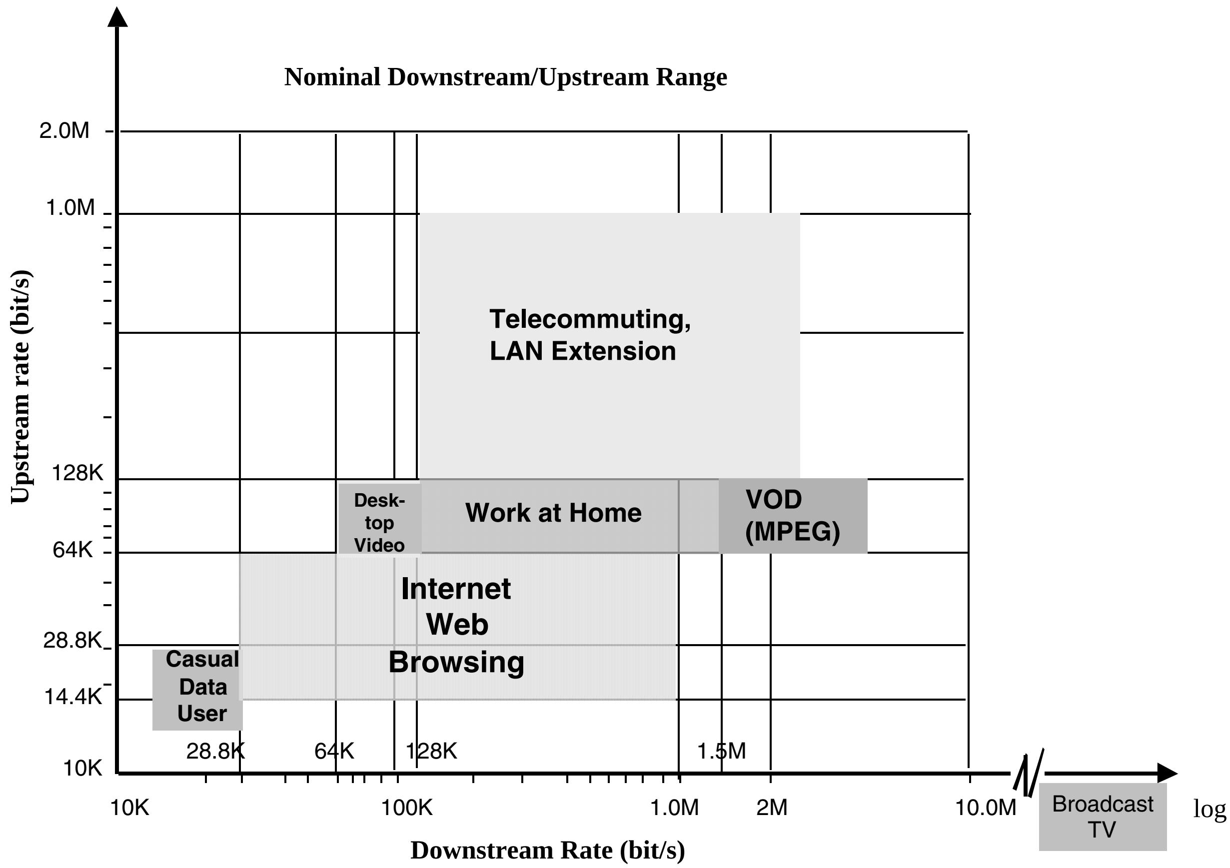

Figure 2 - End-user Application Rates

In summary, we conclude that broadband ought to be of the order of Mbit/s rather than kbit/s. This is a per-desk-top figure. For business purposes it would be necessary to scale this value appropriately, according to the number of desk-tops. Such scaling, however, would not necessarily be linear, since the delay time is usually the most critical factor, rather than continuously sustained bandwidth.

3 The Provision of Broadband

In general, the technology used for last mile, and the actual distance of it, determines the rates that can be achieved. Typical rates and distances are shown in the figure below.

As can be seen, in most wireline cases, high rates can only be achieved over short distances. Traditionally, the local telephone centrex-style infrastructure comprised passive components. More recently, the introduction of fiber middle mile facilities, to access concentration points in the local catchment areas, has offered the opportunity to reduce the length of the last mile segment.

