Broadband Access

Release November 2002

4th Infocomm Technology Roadmap Report 2002 - 2007

iDA INFOCOMM DEVELOPMENT AUTHORITY OF SINGAPORE

Dear Reader,

Welcome to the newest revision of our Infocomm Technology Roadmap Reports.

The "Infocomm Technology Roadmap" programme serves to anticipate the macro infocomm technology trends globally and identify potential strategic technologies for adoption in Singapore. Facilitated by IDA, each "Infocomm Technology Roadmap" report is conceived and written via a collaborative effort between many parties, namely from the industry, research & academic community, as well as from government agencies.

It has been slightly over two years since we inaugurated the "Infocomm Technology Roadmap" programme via the first report on "Broadband Access and Mobile Wireless". To date, we have together travelled through four cycles of technology roadmap exercises with the support from our participants on different but strategic technology areas to Singapore.

In embarking on this intimate journey with the local infocomm community, the Technology Group in IDA is guided by the motto 'to bring technologies to better our lives' to build up Singapore's competitiveness via the infocomm cluster.

We hope that you will find our published reports useful and take your time to enjoy reading this latest version. You too can be part of the local infocomm community, if not already, just by being part of the knowledge, even as an informed user with a sophisticated demand.

Dr Brian Chen
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The roadmap process entails a continual updating exercise. This ITR4 Release November 2002 has combined, revised, added new emerging interests and will supersede the following:

- ITR1 Release July 2000 *("Broadband Access and Mobile Wireless")*;
- ITR2 Release March 2001 *("Broadband Access and Mobile Wireless Updates", "The Connected Home", "Infocomm Security in e-commerce")*;

  ITR3 Release February 2002 *("Next Generation Optical Networks and Photonics", "Next Generation Internet Applications")* remains valid and current.

Objective of Roadmap Reports

Summary of Worldwide Technologies, Standards and Applications. A key objective of this roadmap report is to provide a good overview of past and future developments worldwide, the efforts of key standardisation bodies and industrial forums for interoperability. The report also aims to promote a good understanding of the market and technology undercurrents which are constantly evolving.

Collective Vision for Alignment of Resources. The fast changing landscapes, the multidisciplinary nature of emerging technologies, competing and converging technology standards, and heightened user expectations call for a more collaborative and managed approach to technology development. For this, the report aims to derive a common vision and directions for future work, reflective of the joint work effort between the industry, government, research community and academia. Where possible and appropriate, we would include strategic gaps and opportunities for collaborative exploitation. The roadmap exercise aims to identify synergies and complementary expertise so that we can pool our resources, leverage on each other's strengths to seize technology opportunities.

Your Feedback

Lastly and very importantly, your feedback will be deeply appreciated on either the report itself, or on collaborative proposals for technology development via the survey form attached at the end of this report. We thank you in advance for your time and effort in doing so and this will help us produce better future roadmap reports.

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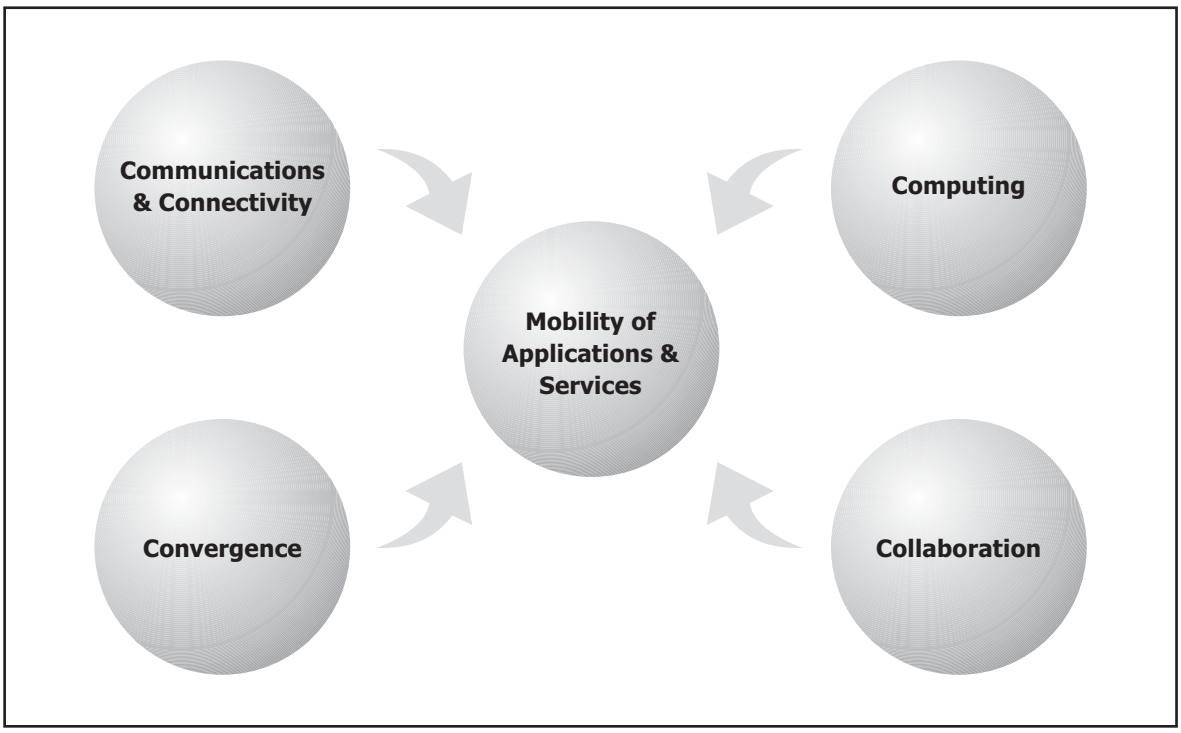
In moving towards 2007 and beyond, this ITR4 report weaves through emerging modern communication technologies for an integrated broadband infrastructure. An integrated broadband infrastructure is a multi-pronged combination of heterogeneous networks (last-mile access, mobile wireless or in-home networks), technologies and end devices closely integrated to allow the key concept of *application mobility and access* anytime, anywhere. Secured payment and authentication mechanisms, non-repudiation of services, communication between trusted parties and access management to information and services will also be an enabler of this integrated infrastructure.



The global trend towards an integrated infrastructure will facilitate three basic human needs for "communication and connectivity", "computing" and "collaboration". The "convergence" of technologies, open standards & platforms, and contents will lend to the ease of mobility of applications and services encapsulated in this infrastructure. Ultimately, working towards the mobility of applications and services regardless of the technology, network and platform used is to enable a convenient and consistent user experience. It is all about users, both consumer and corporate.

We shall now elaborate more on what we see today and the milestones ahead. Some of the technologies or applications to be described below can satisfy more than one of the three basic human needs mentioned above, hence some overlapping is to be understood.

Communication and Connectivity. Communication is a human basic need to contact each other anywhere, anytime and via various platforms and devices, and a means to stay connected. In the area of mobile wireless, we will see new varieties of services apart from simple voice calls such as rich multi-party multimedia communications, instant messaging and presence services, location based services, as well as one-to-many multimedia broadcast and mobile webcasting. This will enhance individual communication features but also open up enterprise opportunities such as in the areas of mobile e-learning, mobile seminars, corporate teleworking and marketing. Emerging 3G mobile networks could offer in Singapore average data rates of around 100 to 200Kbps while in the longer term, 4G networks could reach peak rates of 100Mbps targeting average data rates of 20Mbps at least. In fact, certain 3G standards such as HSDPA (high speed downlink packet access) for WCDMA in 3GPP Release 5 today is exploring downlink rates of up to 10Mbps, with up to 20Mbps downlink for Release 6 (but deployments are expected around 2005). This development coupled with the decreasing computational power differences between hand-held devices and desktops would facilitate the mobility of applications from wireline to wireless domain.

In the area of Broadband Access, it is about creating the necessary connectivity for communication, computing and collaboration. In our vision of 2007, we expect ADSL and cable to replace dial-up as the dominant means for accessing Internet. However, these two access technologies may no longer be considered "broadband". We believe that the access speeds offered by VDSL and fibre will set the stage for the new definition of "broadband". Lifestyle changes like teleworking will become common, resulting in increase use of applications like video-conferencing, workgroup collaboration, and productivity tools. "Always-on" broadband access characteristic is not sufficient and needs to be enhanced by QoS and symmetric downstream/upstream access speed.

Bandwidth for home area networks will even be less of an issue compared to access networks. By 2007, we could expect a home network to support applications with data rate in excess of 100Mbps, made possible by a wide choice of networking technologies, such as Ethernet, Phoneline networking and Ultra-Wideband. The preference for mobility and "no new wire" advantage will make WLAN (802.11a and beyond) and UWB the dominant choices in most homes, enabling applications with speed of 54Mbps or more. Wireline technologies such as structured wiring will be increasingly used as the high-speed backbone for in-home wireless networks. Powerline communication technology may find its niche in smart home kitchen appliances. However, for home technologies to take off, these technologies must become embedded into devices to the point that they become transparent to the users, and that the deployment of IPv6 is critical to meet the demand for addresses, QoS and security. At the same time, the plug and play ease of use is to be enabled by efforts in automatic service deployment and discovery of enabled appliances.

Security will take precedent to address a myriad of issues in diverse communication paths occurring between one-to-one, one-to-many and many-to-many in an open dynamic network. Adding to the complexity is the variety of participants in this network, from humans to machines and software agents. At the base of secured communication channels is encryption. By 2007, DES will be completely phased out and AES will be dominant over Triple-DES.

Computing. Pervasive or anywhere computing advances communications and its success pivots on the creation of more sophisticated user demand. In mobile wireless, computing applications will migrate from simplistic mobile games, rudimentary calculator functions to mobile web services, multi-party role play coloured gaming, Java enabled applications, packet based multimedia applications and mobile VPN solutions. The introduction and more widespread use of feature-rich handsets and smartphones will facilitate this migration. In addition, the development of open specifications (e.g. OSA/Parlay APIs) and IP Multimedia Subsystem specifications will work towards the vision of interoperable roaming of these services across both CDMA and GSM networks across the world.

Computing applications like web services are predicted to change the nature of computing to service based models. But regardless of the setting, in working towards end-to-end security for open and heterogeneous web services, the industry targets by 2007 to have a rather complete stack of security standards to support for dynamic and federated networks of web services. This will be the layer of security infrastructure bridging silo-computing systems.

For computing inside the Connected Home, we see today the first wave of development under the guise of data networking for sharing of resources. A second wave of development will revolve around home information and entertainment space. Towards 2007, many entertainment equipment will transit from analogue to smart digital network-ready appliances, examples are multi-services residential gateway, advanced set-top box, digital/interactive television, home media servers, and to a lesser extent, smart kitchen appliances. Most of these appliances will be integrated with one or more in-home networking technologies and adopting open standard device connectivity, with features such as easy plug and play, zero administration, automatic service delivery and discovery, quality of service and device discovery. Security and a flexible billing mechanism will be built-in to support a variety of home applications.

Collaboration. Collaboration extends communication, connectivity and computing to group interaction and team sharing. It widens the interaction scope to groups of individuals in proximity or geographically disparate around the globe. Ad-hoc networking is an important feature to allow the impromptu set up of local networking for collaborative work or resource sharing in meetings or even for multi-party entertainment and gaming.

Collaboration can also be between trusted or non-trusted parties. To enable more sophisticated user demand by 2007, we need to move towards using appropriate security mechanisms to allow communication and collaboration between trusted parties. As such, in addition to PIN and passwords, we will see the emergence of related security authentication and non repudiation technologies and services such as trust service providers, 3D Secure, PKI, biometrics and smart random tokens and chip cards.

Convergence. Convergence can occur at several levels. At the industry cluster level, it can mean working towards integrating contents across different clusters such as the media, arts and entertainment, home automation, finance, IT & communication, broadcasting, telematics, telemedicine, education or e-learning, and e-government.

At the network level, we already see the convergence of voice, text, data, multimedia video that can be delivered with a single IP based network. At the technology and standards level, convergence can mean the confluence of hardware packaging techniques (e.g. BGA, CSP, stacked packaging), movement towards globally standardised architecture, platforms, open APIs (e.g. OMA, OSA). In services, convergence can happen with aggregated contents with 3G portals, or with IP based bundled multimedia services. At home, the OSGI residential gateway represents a tool for convergence towards a multi-service model and whereby service providers can enter to make headway into the smart home via remote provisioning of new services.

Similarly, at the security level, we see efforts towards identity management, federations and single sign on. If we converge under a federated umbrella model, each partner then agrees to trust user identities issued or authenticated by other organisations, while maintaining control of the identity and preference information of its own users. This will not be easily achieved. Sharing session and authentication information across networks and across disparate application is not only difficult, but resource-intensive as well. The level of trust placed over a given client request might vary across different services. By 2007, management console to talk to any security server or client regardless of device type, brand, OS, application or location will however lend itself to support this convergence.

Mobility of Applications and Services. There can be many different networks, access devices, technology platforms but we should have only one convenient, consistent and connected lifestyle. By this, we mean that we should not need to worry about which network we are connected to, how to access different networks or be preoccupied with end to end security of applications. Increasing online applications from fixed sites mainly confined to environments such as corporate LANs or PC internet access networks (in-home or at public internet access sites) are now ported to mobile devices, leading to ubiquitous connectivity.

Security will also need to interoperate over heterogeneous environments from LAN to public, from wireline to wireless to provide the user with uninterrupted connection to the various forms of services. By 2007, single sign on solutions and portable security such as biometrics (key ones being fingerprint, iris and facial) and smart cards will gain momentum.

The above spells our vision for this report. In gearing up to this vision, the many network and enabling technologies covered in this timeframe of 2002-2007 should take a backseat when compared to the more critical issue of understanding and creating sophisticated user demand, as well as to factor in business perspectives and operational challenges. However, it is a highly volatile task for anyone to anticipate accurately trends in market factors like future user demand and business sentiments. Hence, we can at best provide a technical roadmap of technology vision and trends, and a best-effort attempt to position technology milestones in this timeframe as we collectively judged with the help of industry participants, which the reader should moderate according to prevailing market sentiments.

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In this report, we examine the global trends and future development of last mile broadband access technologies through the analysis of standards development, deployment status, and innovative developments in each access technology.

Broadband Access is about creating the necessary connectivity for communication, computing and collaboration. Currently, Asymmetrical Digital Subscriber Line (ADSL) and cable are the most common broadband access technologies in use. User application demands are characterized by frequent downloads but infrequent uploads. In our vision of 2007 for Singapore, we envision ADSL and cable to overtake dial-up as the dominant means for accessing the Internet. However, in the long run they may no longer be considered "broadband". We believe that the access speeds offered by Very High-Speed DSL (VDSL) and fibre will set the stage for the new definition of "broadband". Lifestyle changes like teleworking will become common, resulting in increase use of applications like video-conferencing, workflow application through corporate Virtual Private Network, and other collaborative peer-to-peer type of applications and services. Therefore, broadband access characteristics of "always-on" will no longer be sufficient and must be enhanced by Quality of Service (QoS) and symmetric downstream/upstream access speed.