Technology	Downstream		Upstream		Range (miles)
	typical	max	typical	max	
V.34 modem	28k	34k	28k	34.0k	3.5
V.90 modem	45k	53k	28.0k	34.0k	2.5
Cellular/PCS	9.6k	20k	9.6k	20k	10.0
3G Cellular	100k	2M	100k	1M	10.0
ISDN BR	128k	128k	128k	128k	10.0
DB Satellite	350k	400k	phone	phone	N.A
MMDS	100k	1M	100k	1M	35.0
DSL	400k	15M	64-256k	500k	3.5
Cable Modem	>1M	27M	200k	10M	3.0
LMDS	155k	155k	155k	155k	4.0
Fiber Home	n x M	n x M	n x M	n x M	>100.0

Figure 3 - Rates versus Distance Comparisons

4 The Standards Muddle

This section outlines the standards maze of the protocols used for access.

4.1 Cable Systems

Figure 4 shows the protocol stacks for a cable system. In this figure, the user interface on the right hand side is based on a USB attachment, say for a PC. Typically, the actual cable modem is supplied by the cable system provider.

A large number of standards are involved, too many to list in here, stemming from a variety of standards organizations, such as ITU-T[3], IEEE[4], IETF[5], ISO/IEC[6] and CableLabs®[7]. Since this is the case, this document will use the system umbrella approach adopted by the two major organizations that have specified complete system architectures, protocol stacks and profile requirements, namely the ITU-T SG 9 and CableLabs.

The CableLabs® Certified™ Cable Modem project, formerly known as DOCSIS™ (Data Over Cable System Interface Specifications), defines interface requirements for cable modems involved in high-speed data distribution over cable television system networks.

a) ____________________________

3 International Telecommunications Union - Telecommunications
4 Institute of Electrical & Electronic Engineers.
5 Internet Engineering Task Force.
6 International Organization or Standardization /International Electrotechnical Council.
7 Cable Television Laboratories, Inc., also known as CableLabs®, is a non-profit research and development consortium of cable television system operators representing North and South America.

As can be seen from Figure 4, the cable modem (CM) and cable modem termination system (CMTS) act as forwarding agents and also as end-systems. The principle function of the cable modem system is to exchange IP packets transparently between the headend and the user premise. Data forwarding at the CMTS may be achieved (theoretically) by transparent bridging at layer 2, or network layer forwarding, i.e., IP routing, at layer 3.

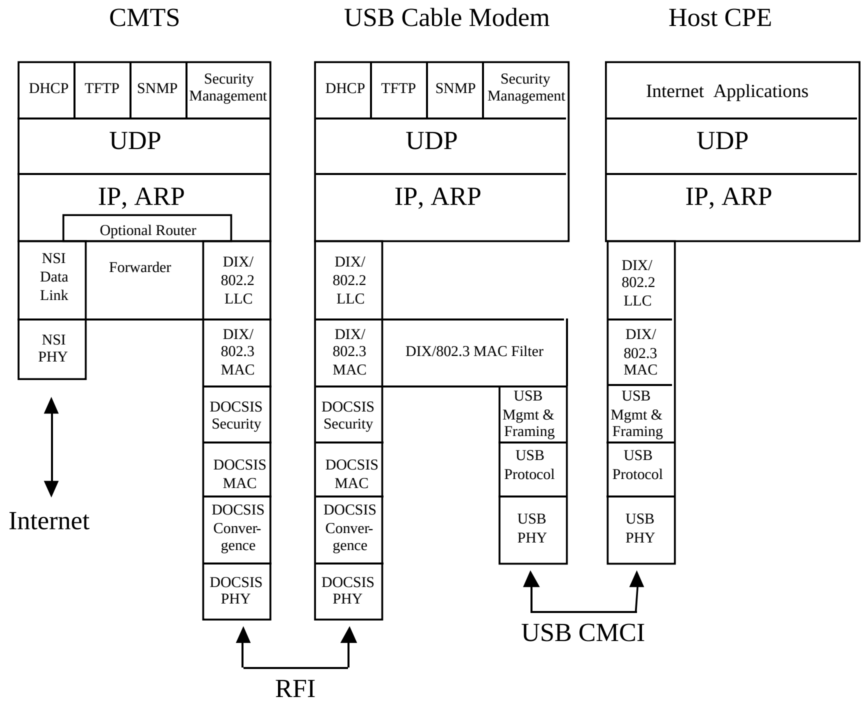

Figure 4 – Protocol stack for cable systems[8]

a)