In this report, eight broadband access technologies are covered. Under the wireline category, we explore the various types of digital subscriber line technologies, cable, powerline communications and optical fibre access technologies. Under the wireless category, radio frequency fixed wireless access, free-space optics, wireless local area network (WLAN) as a "last mile" access technology, and broadband satellite communications will be discussed.

Digital Subscriber Line (DSL) Technologies

Depolyments of DSL access technologies will converge to three major flavours of Asymmetrical DSL (ADSL), Single-Pair High-Speed DSL (SHDSL) and Very High-Speed DSL (VDSL). Currently, ADSL is the dominant broadband access technology and we expect this to remain so for the next five years or more. The globally recommendated ITU-T SHDSL standard is also expected to replace many of the older technologies that offer symmetric access over the coming years. Migration to the higher speed VDSL is slowly gaining traction. However, it may only take off a few years down the road. Enthusiasm in efforts such as Ethernet-over-DSL has also further enhanced the dominant position of DSL technologies.

Cable

Cable has established itself as the second most popular broadband access technology behind ADSL and we expect it to remain so for the next five years. With the release of Data Over

Cable Service Interface Specification (DOCSIS) 2.0 standard, efforts by CableLabs has shifted towards defining specifications for running applications and services over cable. Looking ahead, we expect greater technology innovations in utilizing the higher ends of cable spectrum to boost the current bandwidth limitations of exiting hybrid fibre coaxial networks.

Powerline Communications (PLC)

PLC provides a strategic entrance to the broadband market for the utility providers and will allow them to gain a foothold in the huge broadband market. However, standards and regulatory issues have to be addressed before mass deployment can become a reality. The key trigger event will be the release of an European Union directive on the Electromagnetic Compatabiltiy (EMC)/Electromagnetic Interference (EMI) emission standard, which we expect to occur in 2003/2004. Nevertheless, some PLC vendors have claimed that prototype PLC chipsets with raw data rates of 200Mbps will be ready by 2003. If this development of next generation PLC chipset is able to meet the EMC/EMI guidelines, then we believe the window of opportunity for PLC as an access technology remains open for the next 5 years.

Optical Fibre Access

The last mile access network so far consist predominantly of twisted-pair copper wires and coaxial cables. Despite the many distinct advantages of optical fibre technology, like higher bandwidth and immunity to electromagnetic and radio frequency interference, mass deployment of fibre as a last mile access solution has not materialised yet due to high installation costs, electrical powering and most importantly, the absence of compelling applications to justify the high bandwidth provision. Currently, optical fibre as a last mile technology is most commonly deployed using optical-based Gigabit Ethernet systems or passive optical networks (PONs). Optical-based Gigabit Ethernet is expected to take off shortly in the next few years in the business market. Access speed of up to 10Gbps, LAN compatability, and most importantly cost effectiveness will make it the favourite broadband access technology in high density multi-tenant units. However, we note that the cost of fibre installation remains significantly more expensive as compared with copper. Furthermore, technology improvements on DSL and cable are expected to meet the end-users' bandwidth needs for the next few years. Therefore, we do not expect fibre-to-the-home to take off in the residential market over the next 5 years.

Radio Frequency Fixed Wireless

The future of radio frequency fixed wireless market appears to lie with the new generation of fixed wireless systems operating in the 1.9GHz to 4GHz frequency range. Advances in smart antenna technology and modulation techniques such as Orthogonal Frequency Division Multiplexing (OFDM) have increased the spectral efficiency and system capacity without compromising on the coverage area. Non-line of sight operation is now possible as well, simplifying equipment installation at the customer's premises and extending network coverage to areas shadowed by large buildings. Looking further ahead, several vendors are developing an emerging network architecture, called wireless mesh, which do away with the traditional point-to-multipoint architecture altogether. In a mesh network, there is no central base station. Each node in a network connects to its immediate neighbours and routes its network traffic through them, hopping wirelessly over several nodes before reaching the wire-line network backbone. Mesh radio systems working in the unlicensed 2.4GHz band have already been deployed; systems that operate in the licensed bands will be available soon.

Free Space Optics (FSO)

FSO enables high-speed wireless communication between two locations, delivering fibre-like performance without the fibre. We expect the initial surge in FSO adoption to come from local corporations or institutes looking for a low-cost and rapidly deployable means of providing very high-speed connectivity between buildings. These buildings might be situated close to one another on a campus or in an industrial park, or could be more than 1km apart within a heavily built-up city district. As long as there is guaranteed line-of-sight, the link could even be set up from one office window to another, eliminating the need to access the rooftop and the telecom riser altogether.

Wireless Local Area Network (WLAN)

WLAN have achieved huge success in many enterprise and home deployments. Currently, public WLAN "hotspots/hotzones" deployments in restaurants, coffee shops, shopping centers, airports and hotels, are expected to fuel its next-wave of growth. Efforts are now concentrated on creating the technological building blocks for delivering public WLAN service, i.e. allowing seamless roaming, security, and quality of service. Over the next 5 years, we expect standards based roaming between different WLAN networks and between WLAN-WWAN networks. This will also drive the chipsets supporting wireless access in portable devices, like notebook computers and Personal Digital Assistances.

Satellite

Broadband satellite communications refer to two-way communications and broadcasting conducted via satellites orbiting around the earth. Its advantage includes the ability to provide communications at virtually any granularity of speed to anywhere, an excellent point-to-multipoint delivery architecture, and the ability of satellite to reach anywhere quickly allows it to provide non-broadcast service to locations not served by other means. Currently, the cost of broadband satellite is significantly higher than other access technologies like ADSL and cable. Therefore, the market for broadband satellite lies in areas remote areas with poor or no telecommunications infrastructure. As many parts of the world still do not have a high capacity backbone telecommunication infrastructure, broadband satellite communications will become increasing relevant over the next few years. On top of this, we believe an emerging market for broadband satellite lies in offering Internet services on planes.

1 Introduction

1.1 What is Broadband Access?

Broadband access refers to any technology that deliver high capacity, two-way connectivity between end-users and access network providers, capable of supporting interactive multimedia applications. Traditional definitions of broadband access technologies usually tag a numerical number for access speed or throughput. For example, the Federal Communications Commission (FCC) defines broadband as "having the capability of supporting, in both the provider-to-consumer (downstream) and the consumer-to-provider (upstream) directions, a speed (bandwidth) in excess of 200 kilobits per second (kbps) in the last mile." The International Telecommunication Union (ITU) defines broadband as transmission capacity faster than primary rate ISDN (i.e. 1.5Mbps or 2Mbps). However, we feel that the rapidly changing Internet environment has made any definitions of broadband a moving target that is likely to mean differently in 2007 as compared to now.

Presently, new applications that require higher bandwidth are constantly being introduced to the market. For example, VCR quality TV will require about 1Mbps, while Video-on-Demand with broadcast TV quality based on MPEG2 compresssion technology will require up to 6Mbps. In addition, what is perceived as broadband is also very much affected by end-user experiences. Therefore, we believe the definition of "broadband" should keep in step with the evolution of new multimedia applications and end-user experiences.

1.2 Drivers for Broadband Access

Driver 1: New Bandwidth-Hungry Applications Drive Demand. The popularity of Internet over these past few years has given rise to many new "bandwidth hungry" Internet applications. Referring to Figure 1, simple applications like web-browsing, e-mail, and FTP (File Transfer Protocol) requires only narrowband access of 56kbps. Presently, most Internet websites have incorporated multimedia content. In addition, virtual private network has become an essential component for tele-working and MP3 (Moving Picture Experts Group-1 Audio Layer-3) audio streaming is becoming increasing popular. All these new applications have resulted in the need to have higher access speed for individual subscriber.

In the future, new innovative applications ranging from video conferencing, interactive TV to virtual reality with sub-second response will become the drivers for higher access speeds.

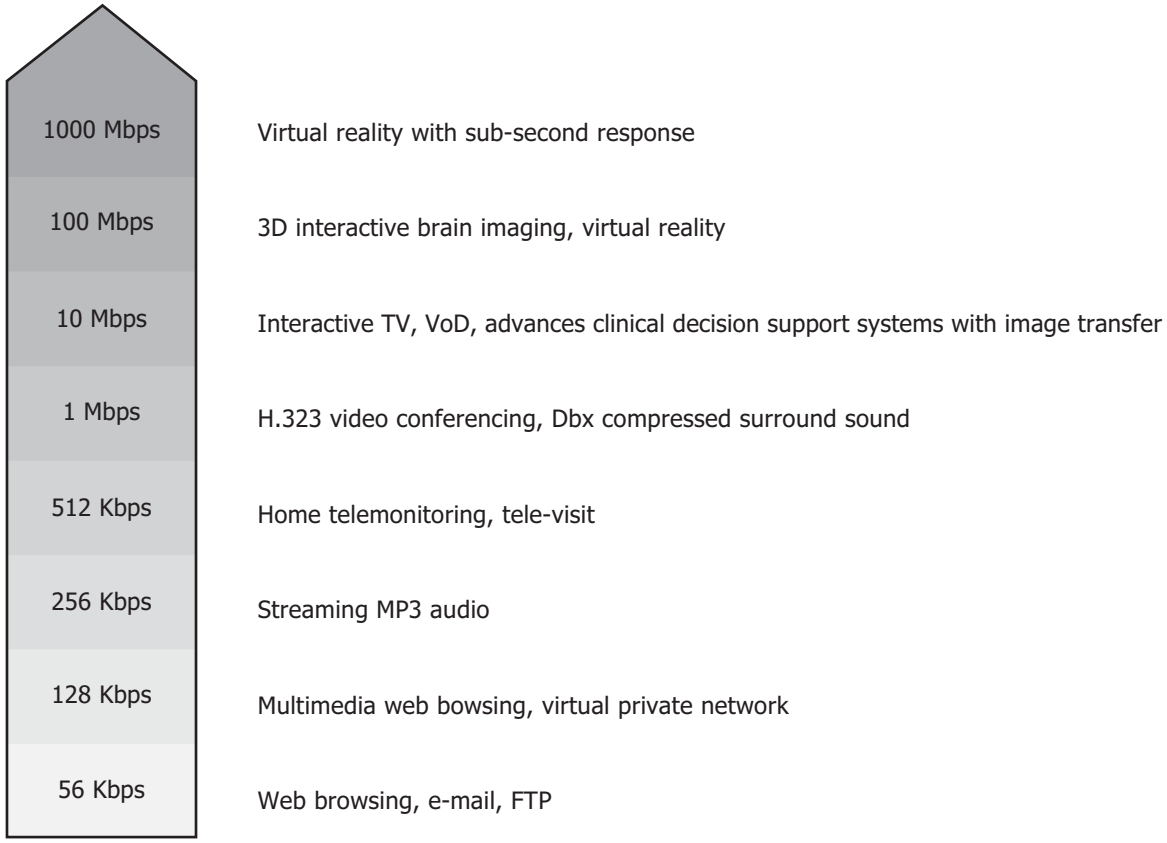

Figure 1. Approximate Bandwidth Requirements for Various Applications

Driver 2: Competition has Driven Down Prices for Broadband Services. The market for certain broadband access technologies like ADSL and cable has become relatively mature. Key technology standards are now in place, allowing vendors and service providers to innovate and offer new products and services over a common platform. All these healthy competitions have driven down the prices of broadband services. In some countries, users only need to pay a small price difference for broadband access. The improvement in terms of end-user experience and productivity have made it more economical to subscribe to broadband access as compared to the traditional dial-up service.

Driver 3: Strong Government Support for Broadband Development. The government in many countries have recognised that the development of broadband is critical to their competitive advantage. For example, South Korea government has announced plans to spend over US$10 billion to deliver VDSL or fibre to over 80% of the Korean population by 2005. Currently, South Korea is already the global leader in terms of broadband penetration with up to 50% of households having either DSL or cable access at the end of 2001. Another example

is the Broadband for Rural and Northern Development Pilot Program in Canada. This initiative provides funding through a competitive process to make available broadband access to Canadian communities, with priorities given to the remote and rural communities, which are not served by Digital Subscriber Line (DSL) or cable modem service. The broadband initiative is part of the Government of Canada's commitment to ensuring broadband access for all Canadian communities by 2005.

Driver 4: New Business Models using Internet as the Platform for Communications. The Internet has gradually evolved into the de-facto platform for communications. Currently, enterprises are already using the Interent as an e-commerce platform for conducting Business-to-Consumer, Business-to-Business and other transactions. Other business models that have appeared with the Internet boom includes Application Service Providers, Internet Data Centers, Content Delivery Networks, Disaster Recovery Planning services, and many others. In the near future, emerging business models based on Web Services, Peer-To-Peer and Grid Computing will push the need for bandwidth to greater heights[1].

1.3 Organisation of Report

The rest of the report is organised as follows. In chapter 2, we will discuss wireline technologies like xDSL, cable, powerline communications and fibre. In chapter 3, we move on to cover wireless technologies. Terrestrial fixed wireless access technologies that will be covered include radio frequency fixed wireless, free-space optics, and wireless local area network (WLAN) as a "last mile" access technology. Broadband satellite will also be covered in this chapter. We end this report by giving an update on the local landscape and conclude with what we expect to see in the future Singapore landscape.

1 For more information, please refer to the ITR report (Release Feb 2002) on Next Generation Internet Applications: Web Services, Peer-To-Peer and Grid Computing.

2 Wireline Broadband Access Technologies

In this chapter, we discuss last mile wireline broadband access technologies. Technologies that will be covered include xDSL, cable, powerline communications, and fibre.

2.1 DSL Technologies

2.1.1 Background of DSL Technologies

Digital Subscriber Line (DSL) refers to a specific implementation of modem technology that is deployed in pairs in a telecommunications network. The first introduction of "DSL" terminology started with High-Speed Digital Subscriber Line (HDSL) technology in the late 1980s, which was meant to be a replacement for T1/E1 high capacity (then referred to as Hi-Cap service) interconnection of corporate data networks[2]. HDSL was successful and by 1990/1991, it had gained a significant mind-share and market-share in Hi-Cap replacements.

The popularity of DSL technologies grew with the introduction of Asymmetric Digital Subscriber Line (ADSL) in 1992 as a access technology capable of delivering Video-On-Demand (VOD) service over telephone networks. ADSL utilizes the same twisted two-wire facility (called the subscriber loop) as the traditional telephone service. However, the initial system objective to use ADSL as a technology choice for offering VOD service was changed to offer high-speed data services in 1994. This attempt achieved mass-market success and ADSL became the vehicle for high bandwidth connection to the Internet and as an enabler of broadband services.

Subsequently, different DSL implementations entered the market to support a variety of market needs. In general, the whole family of DSL technologies can be grouped into 2 broad categories:

1. Asymmetric that includes ADSL, G.lite ADSL, ADSL2, VDSL, and RADSL.
2. Symmetric that includes SDSL, SHDSL, HDSL, HDSL2 and IDSL.

Presently, most deployments are based on the following three technologies:

- Asymmetric Digital Subscriber Line (ADSL)
- Single-Pair High-Speed Digital Subscriber Line (SHDSL)
- Very High-Speed Digital Subscriber Line (VDSL)

We will discuss each of the above technologies in the following sections.

2 Integrated Services Digital Network (ISDN) technology also existed from early 1980s but was not associated with DSL until 1996.

2.1.2 Overview of Asymmetrical Digital Subscriber Line (ADSL)

There are four flavours of ADSL: G.dmt ADSL, G.lite ADSL, G.dmt.bis ADSL2, and G.lite.bis ADSL2.

ADSL (G.dmt ADSL): The most popular DSL technology in business and residential use. The modulation used is Digital Multi-Tone (DMT) coding, and system supports speed of 6.144Mbps downstream and 640kbps upstream. ADSL enables voice and high-speed data to be sent simultaneously over the existing telephone line.

G.lite ADSL (G.lite): G.lite is a medium bandwidth version of ADSL that can deliver up to 1.5Mbps downstream and up to 500kbps upstream. The G.lite standard was developed to meet the plug-and-play requirements of the consumer market segment by eliminating the need for truck-roll. G.lite modems require less power than G.dmt ADSL and were designed to be easy for customers to install, with no splitter needed.

ADSL2 (G.dmt.bis and G.lite.bis): The ADSL2 specifications have been recently approved under ITU-T Recommendations G.992.3/4 in July 2002, where G.dmt.bis and G.lite.bis are enhancements of G.dmt and G.lite respectively. This is the second generation of ADSL, which specifies bit-rate and distance requirements beyond that of ADSL. ADSL2 achieves this through better modulation efficiency by mandating 4-dimensional, 16-state trellis-coded and 1-bit quadrature amplitude modulation (QAM) constellations, which provides higher data rates on long lines with low signal-to-noise ratio (SNR). Another key feature that improves end-user usability is the addition of extensive diagnostic tools for trouble resolution, performance monitoring while in service, and upgrade qualification. Other features of ADSL2 include the specification of power management modes, rate adaptation, and support of DSL bonding for higher data rates.

2.1.3 Overview of Single-Pair High-Speed Digital Subscriber Line (SHDSL)

Single-Pair High-Speed Digital Subscriber Line (SHDSL) is the industry standard symmetric DSL (SDSL), approved under ITU-T Recommendation G.991.2 in Nov 2001. G.991.2 is also known as G.shdsl. This standard was an improvement over earlier HDSL, HDSL2 and other prioriety SDSL systems.

HDSL is the first form of DSL technology. Created in the late 1980s, HDSL delivers up to 2.3Mbps in both directions. It was introduced as an economical replacement of T1/E1 and uses one, two, or three pairs of twisted copper. However, it does not provide standard telephone service over the same line. HDSL is standard specification under ITU-T Recommendation G.991.1.

HDSL2 (2nd Generation HDSL) is a later form of HDSL that is defined under the American National Standards Institute (ANSI)[3]. HDSL2 differs from HDSL in that it uses one pair of wires to convey 1.5Mbps instead of two pairs. HDSL2 supports voice, data, and video, using Asynchronous Transfer Mode (ATM), private line service or frame relay over a single copper pair. However, it does not provide standard voice telephone service on the same wire pair. HDSL2 is not a standard under ITU-T.

SDSL is an umbrella term for the number of vendor-specific implementations of symmetric DSL service. Most SDSL systems are prioriety solutions based on two-binary one-quaternary (2B1Q) modulation over a single twisted pair. However, a lack of standards and spectral compatibility concerns have deterred many network operators from deploying them.

SHDSL is targeted at the business market, unlike ADSL that targets the consumer market. There are two key differences between these two services. The first difference is the asymmetric nature of ADSL service versus the symmetric nature of SHDSL service. The symmetric nature of SHDSL makes it better suited for applications that need high upstream bit-rates, such as video conferencing, remote Local Area Network (LAN) access and Web hosting.

The second difference is that ADSL was designed to be a "best-effort" service, while SHDSL was designed to be a "guaranteed" service. For ADSL, user data rate can vary depending on noise conditions and distance from the central exchange office. On the other hand, SHDSL was developed to delivers a 10e-7 bit error rate (BER) to a specified distance under worst-case noise conditions. User can count on a guaranteed bandwidth and a certain Quality of Service (QoS) for important business transactions.

2.1.4 Overview of Very High-Speed Digital Subscriber Line (VDSL)

Very High-Speed Digital Subscriber Line (VDSL) is the next generation DSL technology that can deliver up to 52Mbps downstream and 2.3Mbps upstream, depending on the wireline distance. VDSL is designed for relatively short distances, up to 1.5km for downstream speed of 13Mbps. This is not seen as an obstacle to deployment because VDSL is designed to be part of a hybrid network, combining fibre from the telecom operator Central Office (switch) to the street curb or building-basement Optical Network Unit (ONU), and then connecting to the existing copper twisted pair to the end-user premises. These hybrid-fibre-copper networks are known as Fibre-to-the-Curb (FTTC), Fibre-to-the-Neighborhood (FTTN) or Fibre-to-the-Basement (FTTB) topology. As telecom operators bring fibre nearer to the user, the possibility for VDSL deployment rises. Currently, VDSL is being introduced in market trials to deliver

3 http://www.ansi.org/

video services over existing phone lines. VDSL can also be configured in symmetric mode with upstream/downstream speed of 13Mbps at a distance of 1km.

2.1.5 Standards Development

ADSL Standards Development. G.dmt ADSL is specified in ITU-T Recommendation G.992.1, while G.lite ADSL is specified in ITU-T Recommendation G.992.2. Both standards were first approved in Jul 1999. The latest two additions that were approved in Jul 2002, G.dmt.bis and G.lite.bis, better known as ADSL2, are specified in ITU-T Recommendations G.992.3 and G.992.4 respectively.

SHDSL Standards Development. The standard for HDSL was first approved in Oct 1998 under ITU-T Recommendation G.991.1 and the standard for SHDSL was approved in Nov 2001 under ITU-T Recommendation G.991.2.

G.991.2 describes a transmission method for data transport in telecommunications access networks. SHDSL transceivers are designed primarily for duplex operation over mixed gauge two-wire twisted metallic pairs. Optional four-wire operation is supported for extended reach applications. Optional signal regenerators for both single-pair and two-pair operation are also specified. SHDSL transceivers supports selected symmetric user data rates ranging from 192kbps to 2,312kbps using a Trellis Coded Pulse Amplitude Modulation (TCPAM) line code. They are designed to be spectrally compatible with other transmission technologies deployed in the access network, including other DSL technologies. SHDSL can transport T1, E1, ISDN, ATM and IP signals. However, SHDSL transceivers do not support the use of analogue splitting technology for coexistence with either POTS or ISDN.

VDSL Standards Development. Development work on VDSL standards include the following:

- ETSI TM6 (European xDSL standards),
- ANSI T1E1.4 (US xDSL standards) and
- ITU-T SG15 (Question 4).

Most of the parameters for VDSL deployment, such as the spectral allocations and other key aspects relevant to unbundling, have been finalised. The European ETSI was the first to have an approved VDSL standard under ETSI TM6 Part1 VDSL Document that was aproved in Nov 2000, while the North America ANSI standard is roughly in line with the ETSI standard. The global ITU has approved the VDSL-foundation specification under ITU-T Recommendations G.993.1 in Nov 2001 that is roughly equivalent to the ETSI TM6 document.

However, consensus has not been reached for a single VDSL line code standard. There are two opposing industry groups involved. The VDSL Alliance, led by Texas Instruments and Alcatel, who has the majority share of the current ADSL market, favours the Digital Multi-Tone (DMT) coding that is used in ADSL. On the other hand, the VDSL Coalition, supported by companies who would like to break Alcatel's lead in the DSL market, favours the CAP/QAM coding standard. The ETSI standard has included both approaches as alternatives. The North America ANSI and global ITU-T have each initiated a selection process that may bring forward early a single VDSL technology.

On another front, the Full Service-VDSL (FS-VDSL) committee under Full Service Access Network (FSAN)[4] has announced the first official global specifications for FS-VDSL on 5 June 2002. This specification will help drive through the standards needed to support the operational rollout of VDSL. ITU-T has agreed to establish a new FS-VDSL Focus Group under its Study Group 16 "Multimedia Services Systems and Terminals" for migration of this specification to ITU-T. Acceptance of this specification by ITU-T is expected in 2003.

Other Complementary Standards. Other approved standards under ITU-T include G.994.1 (G.handshake), G.995.1 (reference), G.996.1 (G.test) and G.997.1 (management). Together, these recommendations form the basis for reliable, compatible and maintainable mass-market DSL deployment.

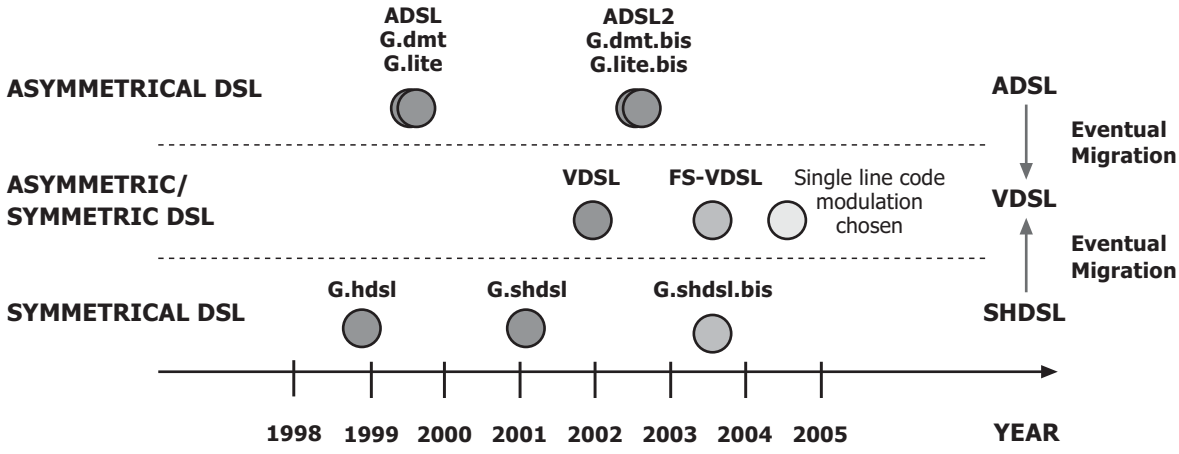

Figure 2. ITU-T Standards Evolution for xDSL Technologies

4 FSAN is an international initiative of 21 telecommunication operators working together with equipment suppliers. As of November 2001, its members includes Bell Canada, Bell South, Qwest, SBC, Verizon, BT, DTAG, Eire, FT/CNET, KPN, Malta, SwissCom, Telefonica, Telia, TI/CSELT, Bezeq, Chunghwa, KT, NTT, SingTel and Telstra. For more information, please visit FSAN website: http://www.fsanet.net/

2.1.6 DSL Deployment

Global Status. Efforts to drive DSL as the broadband access technology for mass-market global deployments is done through the DSL Forum[5]. Established in 1994, DSL Forum is a consortium of nearly 250 leading industry players covering telecommunications, equipment, computing, networking and service provider companies. Best practices for auto-configuration, flow-through provisioning, equipment interoperability and other key facilitators of scaleable, global, mass-market deployment of DSL broadband, are fast-tracked by this Forum.

According to point-topic[6], **Asia Pacific** is the region with the greatest number of DSL subscribers, accounting for over 40% of total global DSL subscribers. Countries like South Korea, Taiwan and Hong Kong are also ranked the highest in terms of percentage penetration of its country's total telephone lines. In particular, South Korea has a DSL penetration of over 26%, significantly higher than Taiwan's 11%. In terms of growth, Japan and China are expected to contribute significantly to the growth for Asia-Pacific. In particular, Japan has increased its installed base by over 115% with 1.8 million new DSL subscribers in the first half of 2002, making it the country with the most number of new subscribers.

North America is the region with the second greatest number of DSL subscribers, accounting for slightly over 25% of total global DSL subscribers. Currently, Canada leads US in terms of percentage DSL penetration of its country's total telephone lines, i.e 6.3% versus 2.7%. However, growth in this region has slowed down significantly due to the upheavals in their telecom sector.

Western Europe is now close to overtaking North America in terms of DSL subscribers. Belgium, Denmark and Germany are leading countries in terms of percentage penetration of the country's total telephone lines. Growth in this region is contributed mainly by Germany, driven by Deutsche Telecom's effort to switch their subscribers from ISDN to DSL.

VDSL Deployment. ADSL can be considered one of the most mature broadband access technology in the market and is already the dominant broadband access technology in most residential market. Similarly, on the business market front, SHDSL is expected to replace previous deployment of symmetric DSL technologies like HDSL, HDSL2 and other propriatory SDSL systems.

Unlike ADSL and SHDSL, the prospects of VDSL are less certain. Currently, there are not many VDSL deployments worldwide, but its deployment appears to be increasing. In North America,

5 http://www.dslforum.org/

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

the biggest deployment of VDSL is in Phoenix, Arizona, where Qwest uses VDSL to serve between 50,000 to 70,000 homes. Other areas with VDSL deployments include Wood County, Texas, Ohio and many others. In Europe, the first VDSL market trial was conducted by Telenor to 750 customers in the city of Stavanger, Norway, since Nov 2000. The pilot users are offered 26Mbps access capacity. Telenor is also conducting trial in Oslo offering 10Mbps. Besides Telenor, Telecom Italia has also conducted a VDSL trial to about 100 people in Turin, Milan and Rome. In Asia Pacific, Korea Telecom is starting to deploy commerical VDSL services to apartment complexes in South Korea.

2.1.7 Future Developments and Outlook

ADSL has established itself as a good broadband access technology that can be easily deployed over the existing copper-based telecommunication infrastructure. Comparing with other technologies, ADSL stands out as the most ready broadband access technology for mass-market deployments.

DSL Technology	1992	2002
Line Code Modulation Technology Used	CAP, QAM and DMT	DMT
Number of Chips in a Modem per line	8	1
Power Dissipation of a single ADSL line (Watts/line)	10	0.75
Line Card Density	1	16
Central Office System Density (per unit)	16	256
IC Price (US$/line)	>150	<12

Table 1. ADSL Technology Evolution

The evolution of some important technology components for mass-market deployment are highlighted in Table 1. The most significant milestone was the decision to support Discrete Multitone (DMT) as the single line code modulation algorithm in 1999. Another was the definition of "embedded operations channel" (eoc) in 1999, which is the method of communication between end user and network DSL modems. These two milestones were important steps towards achieving interoperability among systems.

Other important implementation parameters that have made ADSL more deployable include the reduction in the number of chips required by a single modem, the drop in power dissipation, the increase in line-card density and Central Office system density. All these technology improvements have made ADSL easier and cheaper to deploy.

New technology innovations to increase the reach and bandwidth capabilities of ADSL are still being introduced into the market for purpose of better remote deployments and better ability to compete with other broadband access technologies such as cable. Currently, some vendors are promoting a new DSL variant called **ADSL+** that uses more spectrum for transmission. Companies such as Next Level Communications has announced an ADSL+ system that is able to carry up to 10Mbps to subscribers at distances more than 3km[7]. Currently, South Central Rural Telephone Cooperative, one of the largest independent telephone cooperatives in US is using ADSL+ to offer two streams of digital television, high-speed Internet and a full complement of voice services to subscribers. The ADSL+ system is backward compatible with existing ITU-T approved ADSL standards, and may be adopted as an ITU-T standard some time down the road.