[8] Legend for figure:

ARP	Address Resolution Protocol
DHCP	Dynamic Host Configuration Protocol
DIX	Ethernet Version 2.0, Digital, Intel, Xerox (DIX)
DOCSIS	Data Over Cable System Interface Specification
ICMP	Internet Control Management Protocol
IP	Internet Protocol
LLC	Logical Link Control
MAC	Media Access Control
PHY	Physical Layer
SNMP	Simple Network Management Protocol
TFTP	Trivial file Transfer Protocol
UDP	Universal Datagram Protocol
USB	Universal Serial Bus

4.2 Asymmetric Digital Subscriber Line systems (ADSL)

ADSL technology can provide rates of up to 6 Mbit/s for downstream transmission and up to 640 kbit/s for upstream transmission, depending on distance and configuration options.

Most ADSL systems are still centralized around central offices where ADSLAMs[9] are installed. The use of remote ADSLAMs would allow higher penetration of DSL systems into rural areas. However, length of line is not the only consideration or impediment to ADSL provisioning. Another consideration relates to a restriction on number of pairs used for ADSL in a given cable, arising from interference problems. Thus, it does it does not follow that larger pair cables can carry larger number of DSL circuits.

The following distance limits are typical under favorable circumstances:

- 1.5 Mbit/s up to 18, 000 feet;
- 6 Mbit/s up to 9.000 feet.

The following three organizations are the main players in development of DSL standards:

a) ANSI Committee T1;

b) The International Telecommunications Union; and

c) The DSL Forum.

A detailed comparison between the specifications of these bodies is outside the scope of this current draft. It is understood, however, that ITU-T Recommendation G.992[10] is backwards compatible with ANSI T1.413, and that a number of enhancements are being developed jointly between ANSI Committee T1 and the ITU-T.

The DSL Forum was formed in December of 1994 to promote the DSL concept and facilitate development of DSL system architectures, protocols, and interfaces for major DSL applications.

The DSL Forum has produced a number of Technical Reports (TRs) active reports, containing requirements, both for the ADSL itself plus support for IP access over DSL. A summary of the various arrangements under consideration is shown in Figure 5.

a)

[9] ADSLAM Add/Drop Multiplexer (a concentration device)

[10] G.992.1 Asymmetrical Digital Subscriber Line (ADSL) Transceivers
G.992.2 Splitterless Asymmetrical Digital Subscriber Line (ADSL) Transceivers

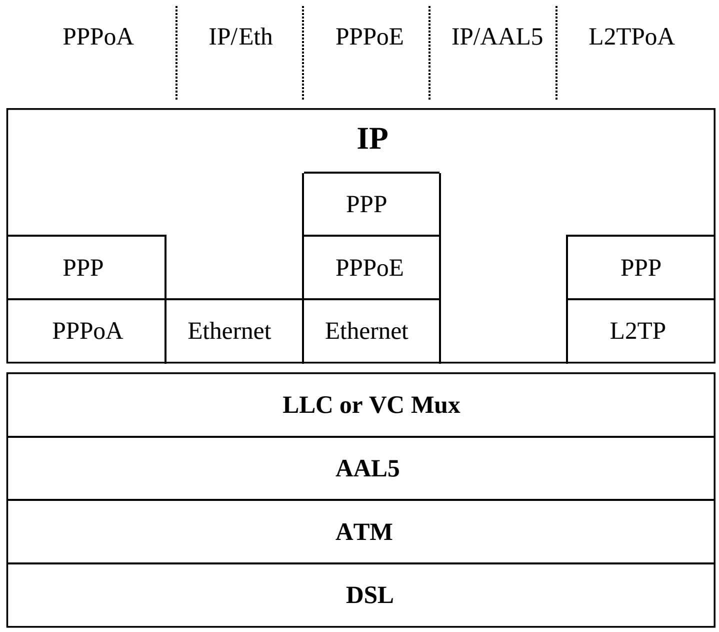

Figure 5 – Protocol stack for digital subscriber line (DSL) systems

Figure 5 shows the protocol stack[11] for a DSL system. In some cases an interface card is supplied for insertion into the user's PC.

4.3 Fixed Wireless Access System

The IEEE endorsed the first publication of a standard for Local Multipoint Distribution Service (LMDS) in December 2001. IEEE 802.16 defines the Media Access Control layer and Physical layer of an LMDS system, using the family of IEEE 802 standards to operate over the 802.16 MAC layer. The family of IEEE 802.16 projects includes specifications for networks operating in the 2 GHz to 11 GHz frequencies using licensed bands and also 5-6 GHz unlicensed bands.

The model used in 802.16 builds on the concept of a Convergence Layer for a specific technology interfacing to the 802.16 MAC layer. This summarized in Figure 6.

a) ___________________________

[11] Legend for figure 3::

ATM	Asynchronous Mode Transfer Mode
AAL5	ATM Adaptation Layer 5
IP	Internet Protocol
LLC	Logical Link Control
PPP	Point to Point Protocol
PPPoA	PPP over ATM
PPPoE	PPP over Ethernet
VC	Virtual Circuit

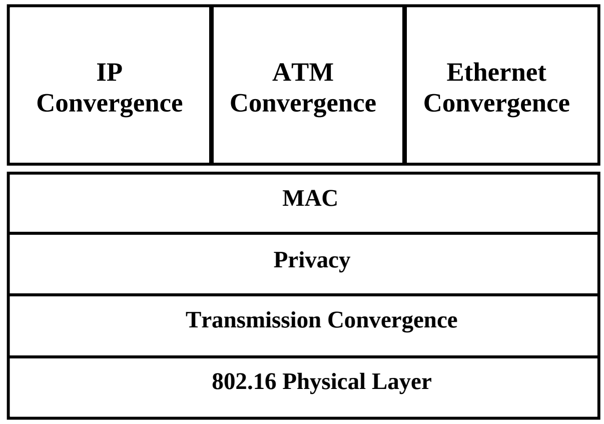

Figure 6 - Protocol stack for fixed wireless access systems

The convergence layer can be used to support either IP, ATM, or Ethernet.

5 Stack Rationalization

The variations between, and within, all these different access systems makes the user's life complicated. It generally means that the user is unable to buy a universal product attachment product (i.e modem or interface card), and specialized expertise is required to set-up the service (the user not being an expert in everything). Some rationalization among the various protocol stacks would be desirable, as depicted in Figure 7.

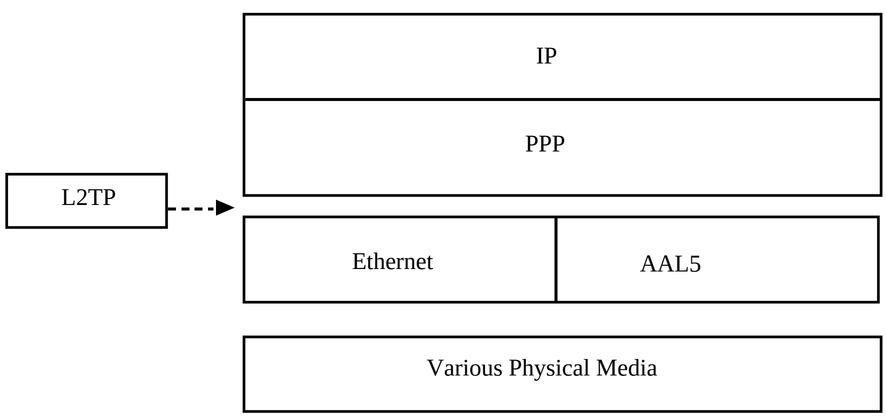

Figure 7 - Rationalized Protocol Stack

PPP has a number of advantages in terms of service provision. It allows for example:

- sessions to be set up and torn down between user and network (avoiding the always-on problem)
- access authorization

- authentication and accounting
- service selection
- QoS selection
- Session multiplexing (important for aggregation)

The use of PPP in all cases would appear to have significant benefits.

PPP is a layer 2 protocol. Peering at layer 2 allows access to independent ISPs via bridging arrangements. L2TP can also be used to aggregate PPP streams for onward transmission to an independent ISP. This avoids the extra hop problem associated with co-locating or interconnecting to a router at the aggregation point.

If AAL5[12] (ATM Adaption Layer 5) is used (without Ethernet), access to an ISP could be made via an ATM broadband network. This avoids the extra hop problem associated with co-locating or interconnecting to a router at the aggregation point.