SHDSL is expected to replace many of the older technologies that offer symmetrical access such as HDSL, HDSL2, SDSL, ISDN, T1, E1 and ISDN-DSL. Before the G.shdsl standard, telecommunication equipment vendors were required to develop different line cards to accommodate each of the services that were offered by the technologies listed above, and worry about spectral compatability issues. Therefore, these vendors can drive down components cost by developing CO loop access equipment and CPE around SHDSL.

Future developments in the area of SHDSL will be in the areas of extending reach and bit-rate, improving end-user usability through adding diagnostic tools, incorporating power management modes, and reduction of cross-talk. Currently, the standards body are working on a "G.shdsl.bis" standard. We believe this new standard will address most if not all the above-mentioned issues, and is likely to appear in 2003.

As for **VDSL**, the key milestone to watch is whether ITU-T will select a single line code modulation standard, and if they do, which one. Several industry analyst believed that VDSL deployment has not picked up due to the lack of a single line code modulation, and DMT will eventually emerged as the winner. Without a standard in place, both the vendors and operators may find it too risky to invest huge capital in this technology. This is especially so in such uncertain economic times.

Ethernet-Over-DSL. Ethernet is the dominant local area network (LAN) technology today. The IEEE 802.3ah Ethernet in the First Mile[8] (EFM) Task Force and EFM Alliance[9] is planning to make Ethernet the dominant technology for delivering data, voice and video over the first

7 Next Level Communications Press Release, New Next Level Product Smashes "Last Mile" Barrier, http://www.nlc.com/NewFiles/PressReleasesPR2002/PR_5602.html, 2 May 2002.

8 http://www.ieee802.org/3/efm/

9 http://www.efmalliance.org/

mile, last mile and local loop. Currently, IEEE is working on solutions to deliver duplex 10Mbps Ethernet at distances up to 750m. Other speeds and reaches have also been proposed. For example, the committee has also agreed to specify standards for 2Mbps Ethernet over copper at distances up to 2 miles. We expect a complete EFM standard to be released in 2004.

Market Forecast. According to Pioneer Consulting[10], worldwide DSL subscribers are estimated to increase from 12.5 million in 2002 to 70.5 million in 2005, and will reach 111.6 million in 2007. On the other hand, worldwide market opportunity for broadband service is expected to increase from US$13.6 billion in 2002 to US$63.6 billion in 2005, and will reach US$79.2 billion in 2007.

Future Outlook. Overall, we believe the future for DSL is bright. In particular, it is expected that ADSL will remain the dominant broadband access technology for the next five years. With over 1 billion telephone lines installed worldwide, the DSL Forum has set itself a target of achieving 20% DSL penetration or 200 million DSL connections by 2005. As of end Jun 2002, there are more than 25.58 million households and small businesses around the world have DSL connections, according to point-topic. This indicates an additional 6.8 million subscribers or global growth rate of 36% in the last six months. If this growth rate is sustainable, then the DSL Forum will be reaching its targeted 200 million subscribers by the end of 2005.

As mentioned earlier, we expect VDSL to take off much later due to lack of single line code standard and present uncertain economic outlook. Being able to operate in asymmetric and symmetric mode, the higher speed VDSL is seen as the future replacement of ADSL and SHDSL. Currently, there is also an increase in VDSL deployments worldwide. This is especially so in areas where competing cable operators are offering video to their end-users. Therefore, telecommunication operators are under considerable pressure to upgrade their ADSL offerings to VDSL.

2.2 Cable Technologies

2.2.1 Overview of Cable Technologies

Cable systems were originally designed to deliver broadcast television signals efficiently. To ensure that consumers obtain cable data service with the same TV sets that receive over-the-air broadcast TV signals, cable operators recreate a portion of the over-the-air radio frequency spectrum within a sealed coaxial cable line.

10 http://www.pioneerconsulting.com/

The typical cable frequency spectrum allocation is shown below. Depending on actual implementations, some cable operators utilize frequencies up to 860MHz.

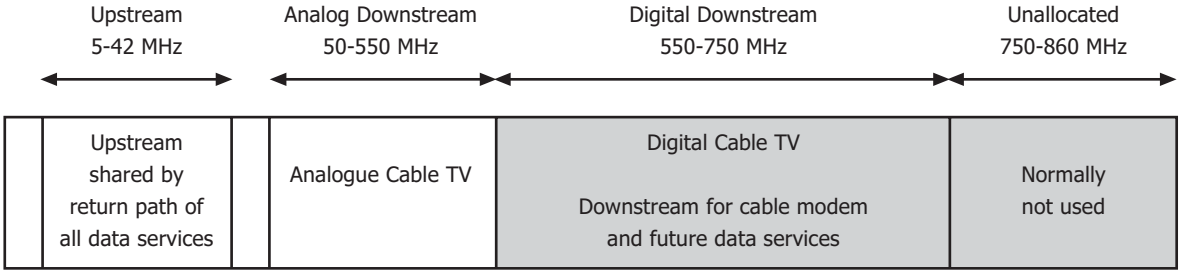

Figure 3. Cable Frequency Spectrum

The 5MHz to 42MHz is usually reserved for upstream communications from subscribers' home back to the headend. The 50MHz to 550MHz band usually supports analogue transmission, while the 550MHz to 750MHz band usually supports digital TV transmission as well as other data services such as cable modem, Internet TV and telephony. Anything above that is normally not used.

Most of cable operators' expenses lie in laying a two-way cable network or in upgrading the existing cable network to carry two-way traffic. Once this has been accomplished, the cost of adding subscribers is incremental. Deployment issues related to adding new subscribers on an existing wireline network are minimum.

2.2.2 Cable Modem Standards

There are currently 2 international standards for cable modem products:

- Data Over Cable Service Interface Specification (DOCSIS) the standard in North America and other International markets, and
- EuroDOCSIS the dominant standard in Europe

2.2.2.1 Data Over Cable Service Interface Specification (DOCSIS)

DOCSIS 1.0. DOCSIS 1.0 was first released in Mar 1997 by Multimedia Cable Network System Partners Ltd. (MCNS), a consortium of MSOs, such as Comcast, Cox, AT&T and Time Warner. It received good response from vendors who build products based on this specification. In early 1998, CableLabs began a formal certification program for DOCSIS

equipment to ensure products built by different manufacturers are indeed compatible. In Mar 1998, the International Telecommunications Union (ITU) accepted DOCSIS as a cable modem standard, called ITU J.112.

To deliver DOCSIS data services over a cable television network, one 6MHz radio frequency (RF) channel in the 50MHz to 750MHz spectrum range is typically allocated for downstream traffic to homes and another channel in the 5-42MHz band is used to carry upstream signals.

DOCSIS 1.1. In Apr 1999, CableLabs issued the second-generation specification called DOCSIS 1.1, which is a functional enhancement over DOCSIS 1.0. The enhanced specification allows for dynamic QoS and hardware fragmentation to reduce application specific transport latency for delivery over 2-way cable systems. CableLabs' certification of DOCSIS 1.1 modems will enable multimedia services, including voice communications and dedicated business-class data services. DOCSIS 1.1 is designed to be backward compatible, enabling DOCSIS 1.0 and 1.1 modems to operate in the same spectrum on the same network.

DOCSIS 2.0. The third-generation standard developed by CableLabs, which focuses on increasing upstream transmission capacity and reliability. The specification adds an Advanced PHY layer implementation allowing symmetrical downstream and upstream access speed, and better noise immunity. DOCSIS 2.0 mandates the use of both frequency-agile time division multiple access (FA-TDMA) and synchronous code division multiple access (S-CDMA) technology. It is backward compatible with the earlier DOCSIS specifications. This specification was completed in Jan 2002.

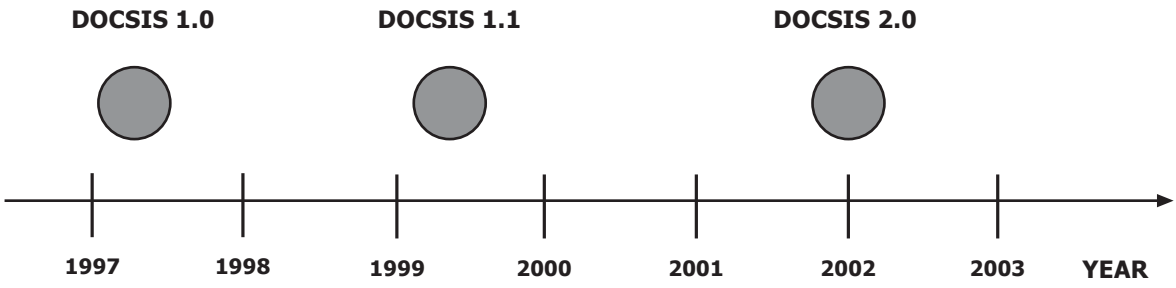

Figure 4. Timeline for DOCSIS Cable Modem Specifications

A simple timeline for the evolution of DOCSIS cable modem specifications is shown in Figure 4. Currently, there is no announcements for a next generation specification beyond DOCSIS 2.0. Table 2 summarizes the characteristics and services that each DOCSIS specification can support.

Specification	Data Speed	Applications/Services	Remarks
DOCSIS 1.0	30 Mbps downstream, 5 Mbps upstream	High-speed data Internet access	Standard Specification
DOCSIS 1.1	30 Mbps downstream, 10 Mbps upstream	Tiered Service QoS applications and services IP Multicast enhancement Operations Security	Double upstream capacity Lower operation costs
DOCSIS 2.0	30 Mbps downstream, 30 Mbps upstream	Symmetric services such as business applications and peer-to-peer applications	S-CDMA and FA-TDMA are mandated as the modulation technique. Up to 20 times the capacity of T1

Table 2. Comparison of Various DOCSIS Specifications

EuroDOCSIS. A European version of DOCSIS, whose technical specifications are an annex of CableLabs Certified DOCSIS standard. EuroDOCSIS is essentially the same as DOCSIS apart from the physical layer, which is DVB-compliant. So far, EuroDOCSIS 1.0 and EuroDOCSIS 1.1 have been specified. Modem certifications for compliance with EuroDOCSIS are done through tComLabs in Belgium.

The European Telecommunications Standards Institute (ETSI) has formally adopted the DVB[11] 2.0 specification as ETS 300 800. This standard describes the out-of-band and in-band transmission options applicable to interactive set-top boxes and cable modems, respectively, enabling the deployment of interactive TV, data and voice services over a common platform. ETS 300 800 has also been selected by DAVIC[12] to be the DAVIC 1.5 specification for cable modems.

2.2.2.2 Services and Application Initiatives developed for DOCSIS

PacketCable. An initiative by CableLabs, this initative is working to develop open standards for delivering Internet Protocol (IP) telecommunications and multimedia services over DOCSIS 1.1 cable modem access networks. Currently, specifications that are available include PacketCable 1.0, 1.1 and 1.2.

11 http://www.dvb.org/

12 http://www.davic.org/

- PacketCable 1.0 defines the call signaling, QoS, Codec, client provisioning, billing event message collection, PSTN interconnection, and security interfaces necessary to implement a single-zone PacketCable solution for residential Internet Protocol (IP) voice services.

- PacketCable 1.1 defines the requirements for offering reliable service using the PacketCable architecture, like access to emergency services during power failure at the customer's premises.

- PacketCable 1.2 defines the functional components and interfaces necessary to allow communication between PacketCable 1.0 networks using an IP transport or backbone network, which includes call signaling and QoS extensions to the PacketCable 1.0 architecture to enable cable operators to directly exchange session traffic on the IP network without traversing the PSTN network at any time.

Future additions to the PacketCable specifications will define protocol support for enhanced capabilities, such as multimedia conferencing and interactive gaming. A Euro-PacketCable initiative is also being defined currently.

OpenCable. Another initiative by CableLabs, which began in 1997, aims to help the cable industry deploy interactive services over cable through the definition of the next-generation digital consumer device (hardware) and the creation of a retail software platform. The hardware specification allows interoperability among retail receivers. The software specification, called the OpenCable Applications Platform (OCAP), creates a common platform for deployment of interactive services, solving the issue of proprietary operating system software.

CableHome. This project aims to develop an interface specification for extending cable-based services to network devices within the home. Issues that will be addressed include device interoperability, QoS (Quality of Service), and network management.

2.2.3 Global Deployments

According to Frost and Sullivan, there are 15.8 million cable modem subscribers worldwide as of Q1 2002. Although less than the figures for DSL, cable modem remains the greatest competitor to DSL service. In certain countries such as US, Ireland, Greece and Portugal, cable is the dominant broadband access technology.

North America is the region with the largest number of cable modem subscribers. According to Kinetic Strategics[13], Q2 2002 figure stands at approximately 10.77 million subscribers, with US accounting for close to 9 million subscribers.

In Europe, cable Internet broadband connections are estimated to be close to 1.7 million, according to European Competitive Telecommunications Group (ECTA)[14]. The top three European countries with broadband cable deployments being Netherlands (330,000), UK (287,000), and Belgium (225,000).

In Asia Pacific, cable modem subscribers are estimated at 3.4 million in 2001, according to IDC. South Korea is the leading country in the region, having approximately 2.7 million cable modem subscribers.

2.2.4 Future Developments and Outlook

Future Developments. Existing coaxial systems do not utilize anything above the 860 MHz. However, this spectrum can be exploited to boost the bandwidth limitations of existing HFC systems. Currently, Narad Networks is one company that has successfully utilized previously unused cable spectrum from 860MHz to 2GHz to provide switched Gigabit Ethernet over the existing last mile portion of cable networks. Using this technology, operators can now offer high-speed bi-directional services that leverages on the performance and reliability of switched Ethernet connections, without affecting existing cable services that utilizes the 5MHz to 860MHz spectrum. Narad have submitted their technology to CableLab for consideration as future DOCSIS standard. In the future, we can expect to see more technical innovations in utilizing the higher ends of the cable spectrum.

Market Forecast. According to Pioneer Consulting, estimated worldwide residential cable broadband access subscribers will grow from 10.3 million in 2002 to 75.3 million in 2007. The corresponding worldwide market opportunity for residential cable broadband service will grow from US$4.67 billion in 2002 to US$33.5 billion in 2007.

Future Outlook. Similar to ADSL, cable has established itself as a good broadband access technology. Over the next few years, we believe that cable will continue to be one of the top two broadband access technologies deployed for the last mile. A reliable track record and continous innovation for higher bandwidth will make it difficult for other alternative technologies to displace it.

13 http://www.kineticstrategies.com/cableip/

14 http://www.ectaportal.com/

2.3 Powerline Communication

2.3.1 Overview of Powerline Communications (PLC)

Powerline Communications (PLC) is a technology that sends high-speed data through existing electric cables, transforming existing electricity grid into a broadband telecommunications network. PLC technology has been around for a long time. Traditionally, powerlines have been used as Carrier Systems in homes as a medium to support low speed control applications. It was also used by utility companies for control and monitoring of substation equipment, through low bandwidth data transmission. With advances in digital signal processing capabilities, PLC has now progressed to the stage where it is used outdoors as a local loop access technology and also in-house as a home-networking technology. In this section, we will focus on how the electricity grid can become another alternative last mile access solution. Note that PLC with respect to home networking will be discussed in "The Connected Home" report.

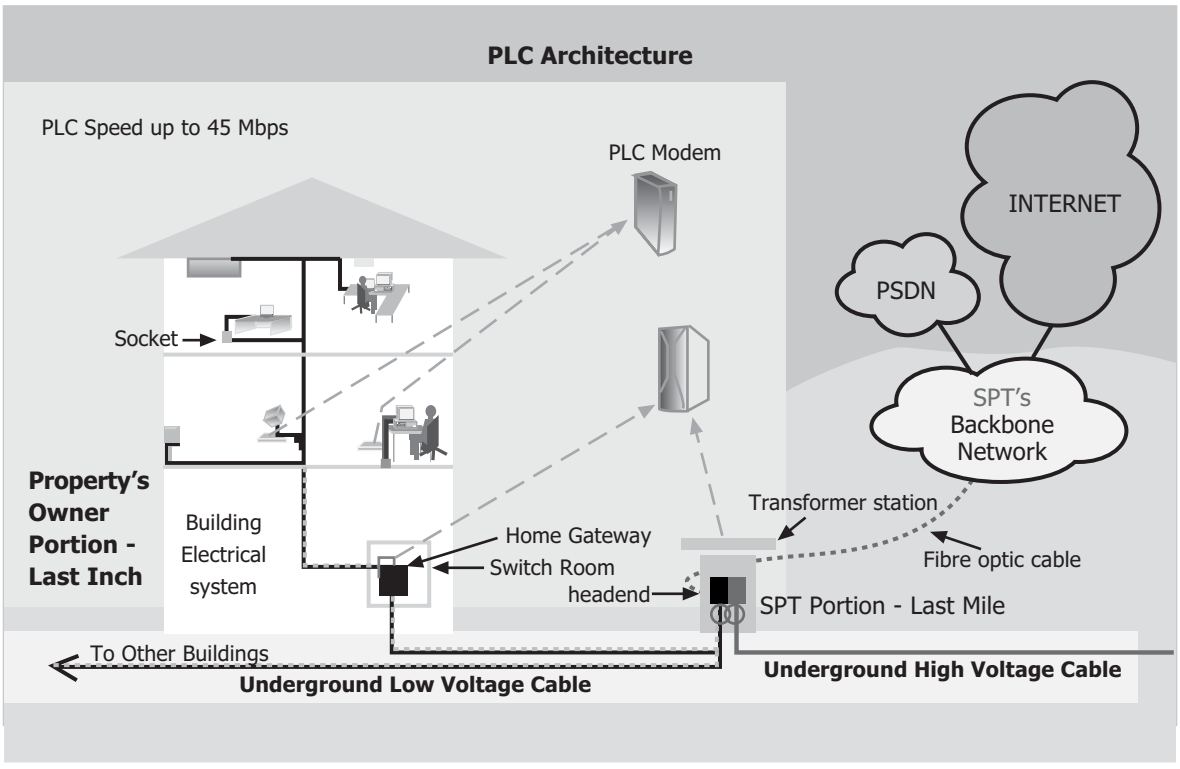

Figure 5. Powerline as a Last Mile Solution
(Source: SP Telecommunications)

Figure 5 shows a simple schematic diagram of how PLC is used as a last mile broadband solution. The data signals from the telecommunication operator backbone network is modulated by a powerline transceiver, commonly known as the PLC modem/router/gateway onto the low voltage (LV) power cable, which will carry the data signals to the electrical sockets inside the building.

To connect any of the access points to the termination devices (e.g. PCs, network servers, IP Phones), a powerline adapter, or Customer Premise Equipment (CPE), is used to couple the device to the electrical network using a standard communication input interface, like an Ethernet or USB port. Wall modules and termination devices containing embedded powerline transceivers are also starting to appear in the market.

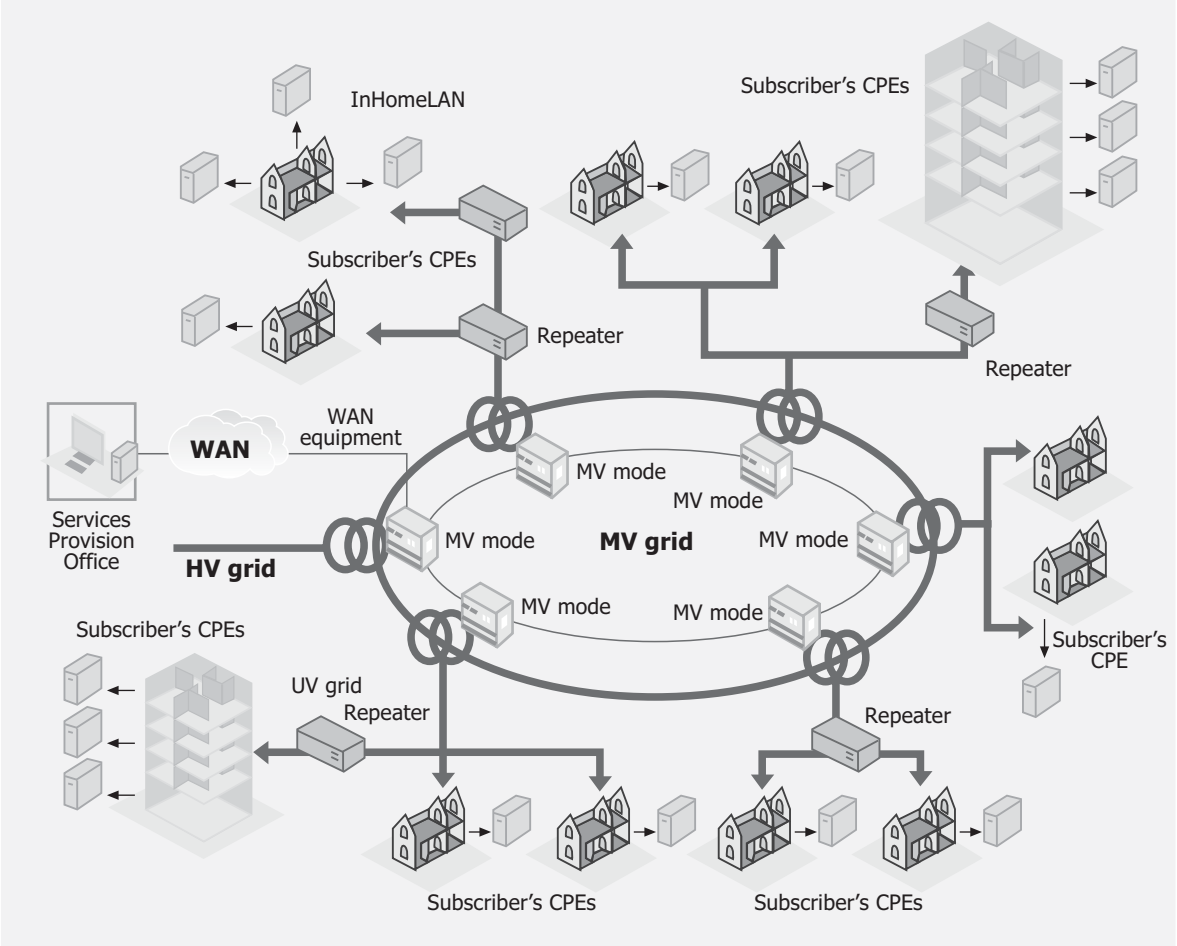

Figure 6. Powerline as a WAN/MAN Solution
(Source: SP Telecommunications)

The key advantage of PLC is the ubiquity of the electricity network. Every residential and office unit and building is connected by LV cables to the electricity substations. All the cables are already laid, with the power sockets in every room to function as a potential communication point for the users. Power cabling is much denser than the current telephony infrastructure. There is no need to extra cables, making it cost effective and convenient to the end users.

From the initial application of PLC technology to the LV distribution network, this technology has recently been applied to the medium voltage (MV) range. Trial installations have been set up to create a WAN/MAN network using PLC over MV distribution network. This is especially useful for utility companies without WAN/MAN telecommunications infrastructure. An overall schematic diagram is shown in Figure 6.

2.3.2 PLC Related Standards

Standardization in PLC technology has not been fully stabilized, making it difficult for manufacturers to reach the economies of scale necessary to lower costs and for utilities to justify long term investment.

One key area is on the Electromagnetic Compatibility (EMC) regulation for last mile PLC deployment. The North American EMC requirements for radio frequency devices are contained in FCC part 15. FCC part 15 requirements for carrier current devices are designed to minimise interference to AM radio broadcast services in the 535kHz to 1705kHz frequency band but outside this band there is no limit on the level of conducted emissions.

The EMC requirements in Europe are based on the International Electrotechnical Commission[15] (IEC) standard CISPR[16] 22. The spurious emissions limits in this standard makes it more strigent than FCC part 15, resulting in significant challenges for vendors of megabit powerline communications equipment. In view of this, the European standards bodies European Telecommunications Standards Institute (ETSI) and European Electrotechnical Standardisation Committee[17] (CENELEC) are collaborating to set new standards for high bit-rate powerline technology. Two standards are under development: ETSI is working on the ETSI Power Line Telecommunication System Reference Document, while CENELEC is working on SC205A (Sec) 75, which is on power line signalling.

15 http://www.iec.ch/

16 The International Special Commitee on Radio Interference

17 http://www.cenelec.org/

2.3.3 Global Deployments

PLC trials started back in 1998. Since then, there have been several power line broadband access trials worldwide, with most of them conducted in Europe. Some have now entered into commercial phase. Examples of electricity utilities that have been running successful trials include Endesa[18] (largest Spanish utility) with more than 2000 users having access throughput of 12Mbps to 20Mbps, Enel (largest Italian utility) with more than 1400 users, MVV (in Germany) with around 1000 users and Singapore Power's subsidiary SP Telecom[19] with some 300 users.

In North America, the initial focus has been in in-home PLC. An industry alliance, called Homeplug, was formed, and include companies such as Sharp, Philips, Motorola, Radioshack. A powerline home networking technical standard has been developed and a number of companies, including Netgear and Linksys, have developed modems based on this specification. On the last mile front, several successful market trials have been carried out. For example, Ambient[20] has run trials with ConEd on LV power system in Manhattan. Trials on MV system above New York City have also been carried out successfully. Main.Net is working with Ameren, PPL and two other utilities in extensive field trials. PowerComm is also working with Fayetteville Electric System to do testing on their facilities. 5 trials are slated for mid-2002. Other companies like Amperion[21] and Current Technologies have also announced successful trials using both LV and MV PLC. Overall, however, commercial launch of access PLC in North America is not expected until 2003 or later.

2.3.4 Future Developments and Outlook

Future Developments. Despite the numerous trials that have taken place for PLC, the burden of proof remains on the side of utility companies that their PLC-based telecommunication services are able to satisfy both the telecommunication regulators and the power utility regulators. The three key areas that any PLC operators must justify to the regulators are:

- **Electromagnetic Compatibility (EMC) / Electromagnetic Interference (EMI)**
  The 1MHz to 30MHz frequency band utilized by PLC can potentially cause interference to certain radio communications services. This includes military communications, aeronautical/ maritime safety services (Search & Rescue operations), broadcasting, radio amateurs,

18 http://www.plcendesa.com/

19 http://www.spower.com.sg/sp_tele_frame.htm/

20 http://www.ambientcorp.com/

21 http://www.amperion.com/

induction loop for hearing-aid systems, new digital services such as Digital Radio Mondiale and others.

- **Co-existence of Access and In-home PLC Systems**
  Presently, access and in-home PLC systems are not based on a common spectrum usage standard. This is because PLC vendors in the US and EU started with different technologies, targetting different markets, resulting in overlapping spectrum bands for the different usage of PLC. However, some efforts are being initiated towards resolving this issue.

- **Power Quality and Safety**
  An issue that is of key concern to the power regulators. PLC signals must not affect the power quality, i.e. degrade the harmonics content, and associated PLC services. There is a need to demonstrate that PLC deployment will not cause disturbance to the Power Transmission & Distribution networks, and Ripple Control & Metering services. In addition, PLC must not inadvertently trigger other electrical appliances (microwave, kettle, stove etc.) in both the resident's apartment and those of neighbours.

Therefore, PLC vendors and potential operators must work towards addressing all the above-mentioned issues before mass-deployment can be expected.

Next Generation PLC Equipment. Current data rates for PLC access systems are in the range of 2Mbps to 50Mbps. Various vendors have claimed that over the next two years, second generation of PLC equipment will be capable of delivering data rates in the range of 50Mbps to 200Mbps. Future third generation of PLC equipment capable of delivering data rates in excess of 200Mbps can also be expected. For example, DS2 has announced a prototype 200Mbps (raw) PLC chipset will be ready by end 2003. At such high data speed, PLC will surpass anything that DSL and cable can offer, leaving fibre as its only competitor.

Future Outlook. PLC provides a strategic entrance to the broadband market for the power utilities and will allow them to gain a foothold in the lucrative broadband market. Unlike their telecommunication counterparts, power utilities do not have to spend large amount of money to lay cables since the power grid is already installed. Rather, they are likely to use this option to deliver value-add telecommunication services on top of the electricity supply. However, the standards and regulatory issues have to be addressed before mass deployment can become a reality. Nevertheless, if the development of next generation PLC equipment holds true, then we believe the window of opportunity for PLC as an access technology remains open for next 5 years.

2.4 Optical Fibre Access Technologies

The last mile access network so far consist predominantly of twisted-pair copper wires and coaxial cables. Despite the many distinct advantages of optical fibre technology, like higher bandwidth and immunity to electromagnetic and radio frequency interference, mass deployment of fibre as a last mile access solution has not materialised yet due to high installation costs, electrical powering and most importantly, the absence of compelling applications to justify the high bandwidth provision. However, we believe that as the price/performance ratio of optical fibre components continue to come down and future applications continue to require ever-increasing bandwidth, fibre access technologies will become an eventual reality.

2.4.1 Overview of Optical Fibre Access Technologies

Optical fibre is seen as the ultimate solution for delivering Interactive Broadband Multimedia (IBBMM) content to the residential or business consumers. Unlike transition solutions like Digital Subscriber Line (DSL) and Hybrid Fibre-Coax (HFC) systems, optical access networks are unlikely to encounter any bandwidth bottleneck.

Currently, optical fibre as a last mile technology is most commonly deployed using optical-based Gigabit Ethernet systems or passive optical networks (PONs).

Gigabit Ethernet. Gigabit Ethernet is a high-speed optical networking implementation of Ethernet that supports speed of 1Gbps and above. Presently, Ethernet is the most popular networking technology accounting for over 90% of today's Internet end points. Ethernet is deployed as a "last feet" solution in Local Area Network (LAN) environment. Gigabit Ethernet is a natural evolution to a higher-speed Ethernet networking platform. It is easily interfaced with earlier forms of Ethernet, and due to its higher speed, it is now being used as an access technology for last mile, metropolitan and even wide area networks. More importantly, it offers cost savings on optoelectronics on a per Mbps basis compared to Synchronous Optical Network/ Synchronous Digital Hierarchy, the most popular networking platform for MAN/WAN.