If these two cases shown in the figure are accepted, then it follows that the two last mile requirements are AAL5 or Ethernet, and the middle mile components should be either Ethernet or ATM networks.

It would be possible to use Ethernet over AAL5 as a further rationalization. This would provide more choice at the POI (points of interconnection) at the community aggregation point with respect to exploitation of either Ethernet or ATM. This is conversion from last mile usage of Ethernet over AAL5, to either Ethernet or ATM for onward middle mile facilities would be equally possible. However, this does create some redundancy the last mile component (including the user interface).

It is concluded that the introduction of PPP into all stacks offers significant advantages, not only from the services point of view, but from the isolation it offers from the underlying media and elimination of the need for co-location (because switched media can be used between the aggregation point and the ISP).

6 Access to Services: Bundled versus Unbundled Access Architectures

The transition from dial-up PSTN access to Broadband Access represents a major shift and problem for the traditional dial-up ISPs. The transition is almost unavoidable, since PSTN is inadequate for present day applications, let alone future applications where even speed requirements may be expected.

The key to provision of services is being able to gain access to them. But, in addition to the "standards maze " problem facing users, users also have to face the problem of how to gain access to a service provider.

If service innovation is to be encouraged, access to services has to be relatively free from impediments. In this respect, users must be able to choose among different service providers

a)

[12] AAL5 (ATM Adaption Layer 5) adapts multi-cell higher layer PDUs into ATM with minimal error checking and no error detection.

freely and be able reach them easily. Similarly, service providers must be able to deal directly with their customers.

It is interesting to note the market difference between provision of dial-up access and broadband access. In the case of dial-up:

a) the modem(s) can be supplied independently of the facilities, based on standards-based implementations from competing modem manufacturers;

b) users are free to subscribe to, and access, any available ISP of their choice;

c) users can have subscriptions with more than one ISP at a time; and access each of them in turn or simultaneously;

d) ISP services are completely independent from the access facilities provider; and the type of facilities provided, i.e., DSL, cable or fixed wireless;

e) there is separation (of layering) between the facilities (operating at layer 1), and the layer 2 protocol such as PPP[13] and from the layer 3 IP protocol, both of which pass transparently over the PSTN. The facilities (PSTN) provider does not control layer 2 or layer 3 protocols and services;

f) ISPs can be established and operate without requiring any special dispensation from the facilities provider. Additionally, ISPs have freedom to offer specific services allowing competitive differentiation.

In the case of broadband access, it is almost universally true that the owner and provider of the transmission facilities is also the Internet Service Provider (ISP). In such a case, none of the capabilities a) – f) above can be achieved. More information on this can be found in reference [3].

In the context of access networks the various protocol stacks showing various combinations that users may encounter when connecting to an ISP over either cable, digital subscriber line or fixed wireless systems have been described. The user has little choice in this matter, the particular stack is usually dictated by the particular ISP concerned. If there is no transparency at layers 2 or 3, and layer-specific Point of Interconnection (POI), and the users are more closely “bound” to the ISP. This may mean the inability for users to supply their own attachment equipment (modems, etc), susceptibility to changes made by the ISP, and service restrictions.

6.1 Equal Access Service Paradigm

An “equal access” scenario is shown in Figure 8 below. Any user can access any service provider on an equal access basis. The service providers may be fairly close (local) to a given user or, alternatively, located anywhere on the transport network. In this sense, no distinction is made between an access network and a core network. The interactions between service providers are not shown in this diagram.

a)

---

13 The Point to Point Protocol (PPP) is commonly used for establishment of authenticated sessions between the user and the Network Access Server (NAS). Such sessions can be the subject of various services, such as authentication, accounting, service selection, etc.

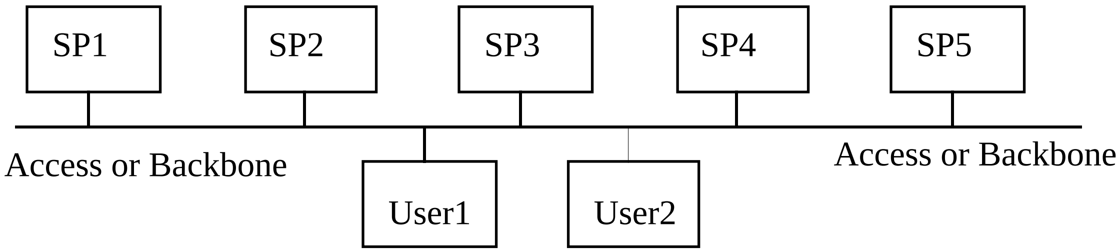

Figure 8 - Equal Access Service Paradigm

It is very important to note that in this scenario, there is independence between service providers and the providers of transport facilities right up to the user's premise. This may be contrasted with the Figure 10, where no such independence exists.

The introduction of Ethernet or ATM into the "last mile" infrastructure, over DSL or cable media, makes access networks capable, in theory, of providing switching or routing capabilities, facilitating the equal access scenario.

This scenario provides fair and open access between users and Internet Service Providers. The slight complication in this scenario is the need, by users, to address specific service providers. However, this capability is easily provided using appropriate and available standards. It is clear that this case offers unbundled service provision. All the conditions a) – f) listed in 6 above can be met.

The use of appropriate standards is also a key factor in facilitating unbundling together with the identification and definition of points of interconnection[14] (POIs). Various degrees of unbundling are possible, i.e at layer 1, 2, or 3.

An example deployment scenario is shown in Figure 9.

It should be noted that the two base cases do not, necessarily, require co-location arrangements for all ISPs since they can connect to an Ethernet or ATM metropolitan area network.

a)

[14] A Point of Interconnection (POI) identifies a point in the architecture, at which an open interface is provided for the purposes of permitting interconnection among network and service providers. A POI has both vertical and horizontal aspects, i.e. both protocol layering and topological aspects.

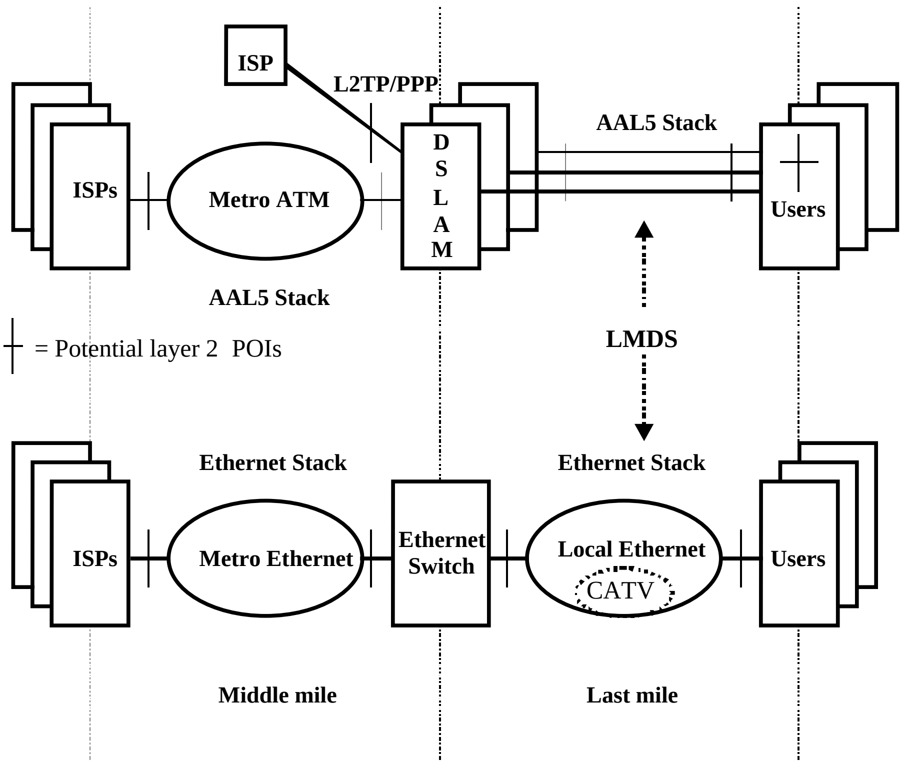

Figure 9 – Points of Interconnection

6.2 Bottlenecked Service Access Paradigm

In the arrangement shown in Figure 10 below, the same organization that provides the medium to the user's premises also provides the services, and controls access to all other service providers. The service(s) and transport facilities are bundled together, as indicated in the figure by the dotted box. The user can only reach "other" service providers via his "home" access network provider.