Passive Optical Networks (PONs). Referring to Figure 7, PONs are splitters connecting a few subscribers onto one shared fibre network by using passive components between the Optical Network Unit (ONU) and Optical Line Terminating (OLT). The former is to be installed in or close to customer premises while the later is needed in the local exchange. PONs eliminate bandwidth bottleneck by bringing the fibre closer to the building/curb/home. Today, most of these network elements are still expensive to deploy. Cost-effective ONU and OLT equipment are much needed. Beside price, electrical powering these network elements and the absence

of compelling high-bandwidth applications are prime considerations to the early deployment of PONs in access network.

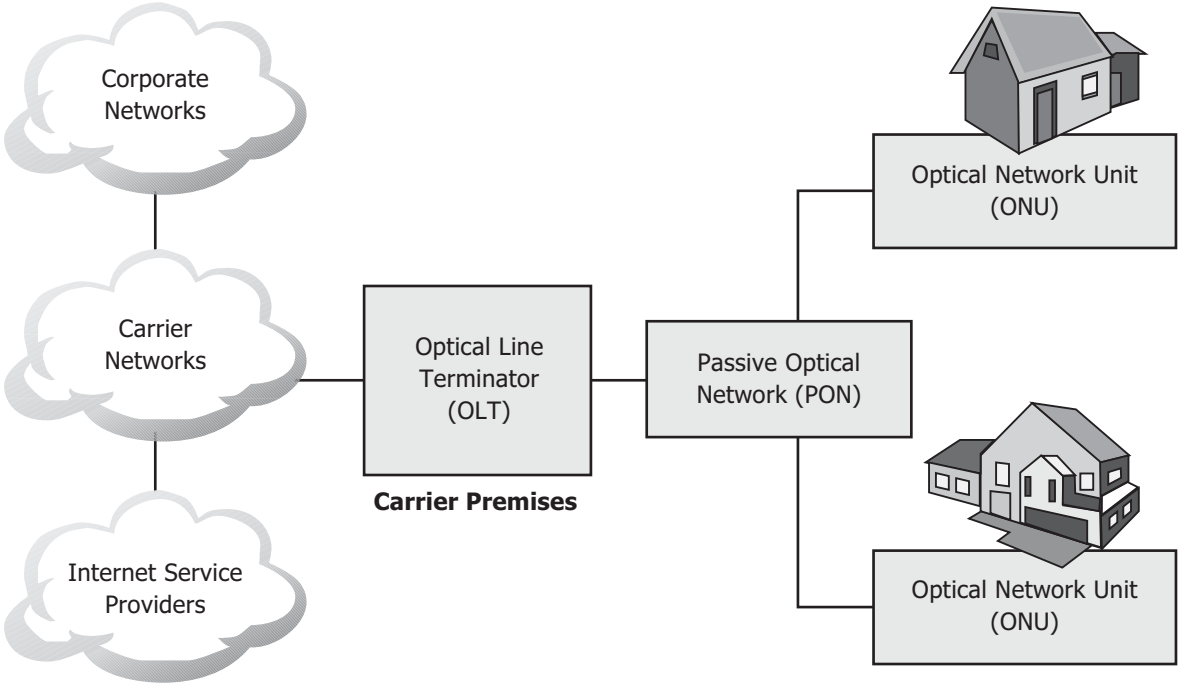

Figure 7. Simple Schematic Diagram of using Fibre as a Last-Mile Solution

2.4.2 Gigabit Ethernet and Passive Optical Network (PON) Standards

10 Gigabit Ethernet. The IEEE 802.3ae[22] Task Force has recently approved the final draft of the 10 Gigabit Ethernet standard in Jun 2002. This clears the way for vendors to begin shipping non-proprietary and interoperable 10Gbps Ethernet equipments. Compared with the earlier Gigabit Etherent standard (IEEE 802.3z that was approved in 1999), the new 10 Gigabit Ethernet standard is able to move data 10 times faster over single-mode and multi-mode fibre, over distances of up to 40km.

Supporting the IEEE 802.ae group is an industry alliance, **10 Gigabit Ethernet Alliance**[23] (10GEA) that was formed to facilitate and accelerate the introduction of 10 Gigabit Ethernet

22 http://grouper.ieee.org/groups/802/3/ae/

23 http://www.10gea.org/

into the networking market. The Alliance will support the IEEE activities by fostering the development of the 10 Gigabit Ethernet standard and promote interoperability among the differnet vendor products.

On another front, another industry consortium, Metro Ethernet Forum[24] (MEF), is pushing for the accelerate adoption of optical Ethernet as the technology of choice for metro networks worldwide. MEF is a consortium of equipment manufacturers that was created in June 2001 to fulfil this vision. The primary priorities of MEF are to define:

- Ethernet services that can be delivered over native Ethernet-based metro networks and could also be supported by other transport technologies, and

- carrier-class Ethernet-based metro transport technologies by specifiying architecture, protocols, and management for such networks.

Presently, MEF has developed metro Ethernet services definitions to enable standardized service offerings from service providers to end-customers and metro Ethernet protection that enables sub-50msec network restoration and hitless protection capabilities to enable support of time division multiplexing and other time-sensitive applications over Ethernet. They have also established QoS specifications to enable guaranteed service level agreements, a user-interface standard for services provisioning, monitoring, and communicated between user and network interface, and other end-to-end network management specifications.

Broadband Passive Optical Network (BPON). This standard was previously referred to as ATM-based passive optical network (APON), and its development is spearheaded by the FSAN consortium. It defines a basic set of common requirements for broadband access systems to support a full range of integrated broadband and narrowband services. The wavelength window in the recommendation specifies the 1550nm region for downstream and 1310nm region for the upstream direction. The specification was adopted by ITU as G.983.1 in Oct 1998. A related PON management and control interface (OMCI) standard G.983.2 was issued in Apr 2000. Subsequently, an amendment G.983.1 was issued in Nov 2001 to increase the upstream bit rate from 155Mbps to 622Mbps. This recommendation has now been superseded by a new version approved in Jun 2002.

In Mar 2001, the Recommendation G.983.3 was completed for **increased service capability.** It defines a new wavelength allocation by specifying a narrower portion for the downstream window. This portion, referred to as basic band, is used for transporting BPON downstream

24 http://www.metroethernetforum.org/

Number	Status	Description	Details
G.983.1	In force Approved Oct 1998	Broadband optical access systems based on Passive Optical Networks (PON)	Describe the optical layer, transmission convergence layer, and ATM layer for BPON systems
G.983.1 Amd 1 (11/01)	In force Approved Nov 2001	Amendment 1	Modifications are to address 622.08Mbps upstream bit rate operation.
G.983.2 (04/00)	Superseded	ONT management and control interface (OMCI) specification for ATM PON	Specifies operations channel protocol and message set (OMCI) between the BPON OLT and the ONT
G.983.2 (06/02)	Pre-published Approved Jun 2002	ONT management and control interface specification for ATM PON	Specifies operations channel protocol and message set (OMCI) between the BPON OLT and the ONT
G.983.3 (03/01)	In force Approved Mar 2001 Amd 1, Approved Jun 2002	A broadband optical access system with increased service capability by wavelength allocation Managed objects for diagnostic information of public switched telephone network connected V-series modem DCE's	Defines new wavelength allocations to distribute BPON signals and additional service signals simultaneously. New wavelength bands for additional services are made available by constraining the current ATM-PON downstream wavelength to a portion of downstream optical spectrum originally specified in ITU-T G.983.1.
G.983.4 (11/01)	Pre-published Approved Nov 2001	A broadband optical access system with increased service capability using dynamic bandwidth assignment	Specifies a Dynamic Bandwidth Assignment (DBA) mechanism which improves the efficiency of the PON
G.983.5 (01/02)	Pre-published Approved Jan 2002	A broadband optical access system with enhanced survivability	Specifies a number of protection options for PONs which will enable enhanced survivability for fibre-to-the-cabinet (FTTCab) and fibre-to-the-office (FTTO)
G.93.6 (06/02)	Pre-published Approved Jun 2002	ONT management and control interface specifications for BPON system with protection features	Describes the ONT management and control interface (OMCI) specifications required for the BPON system with enhanced survivability, building on G.983.2
G.983.7 (11/01)	In force Approved Nov 2001	ONT management and control interface specification for (DBA) BPON system	Describes the ONT management and control interface (OMCI) specifications required for the Dynamic Bandwidth Assignment (DBA) function in a BPON system, building on G.983.2

Table 3. BPON Standards Development
(Source: ITU-T)

signals and the spectral width of 20nm makes it cost effective for using conventional distributed feedback laser diodes. An additional waveband, known as enhancement band, is specified with 2 options available, i.e. 1539nm to 1565nm and 1550nm to 1560nm. An amendment to G.983.3 was recently issued in Jun 2002.

In Nov 2001, two new Recommendations, G.983.4 and G.983.7, were approved by ITU. G.983.4 specifies a **Dynamic Bandwidth Assignment (DBA) mechanism** that improves the efficiency of the PON by dynamically adjusting the bandwidth among the ONUs in response to varying traffic conditions. While G.983.7 builds on the OMCI specifications of G.983.2 by addressing issues related to the DBA mechanism of G.983.4.

G.983.5 was approved in Jan 2002. This Recommendation specifies a number of protection options for PONs that will enable enhanced survivability for fibre-to-the-cabinent (FTTCab) and fibre-to-the-office (FTTO) deployments. Subsequently in Jun 2002, the OMCI for BPON systems with protection features were approved under G.983.6. Table 3 provides the details for BPON standards development.

Ethernet Passive Optical Network (EPON) - The IEEE is also working on this standard under its *Ethernet in the First Mile, EFM*[25] Study Group. When the standards complete, service providers would be able to deploy a faster and lower cost network, and support more users than BPON technology. Since its formation in Dec 2000, the Study Group has identified several key objectives that will be used to evaluate technical proposals for the 802.3ah Task Force. The standard, which we believe will be completed in 2004, will define operations, administration, and maintenance (OAM), which include remote failure indication, remote loop-back, link monitoring, and support of three subscriber access network topologies and physical layers:

- Point-to-point copper over the existing copper plant at speeds of at least 10Mbps up to at least 750m;
- Point-to-point optical fibre over a single fibre at a speed of 1Gbps up to at least 10km;
- Point-to-multipoint fibre at a speed of 1Gbps up to at least 10km.

25 http://www.ieee802.org/3/efm/

2.4.3 Global Deployments

Currently, the majority of the products in the market are BPON systems. Vendors that are pushing out BPON products include, Alcatel SA, Marconi, NEC Eluminant Technologies, Oki Networks, Optical Solutions, Paceon, Quantum Bridge Communications and Terawave Communications. This popularity can be attributed to the presence of an ITU approved G.983 standard and that most FSAN members are large telecommunication operators.

PON deployments are gaining traction worldwide. For example, SBC Communications had announced that their first PON installation would take place in Houston, where it would initially move 1,000 business customers from copper to PON access. The PON rollout is expected to reach 9,000 small business customers in 2002. For residential access, SBC would also install PON in a new California housing development. Elsewhere, Brambleton Group LLC has also announced the development of a master planned community in Loudoun Country, Virginia that will feature an FTTH system backed by Verizon Communications. The initial phase of the deployment will cover approximately 700 residences, but it will eventually cover 6,200 residences and businesses. In Canada, Futureway Communications is offering FTTH to over 20,000 homes in Toronto. Internationally, Japan, Sweden and Iceland also have FTTH providers.

In Asia Pacfic, China has the most number of subscribers to fibre access networks, according to IDC. Massive deployment of fibre optic networks have been taking place across the country, spanning both the backbone and local access networks. The main reason can be attributed to the need to compete with the incumbent China Telecom by the other telcos such as China Unicom, China Netcom and China Railway. Currently, without access to China Telecom's local loop, other telcos are choosing to build their networks using fibre so as to better compete with the incumbent. According to IDC, metro ethernet service subscribers reached approximately 132,000 in 2001, which accounts for almost one-third of its total broadband subscribers. This metro ethernet service subscriber figure is expected to reach over 3.8 billion by 2006.

2.4.4 Future Developments and Outlook

Future Developments in MEF Standards. Presently, the MEF divides its efforts into four major areas: protocols and transport, service, management, and architecture. In the protocols and transport area, three areas that are currently being worked on:

- Metro Ethernet Protection Requirement Document, which defines service providers' requirements for deploying Ethernet-based metro networks.

- Protection Framework 1.0, which describes a model and framework to deliver network-protection services.

- QoS Framework that details a QoS network reference model, which includes the metro Ethernet networks (MEN) architecture and QoS functional model/mechanisms that can be applied at MEN to achieve required performance characteristics for any MEF Ethernet services.

In the services area, MEF is chartered to define specific service offerings at the request of service providers. Committees in the services group are working to define Ethernet virtual private line services (EVPLS), Ethernet virtual private LAN services (EVPLnS), and circuit emulation service (CES). The group is also working to define the mechanisms of traffic and performance parameters, including bandwidth scalability over a metro Ethernet network.

In the management area, they are defining the requirements and information models for operation, administration, and maintenance (OAM), element management systems, and network management services. Finally, the architecture area is working to define the framework between end user and service provider.

Future Developments in PON Standards. Presently, the BPON G.983 standard specifies line-rate up to 622Mbps only. On the other hand, the EPON standard promises speed up to 1Gbps and compatibility with the rest of the Ethernet standards. However, the EPON specification is far from complete and needs the blessings of ITU before large-scale deployments can be expected. Furthermore, FSAN (the group that developed BPON) is working on a Gigabit-PON (GPON) standard that will increase the bandwidth specified from 622Mbps into the Gbps range.

Presently, even without approved standards in EPON, we are seeing exciting innovations to increase capacity and improve operating efficiencies. Companies such as Salira Optical Network Systems has already come out with EPON equipment capable of delivering symmetric rates of 1Gbps over distance of up to 20km. Other vendors that have announced EPON equipment include AllOptic, OnePath Networks and Wave7 Optics.

Super-PON. Other possible upgrades of the BPON have been explored. The most notable work is the Super-PON system, which is funded within the European Advanced Communications Technologies and Services (ACTS)[26] projects PLANET and PELICAN. A Super-PON prototype has been developed to achieve bit rates of 2.4Gbps downstream and 311Mbps upstream, a maximum split of 2048, a range of 100km, and a dynamic upstream MAC protocol. This system has already been field trialed in Brussels-Belgium, demonstrating the stability of the Super-

26 More details on ACTS can be found at http://www.cordis.lu/acts/home.html

PON prototype. A cost study, assuming 0.18mm CMOS and Si-bipolar technology for the 2.5Gbps demultiplexer, indicated that this system is expected to be cost effective within 1 to 3 years time[27].

WDM-PON. In the future, Wavelength Division Multiplexing (WDM) techniques will be used to boost the capacity of single-fibre PON strands to as high as 10Gbps. However, we do not expect this technology to be commercially viable in the local access network for at least the next 3 years. DWDM transceivers are still used mainly in Wide-Area-Networks (WAN) and WDM is just beginning to be used in Metropolitan Networks (MAN).

Market Forecast. According to RHK[28], growing demand for bandwidth is expected to create US$4 billion in new revenues by 2006 for North America service providers offereing optical Ethernet services. The report examines the emerging market for Gigabit Ethernet services delivered over the MAN and WAN. Enterprises and specialized service providers with fast-growing bandwidth needs will be the key derivers because Ethernet services are LAN compatible and cost effective.

In the Asia Pacific region (excluding Japan), IDC forecasts that the number of metro Ethernet subscribers will grow from just 0.28 million in 2001 to 9.29 million in 2006, representing a compound annual growth rate (CAGR) of 110%. The market for metro Ethernet services was worth US$395.34 million in 2001 and is set to reach about US$1.5 billion in 2002. It will grow at a 2001-2006 CAGR of 118% to US$19.44 billion. IDC believes that key growth markets will be in China, Hong Kong and Korea. The push of governments and services providers for next generation networks, and the cost effectiveness of deploying fibre in high density housing or central business districts will be the key drivers of growth according to IDC.

Similar to the metro Ethernet, most market analyst firms believe that PON will gradually catch on. According to In-Stat/MDR, worldwide PON equipment revenue will grow from US$67.1 million in 2001 to US$833.5 million in 2006 at a CAGR of 65.5%. In particular, they forecast that by 2006, 50-60% of that year's greenfield (i.e. laying of fresh fibres and activating some of them) developments will have fibre pulled all the way to their homes.

Another market analyst firm KMI[29], predicted that FTTH systems in the US will reach 2.65 million homes by 2006, starting from a base of 89,000 homes in 2001. As a result, the FTTH equipment market will grow from just US$100 million in 2001 to nearly US$1 billion in 2006.

27 P. Vetter et al, "Economic Feasibility of Super-PON Access Networks", Proceedings of ISSLS 98, Venice, March 98, pp. 383-389

28 http://www.rhk.com/

29 http://www.kmicorp.com/

Future Outlook. Optical-based Gigabit Ethernet is expected to take off shortly in the next few years in the business market. Access speed of up to 10Gbps, LAN compatability, and most importantly cost effectiveness will make it the favourite broadband access technology in high density multi-tenant units.

The cost of fibre and optical splitter/couplers has dropped significantly over the last two years and will continue to further over the next few years. Presently, deploying FTTH in certain new housing developments and network rebuilds are already lower than deploying copper, twisted pair or coaxial. In fact, FTTH is experiencing healthy adoption from small towns/cities in the US, which can be attributed to the following reasons:

- Deploying fibre in these areas are less difficult due to fewer roads and few driveways to cross.
- A fibre infrastructure will allow the smaller telcos that service these areas to be competitive and help keep out the bigger players.
- Municipal governments do not want to be left behind technologically without a broadband infrastructure.

However, we note that the cost of fibre installation remains significantly more expensive when compared with copper installation. Furthermore, technology improvements on DSL and cable are expected to meet the end-users' bandwidth needs for the next few years. Therefore, the possibility of FTTH taking off in the next 5 years remains elusive.

3 Wireless Broadband Access Technologies

In this chapter, we discuss last mile wireless broadband access technologies. Technologies that will be covered include terrestrial fixed wireless technologies like radio frequency fixed wireless and free space optics, wireless local area (WLAN) network as a "last mile" and broadband satellite. This category of technologies normally promises rapid and incremental installation by doing away with the need to lay physical wires to customer premises.

3.1 Radio Frequency Fixed Fixed Wireless

3.1.1 Overview of Radio Frequency (RF) Fixed Wireless

Broadband wireless point-to-multipoint communication systems that use radio frequency waves to carry information between a central base station and several subscriber stations are collectively referred to as RF fixed wireless systems. Examples of such systems include the Local Multipoint Distribution Service (LMDS), which generally operates in the 3.5GHz, 26GHz or 38GHz frequency bands, and the Multipoint Multi-channel Distribution System (MMDS), which uses the 2.5GHz band. RF fixed wireless is often touted as a last mile solution that allows service providers to offer broadband connectivity to their customers at a fraction of the cost and time it takes to deploy fibre.

The frequency band in which the RF fixed wireless system operates largely determines its capabilities. At frequencies of around 3.5GHz and below, these systems can exploit multi-path (i.e. the reflection of signals off obstacles) to provide non-line-of-sight capability. In addition, a few of the newer fixed wireless systems incorporate smart antenna technology to increase system capacity, whereby the same amount of spectrum resources can be used to serve a greater number of users. At such low frequencies, radio wave propagation is virtually unaffected by rain. The base station and the subscriber station can be placed more than 20km apart, thus allowing the operator to serve a wide area using relatively few base stations.

Systems operating at the higher frequencies (>10GHz) suffer from attenuation caused by rain and require strict line-of-sight for operation. The radius of such systems can range from 2.5km to 10km depending on the modulation scheme used (which in turn affects the data throughput) and the climate of the deployment region. There is considerably more spectrum available for fixed wireless deployment at higher frequencies compared to, for instance, the 200MHz in total available in the 2.5GHz MMDS band. Current LMDS systems are able to offer data rates of up to 622Mbps at the expense of dedicating a large chunk of allocated spectrum (100MHz to 112MHz) to a single subscriber. Point-to-point millimetre RF links operating at 60GHz are able

to take advantage of the abundance of licence-free spectrum available in that band to deliver beyond 1.25Gbps of throughput. However, such equipment are expensive and range is limited to less than 1km in rain abudant regions such as Singapore.

3.1.2 RF Fixed Wireless Standards

The IEEE 802.16 standard[30], published on 8 Apr 2002, specifies the air interface of fixed point-to-multipoint broadcast wireless access systems operating between 10GHz and 66GHz. Two amendments to this standard are expected to be approved in December 2002:

- IEEE 802.16a, which covers operation in the 2GHz to 11GHz range, including the licence-free 2.4GHz and 5.8GHz Industry, Scientific and Medical (ISM) bands. It may include extensions for a mesh-type topology. China is now deciding whether to adopt IEEE 802.16a as the Chinese national standard for fixed broadband wireless access at 3.5GHz.

- IEEE 802.16c, which covers detailed system profiles for the 10GHz to 66GHz range.

Currently, the 802.16 working group has also started a mobile wireless Metropolitan Area Network (MAN) study group and 802.16 ad-hoc enhancements.

In Europe, the Broadband Radio Access Networks (BRAN) project established by ETSI is currently working on HIPERACCESS, a fixed wireless specification optimised for the 40.5GHz to 43.5GHz band, and HIPERMAN, which is intended for the 2GHz to 11GHz band. BRAN is working closely with the 802.16 Working Group to harmonise their standards

The objective of these standardization efforts is to enable interoperability between different vendor equipment. Network management and resource planning are much easier when the user does not have to worry about interfacing among different vendor management systems. But more importantly, equipment standardization will lead to a significant reduction in the cost of these fixed wireless systems, an outcome that should come as a relief to the operators, some of whom have paid as much as Euro$500,000 for an LMDS base station.

3.1.3 RF Fixed Wireless Global Deployments

2001 was a bad year for RF fixed wireless. LMDS broadband wireless service providers such as Advanced Radio Telecom, who owns a US-wide footprint of 39GHz LMDS spectrum licences,

30 More details on the IEEE 802.16 Working Group on Broadband Wireless Access Standards can be found at http://grouper.ieee.org/groups/802/16/index.html

folded up only a few weeks after executives claimed that the company's US$1,000 a month wireless broadband service was a big hit. Other US service providers like Teligent and Winstar filed for Chapter 11 bankruptcy protection after funding suddenly dried up.

European service providers, most of whom were awarded fixed wireless licenses more than three years ago, had little choice but to try to squeeze a profitable business out of the wireless network they had committed to build in happier times. Operators in Spain and France soon found themselves scrambling for funds and consolidating their spectrum to stay alive. Only 1 out of the 32 German fixed wireless operators is still standing.

The situation was no better in Asia. In Hong Kong, SmarTone's capital outlay was about HK$200 million, but its revenue for 2001 was less than HK$48 million. In fact, its broadband division was responsible for HK$153 million of the company's HK$284 million loss for 2001. PSINet, which has gone bankrupt, sold its Hong Kong operation to local interests. CTI has switched to reselling the incumbent's DSL lines. In Australia, Cable & Wireless Optus uses fixed-wireless only in areas where its fibre network cannot reach.

On the bright side, the newer fixed wireless systems operating at the lower frequencies (2-4 GHz) have been attracting quite a bit of attention lately because of non-line of sight capabilities, cheaper manufacturing cost and minimum rain attenuation. Verizon is conducting field trials of BeamReach Network's 2.3GHz system with a view to using fixed wireless to supplement its DSL service. Sprint is now running trials on Navini's 2.6GHz systems to see if fixed wireless could supplement mobile wireless better than WLAN. Airspan Networks, whose 3.5GHz range of equipment is already being used to provide wireless DSL service to 18 sectors of the Chinese port city of Qingdao, has been contracted to supply US$8.2 million of fixed wireless equipment to provide 24,000 wireless DSL links in South Africa.

3.1.4 RF Fixed Wireless Future Developments and Outlook

Right now, the silver lining in the fixed wireless market appears to lie with the new generation of fixed wireless systems operating in the 1.9GHz to 4GHz frequency range. Thanks to smart antenna technology and advanced modulation techniques such as Orthogonal Frequency Division Multiplexing (OFDM), these systems offer higher spectral efficiency and system capacity, packing more Mbps in the same amount of the spectrum (e.g. almost 4Mbps/MHz up from around 1Mbps/MHz in older systems) without compromising on the coverage area. Non-line of sight operation is now possible as well, simplifying equipment installation at the customer's premises and extending network coverage to areas shadowed by large buildings.

Looking further ahead, vendors such as Nokia, CALY Networks, Radiant Networks and Mesh Networks are developing fixed wireless mesh radio systems that do away with the traditional point-to-multipoint architecture altogether. In a mesh network, there is no central base station. Each node in a network connects to its immediate neighbours and routes its network traffic through them, hopping wirelessly over several nodes before reaching the wire-line network backbone. Mesh radio systems working in the unlicensed 2.4GHz band have already been deployed; systems that operate in the licensed bands will be available soon. Potentially, mesh fixed wireless systems could significantly reduce the amount of capital outlay needed for building out a citywide wireless broadband network. In a point-to-multipoint system, operators have to install expensive base stations all over the city first before signing up their customers. On the other hand, a mesh network can be grown incrementally, expanding its coverage as the number of subscriber increases.

3.2 Free Space Optics

3.2.1 Free Space Optics (FSO) Overview

FSO enables high-speed wireless communication between two locations, delivering fibre-like performance without the fibre (see Figure 8). FSO is often regarded as a fixed-wireless technology, although the term is more frequently used to describe systems that rely on radio waves (not light) to transport information wirelessly between two stationary points. Other wireless transmission technologies, such as WLAN and Bluetooth, allow for a certain range of motion within which communication is still possible. In the case of FSO, both ends of the link must be absolutely stationary; otherwise, the communication could fail.

FSO offers the following advantages:

- FSO transmits data faster than any other wireless technology, at speeds of up to 2.5Gbps.
- FSO eliminates the need to lay cables, offering an optimal connectivity solution for locations characterised by railway tracks, waterways, historical sites or difficult terrain.
- FSO can be deployed in a very short period of time, allowing service providers to accelerate the rollout of their networks.
- FSO can also be removed and redeployed easily, resulting in essentially no stranded capital.
- FSO offers very high transmission reliability over distances of 1km to 2km.

- A cost-effective solution, FSO is cheaper than microwave radios or laying fibre, and eliminates recurring costs and the need for operators to own radio spectrum.

- FSO integrates easily into any existing network; the user is not tied to a specific network protocol.

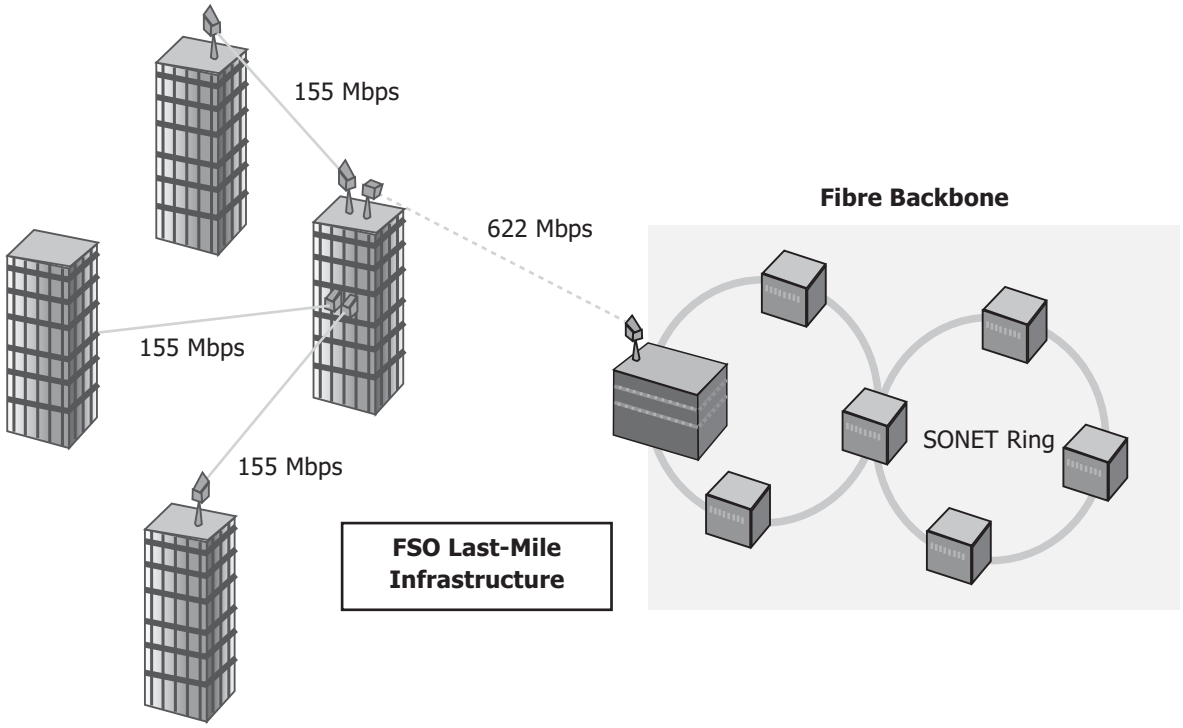

Figure 8. Free Space Optics Being Used to Provide Last Mile Connectivity

FSO systems transmit data from one end to another using a narrow laser beam. A single link consists of two FSO transceivers pointed at each other. FSO systems rely on virtually the same technology that has been used for years to transmit data through fibre optic cables. However, instead of bouncing a weak laser beam within a glass core to transport the light signal from point A to point B, an FSO transceiver transmits a laser beam powerful enough to penetrate the atmosphere ("free-space") and arrive at the intended receiver up to several kilometres away. However, for the communication link to function properly, the receiver must be able to see the narrow beam of light arriving from the transmitter at the other end. This is reason that the transceivers have to be fixed in position; even small movements could cause the laser beam to swing out of the receiver's view and break the link.

Unfortunately, free-space is a hostile and unpredictable medium for data transport. Because no conduit is used to contain and guide the laser beam, much of the light transmitted is

spread out to the extent that the receiver manages to collect a only small fraction of this energy. In addition, rain, fog and other weather phenomena can cause severe and sometimes unpredictable degradation to the link.