None of the conditions a) – f) listed in 6 above can be met. The lack of generality in this scenario "allows" the facilities provider to employ proprietary solutions which bind the user to a single service provider.

There are obvious disadvantages to this arrangement, which may or may not be outweighed by economic factors.

Again, the interactions between all the service providers (SPs) are not shown in this diagram, except in the sense that SP1 is always involved for users 1, 2, and 3, and SP2 for users 4, 5, and 6.

Bottlenecks constrain competition and can lead to discriminatory situations. Many ISPs are independent of traditional telecommunications or cable-TV incumbents. Their future is uncertain when faced with the bundled broadband scenario depicted in Figure 10.

On the other hand, incumbents stand to gain from the shift to Broadband Access simply because of their existing ownership of facilities such as copper plant, or cable plant.

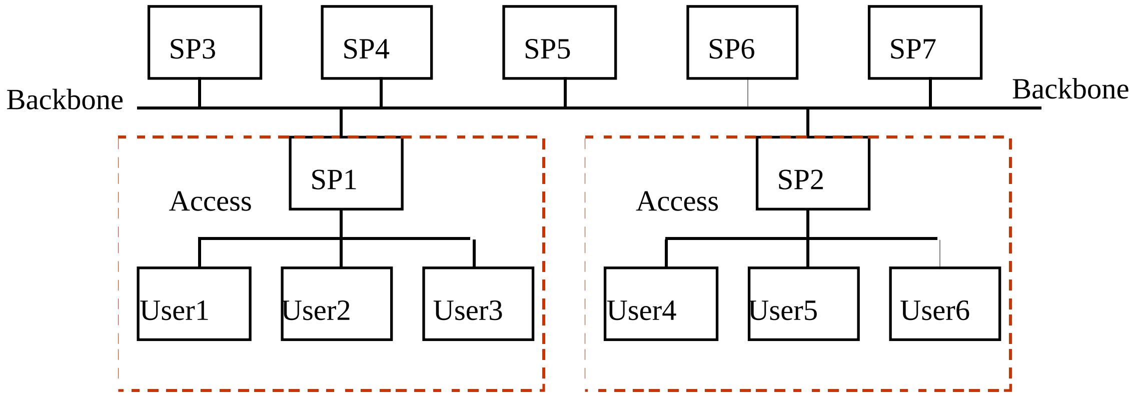

Figure 10 – Bottlenecked Service Access Paradigm

7 Broadband Deployment – The Digital Divide

A large number of countries have initiated studies and programs directed at solving what is sometimes called the 'digital divide" or the "haves and have-nots" problem. The Savage Report [4] provides further information on various world-wide initiatives.

Several countries are convinced that the rural or out-of-town users are the least well served and that something needs to be done to remedy this impediment to the growth of e-commerce and other applications. These countries are considering campaigns or policies to achieve the re-engineering required to shorten the last mile to the home and build out high capacity points of presence closer to the home.

The Savage Report noted that although governments of the world share the common belief in the benefits of broadband access, there were dramatically different strategies for the achievement of these strategies. It identified three approaches to extending and improving broadband access: Light Touch, Cooperative, and Comprehensive.

> *The "Light Touch" Regulatory Reform Approach* involves minimal government intervention in the private sector's expansion of broadband networks and services. Although there is no national program and no direct government funding for broadband network and access expansion, this is not 'hands off' or no intervention. There is indirect funding and targeted programs to tackle specific items such as Digital Divide, etc. New Zealand and Switzerland have followed this approach.

> The "*Cooperative Approach: Programs Targeting the Digital Divide and Improving Access"* involves targeting areas and groups where it is believed market forces cannot adequately address disparities such as rural/remote access, disadvantaged communities, etc., that is, those on the wrong side of the Digital Divide. In this approach the Government does not actively fund new backbone or major initiatives, but concentrates on access such as last mile funding for qualifying groups. The United States, Australia, Germany and the UK are following this approach.

The *"Comprehensive National Broadband Plans Approach"* involves proactive government involvement with direct funding for broadband infrastructure development and a national broadband development program. Examples include Korea's "CyberKorea21", Norway's "eNorway", Singapore's "Singapore One" and Japan's "Info-Communications Strategy for the 21st Century".

With respect to the subject of what constitutes adequate access rates, some countries consider that only rates of 20 Mbit/s and above really constitute the broadband access requirement.

8 Conclusions

Although definitions of broadband vary, acceptable rates per desk-top can be calculated based on common applications and expectations for future applications. There seems to be general agreement that rates of 1 Mbit/s or more are required to operate e-commerce and other web-based applications. Simply assuming broadband to be rates in the range of 64 kbit/s or 200 kbit/s is not a good measure of the broadband access requirements.

A large range of technology is available for delivery of the recommended access speeds for the last mile, such as Coaxial Cable (TV), Digital Subscriber Loop (DSL), optical fiber, fixed wireless and future 3G mobile.

Users within certain current infrastructures are beyond the distances from central offices or distribution centers at which broadband services can be directly supported and are, thus, less well served. Even so, this is not primarily a technology or standards problem, per se. The problem is primarily one of having the right equipment in the right place and in a sufficient number of places. Thus, the problem can be easily remedied by the introduction of alternative engineering arrangements in the local infrastructure using existing technology but arranged in more suitable topologies. The build-out of high capacity to intermediate distribution points can shorten the "last mile(s)" sufficiently to permit delivery of high-speed services. This principle of inserting "middle mile" technology applies to almost all cases of reducing the length of the last mile technology, particularly twisted pair and co-axial (TV) cable. This boils down to a question of economics. It is of interest to note the US has voiced the idea of making high speed Internet access an essential service, as a way of solving the economic problem in a way similar to that previously used to ensure provision of telephone service to rural areas.

For incumbents, bundled service provision provides a way of protecting their revenue streams, and only represents a technology shift rather than a business shift. It would seem unlikely that incumbents would voluntarily "go out of their way" to unbundle services from transport and provide easy access at layer 1, 2, or 3, to other service providers. This prevents others from offering cheaper, better, or different services. The continuing existence of "independent" ISPs may very well depend on a government policy of unbundling.

As far as the first/last mile technologies are concerned, it can be envisaged that users will migrate to a single delivery system for all types of service, to provide integrated services access. However, users will still have to choose between DSL and cable system technologies as the single delivery system. These systems have, traditionally, belonged to two different business sectors, namely, the telcos and the TV broadcasters, being based on copper local loop and cable-TV technologies, respectively. It would seem that cable systems have some advantage since they can (relatively) easily add telephone service[15] to their existing TV and Internet capabilities. Adding a full range of simultaneous TV channels to a DSL type system poses a technical challenge. Of course, there is nothing to prevent telcos deploying new technologies in metropolitan and last/first mile infrastructures capable of providing similar capabilities to those of cable systems. It also may be the case that cable system providers could choose to eliminate their simultaneous channels in favor of an on-demand system in a digital world.

There is no doubt that users are going to encounter difficulties in configuring their equipment. All this new technology comes at the expense of complexity. Everything these days seems to require "programming" in some fashion before it can function. This poses significant challenges to the non-technical segment of the population.

We have also noticed that most users are beholden to their facilities providers, with respect to operation of their own terminal equipment. It is rare that a user can purchase his terminal equipment from a general purpose electronics store. Most cable and DSL modems are supplied by the facilities provider. This permits proprietary solutions and customers become locked in to a particular provider. A policy on Broadband Access standards would seem to be desirable, if open provision of modems is to be achieved.

Finally, we conclude that broadband is not a passing fancy reserved for business or select residential users, but an increasingly essential part of today's commercial and social infrastructure.

9 References

[1] Advanced Telecommunications in Rural America – The Challenge of Bringing Broadband Service to all Americans, National Telecommunications and Information Administration, April 2000.

[2] Survey of Telecommunications Scenarios, IEC Future Watch Working Group, ACET/194/INF, November 2000.

[3] Technological Analysis of Open Access and Cable Television Systems, American Civil Liberties Union, December 2001.

[4] International Programs to Provide Broadband Access to the Internet, James Savage, Raincoast Group, 5 January 2001.

10 About the Author

Keith G Knightson has been involved in data communications for more than 25 years, and has worked for British Telecom, Nortel Networks. He has operated a consulting company since 1995

a)

[15] ITU-T has developed standards in Study Group 9 to provide telephone service over cable systems.

concentrating on network architectures and next generation networks. He may be contacted at kgk@rogers.com.