3.2.2 FSO Standards

As FSO transceivers are always sold in pairs, the issue of interoperability among transceivers from different FSO manufacturers never crops up. As it is, users have the option of mixing and matching FSO links from different vendors with no impact at all to his or her network configuration, since FSO links essentially behave like physical wire connections. Although it may be desirable for a user to be able to replace a malfunctioning transceiver with a transceiver from a different vendor, it is not clear that this additional benefit would justify the efforts needed to put standards in place.

The closest thing the FSO community has to a "standardization" body is the Free-Space Optical Alliance[31], established to provide a unified FSO strategy position to the technical community. The alliance, supported by virtually all the major FSO vendors, aims to make available FSO-related information for the purposes of conveying the technical and operational criteria, business application, safety, and market opportunity of this technology, as well as to correct misunderstandings or misinterpretation of FSO technology encountered in published articles.

3.2.3 FSO Global Developments

The FSO industry is relatively young. PAV Data Systems, one of the most established vendors with many reference sites worldwide, was established only in 1994. Within the span of a few years, many companies have entered the fray, largely encouraged by the relatively low barrier to entry: A simple FSO transceiver can in fact be put together using commercial off-the-shelf items. Today, one can easily count at least a dozen FSO manufacturers, ranging from Japanese electronics giant Canon to small German start-ups such as CBL and GoC.

In such a crowded market, strategic marketing and product differentiation are key. LightPointe, whose founder and Chief Technology Officer have co-written the first book on FSO, is arguably the most visible FSO vendor today. Together with AirFibre, these two vendors have embarked aggressively on their independent marketing campaigns to specifically address the concern that FSO might not be able to provide telcos with carrier-class reliability. Other vendors, such as LaserBit and smaller outfits such as Silcom and Plaintree, offer no-frills systems at prices

31 Free-Space Optical Alliance website: *http://www.fsoalliance.com*

lower than those of their competitors. And there are companies, such as Holoplex and AOptix, who incorporate unique cutting-edge technologies into their transceivers, claiming they can offer higher transmission reliability than is possible with conventional technology. Another noteworthy FSO vendor is Terabeam, who has gone beyond the role of equipment manufacturer by becoming a service provider as well.

Many of the major FSO vendors in the world have regional offices or are represented by system integrators in Singapore. These vendors include AirFiber, Canon, CableFree, LaserBit, LightPointe, OpticalAccess and PAV.

3.2.4 Future Developments and Outlook

Future Developments. The research and development efforts in the FSO industry are directed towards three main areas: increasing data throughput, moving beyond the point-to-point architecture, and improving transmission reliability. The last area is of particular interest because of the significant impact bad weather has on the laser beam. Since it is impossible to manipulate the environment to reduce the amount of signal attenuation, researchers are looking at ways of enhancing the characteristics of the laser beam such that it can transport light energy more efficiently and yet still remain safe to the human eye.

- **Wavelength Division Multiplexing**
  Wavelength Division Multiplexing (WDM) refers to the use of more than one optical wavelength to transport data over a single medium. WDM technology is already being used in optical networks to pack as many as 80 wavelengths into a single strand of fibre. An experimental WDM FSO system with an error-free throughput of 40Gbps over a transmission distance of 4.4km was demonstrated by a team of researchers from Lucent and the California Institute of Technology back in 1999[32]. The system consisted of 16 tunable lasers, each transmitting data at 2.5Gbps at a wavelength between 1548.6nm to 1573.2nm.

  Although the technology seems to be ready—LightPointe has already announced its intention to offer a 10Gbps (4x2.5Gbps) FSO system—WDM FSO system development has not been given a high priority because there appears to be very little demand at present for such high capacity FSO links.

- **True Point-to-Multipoint Capability**
  Unlike MMDS or LMDS, FSO is, strictly speaking, a point-to-point system. Each transceiver is capable of communicating with only one other transceiver; there is no base-station/

32 G. Nykolak, et. al., "A 40 Gb/s DWDM Free Space Optical Transmission Link Over 4.4 km", *Free Space Laser Communication Technologies XII*, Proc. SPIE Vol. 3932, 2000.

remote-station distinction, nor is there any form of medium access control (MAC) layer or data multiplexing.

Since 1997, QuantumBeam, a spin-off from the Generics Group, has been working on an FSO system that is truly point-to-multipoint. Its solution involves a hub that contains a pixellated electro-optical array but no laser element. The customer premises equipment (CPE) shoots a laser beam toward the hub, where it is picked up by one of the elements in the electro-optical array, modulated with data for the return path, and then reflected back along the exact same path to the CPE. Up to 1Gbps can be delivered to each user over a distance of around 200m. Full-scale beta trials are expected during the first half of 2002, with full commercial deployment possible by late 2002 or early 2003.

- **Enhanced Optics**
  AOptix has announced an FSO transceiver that incorporates adaptive optics, the same technology that allows terrestrial observatories to produce ultra-sharp images of the universe rivalling those taken by the Hubble Space Telescope. Holoplex, another vendor at the cutting edge of technology, will be offering an "Enhanced FSO" system that uses an ultra-collimated beam stabilized by an active tracking system. The beam has a divergence of only 30 micro-radians, or about a hundred times smaller than that of the other FSO systems on the market today. Both vendors claim their system will provide substantially more link margin than what conventional FSO systems can offer. More vendors will certainly incorporate such advanced features into their systems within the next year or so. LightPointe is likely to be next in line, having already declared its intention to develop an advanced beam-tracking system based on Micro-Electro-Mechanical Systems (MEMS) mirrors.

Market Forecast. Depending on the date of publication, the downturn of the global telecommunications industry has resulted in market analyst firms making increasingly conservative forecasts. For example, according to a broadband access technologies report published by Merrill Lynch & Co. in May 2001, analysts predicted sales would reach US$2 billion in 2005. The IGI Group, which made a FSO market forecast during the same period, even expected sales to reach US$3.2 billion by 2005. Another report published by Strategis Group in Sep 2001 forecasted sales would reach US$2 billion in 2006. A later report, published by Frost & Sullivan in March 2002, reported more conservative figures. They forecasted FSO revenues would grow from a base of US$71 million in 2001 to $215 million by 2005.

Future Outlook. We expect the initial surge in FSO adoption to come from local corporations or institutes looking for a low-cost and rapidly deployable means of providing very high-speed connectivity between buildings. These buildings might be situated close to one another on a campus or in an industrial park, or could be more than 1km apart within a heavily built-up city

district. As long as there is guaranteed line-of-sight, the link could even be set up from one office window to another, eliminating the need to access the rooftop and the telecom riser altogether.

FSO will truly gain prominence in Singapore when service providers begin using FSO links on a large scale as part of their core infrastructure. For example, a mobile cellular operator needs a network to link up its mobile switching centres (MSC) to its base station controllers (BSC), which are then linked to the individual base transmitter stations (BTS). Operators who do not own their own wire-line infrastructure need to rely on lines leased from a competitor who does. This approach may suffice for the narrowband-leased lines used in today's 2G GSM networks but may prove too costly for more advanced 3G cellular networks that require higher capacity lines. Mobile cellular operators in Singapore already have access to plenty of rooftop space where their GSM base stations are. These locations will make a good starting point for rolling out an FSO network.

Apart from expanding their mobile cellular networks, operators can also use FSO technology to provide high-speed leased line services to commercial buildings. Almost all commercial buildings in Singapore are connected to fibre, but most tenants are unwilling to pay tens of thousands of dollars per month for a 155Mbps line. Indeed, emerging competitive service providers will realize how rapidly they are able to use FSO to build out a broadband infrastructure whose performance and reliability rival that of underground fibre networks owned by the incumbents. These service providers can use their wireless network to offer high-speed leased line services at attractive rates to small and medium enterprises (SME), bypassing the dominant players altogether. This will introduce competition in the local access market. The current price for broadband local access for an SME is quite high and can become a barrier to the pervasive use of Internet to offer commercial services.

3.3 Wireless Local Area Network (WLAN)

3.3.1 Overview of WLAN as a Last Mile Solution

WLAN was initially designed to work as a wireless extension of wired LANs. The first IEEE 802.11 standard for WLAN appeared in 1997. At that time, the standard supported wireless speed of 1Mbps to 2Mbps utilizing both Frequency-Hop Spread Spectrum (FHSS) and Direct-Sequence Spread Spectrum (DSSS) techniques within the 2.4GHz ISM band. Unfortunately, the inadequacy of these speeds hindered wide acceptance of the standard. Subsequently, the standard was revised to 802.11b with speed of up to 11Mbps using DSSS modulation techniques. With higher speeds, this technology gained wider acceptance from vendor and consumers. Currently, WLAN is emerging as a feasible technology for last mile broadband

access. Some even see it as an alternative technology for 3G in providing mobile data service. With its increased scope of usage, a whole family of 802.11 standards is being defined to address the various related issues.

In this section, we will focus on how WLAN can become another alternative last mile access solution. Hotspots/hotzones deployment, community connections, and full commercial services to business and residential customers will be considered. However, we will not cover WLAN with respect to in-building connectivity, which will be covered in greater detail under "The Connected Home" report.

3.3.2 WLAN Standards Development

There are three issues facing WLAN: consistent roaming across all sites, security and QoS must be addressed. In this section, we will look at the standardization activities in these three areas.

Roaming. Task Group F of the 802.11 Working Group is working to develop an Internet Access Point Protocol (IAPP) that allows multi-vendor Access Point (AP) interoperability. Strictly speaking, this standard will not allow roaming, but sets the foundation for roaming through a multi-vendor infrastructure.

The other major WLAN standards in the market is the European HiperLAN standards. IEEE and ETSI have started a working group called IEEE 802.11j and 5UP respectively to harmonize both standards in the 5GHz band. This effort will make worldwide WLAN interoperability feasible.

The Wireless Internet Service Provider roaming (WISPr) subcommittee under the Wireless Ethernet Compatibility Alliance (WECA) is working on a Best Practices Document for WISP roaming. WECA focuses its efforts exclusively on the IEEE 802.11 family of standards.

Another group that is entering the roaming standardization race is Pass-One, an industry group consists mostly of WISPs and some WLAN equipment vendors. Pass-One members sign a multi-lateral roaming agreement when they join this group. Presently, Pass-One has a broader technology scope than WISPr because it will deal with roaming to other broadband wireless technologies such as GPRS and 3G. Besides technology issues, Pass-One will also address business and legal issues related to implement global roaming agreements.

Worthy of mention includes the Generic Interface Standard (GIS) of iPass[33]. iPass has released a free GIS for products supporting roaming, hoping this will help it leap-frog other efforts to become the de-facto roaming standard.

33 http://www.ipass.com/

Standard	Description	Status
Roaming		
IEEE 802.11f	Develop recommended practices for an Inter-Access Point Protocol (IAPP), which provides the necessary capabilities to achieve multi-vendor Access Point interoperability across a Distribution System supporting IEEE 802.11 WLAN Links.	Expected completion in 2nd half of 2002.
IEEE 802.11j, 5UP	An effort to converge 802.11 and HiperLAN standards to permit interoperation in the 5 GHz band.	Committee forming
WISPr sub-committee under WECA	Develop recommended practices for WISP roaming. The focus is on 802.11 family of technologies.	Working on Best Practices document for WISP roaming
Pass-One	Develop recommended practices for roaming between WLANs and other "broadband wireless technologies" such as GPRS and 3G.	Also address business, technical and legal issues that are required to implement a global roaming agreement.
Generic Interface Standard	Propriety standard from iPass, seeking to be de-facto standard.	Available
Security		
IEEE 802.11i	Enhance the 802.11 Medium Access Control (MAC) to include security and authentication mechanisms.	Expected completion in 2nd half of 2002.
Quality of Service		
IEEE 802.11e	Enhance the 802.11 Medium Access Control (MAC) to improve and manage QoS and provide classes of service. These enhancements should provide the quality required for services such as IP telephony and video streaming.	Expected completion in 2nd half of 2002.

Table 4. WLAN Standardization Activities in the Areas of Roaming, Security and QoS

Security. The failure of Wired Equivalent Privacy (WEP) algorithm of the IEEE 802.11 standard to protect communications from eavesdropping and other forms of security attacks has made security the major weakness of WLANs. Task Group I of the 802.11 Working Group is working to enhance the 802.11 Medium Access Control (MAC) to improve security. This standard will apply to the physical standards 802.11a, 802.11b and 802.11g. Among the proposals to enhance the security of WLANs includes Temporal Key Integrity Protocol (TKIP) and the Advanced Encryption Standard (AES) algorithm. Products rollout will begin with firmware upgrades using the TKIP. Adoption of AES will be later because it requires major hardware replacement.

Quality of Service. Task Group E of the 802.11 Working Group is working to enhance the 802.11 Medium Access Control (MAC) to provide classes of service with managed levels of QoS

for data, voice and video applications. These enhancements should provide the quality required for services such as IP telephony and video streaming.

Others. Presently, most of the global WLAN hotspots deployments are based on the IEEE 802.11b standard, which operates in the 2.4GHz range and has data rate of up to 11Mbps. There are two standard efforts to increase this data rate to 54Mbps, which are the IEEE 802.11a and the IEEE 802.11g. The 802.11a operates in the 5GHz and is not backward compatible with 802.11b. This standard was completed in 1999 and products are availabe since 2001. On the other hand, the 802.11g operates in the 2.4GHz and is backward compatible with 802.11b. This standard is expected to be completed in 2003.

3.3.3 Global Deployment

WLAN hotspot numbers are growing rapidly with deployment announcements being made almost weekly. Presently, WLAN hotspots can be found in many places such as airports, hotels and restaurants[34]. According to Cahners In-Stat, US has around 4,100 hotspots today, and this number is expected to reach 41,000 by 2006.

Presently, many players are moving into the public hotspot space, despite the demise of MobileStar. Worthy of mention is hotspot aggregator Boingo Wireless[35], which has more than 600 partner access areas in United States. Among its partners are companies like Wayport (460 hotels and 4 airports) and Surf and Sip (126 coffee-shops). Recently, Airpath Wireless, a company offering wireless Internet access in public spots and in residential set-ups, also announced their partnership with Boingo.

In Europe, public WLAN have been rollout by providers like Sonera (Finland), Telia (Sweden), and Telenor (Norway), with announcements from other companies including British Telecom (United Kingdom) and Jippii (Finland). In particular, Telenor has announced that it is set to deploy Europe's largest WLAN-enabled campus, at its new Fornebu headquarters, which occupies 137,000 square meters.

In Asia Pacific, many public hotspots are providing high-speed Internet access via WLAN connectivity. For example, most international airports in Asia Pacific, Chek Lap Kok (Hong Kong), Changi Airport (Singapore), Inchon International (South Korea), Nino Aquino International (Philippines) and Kuala Lumpur International Airport (Malaysia) are already fitted with such services. Many top class hotels in the region are also dishing out WLAN services to

34 A detail lists of North America WLAN hotspots can be found in http://www.80211hotspots.com/

35 http://www.boingo.com/

its guests. High speed Internet access provider for the hospitality industry, inter-touch, rolled out WLAN in hotels, such as ANA Harbour Grand Hotel Sydney and a host of others in Australia, Hong Kong and Singapore.

On a metro scale, incumbent South Korea carriers Korea Telecom and Hanaro Telecom have embarked on ambitious plans to wirelessly network key locations in the city center. Korea Telecom has identified subways, universities and shopping malls in the Korean metropolitan areas and aims to build a wireless cloud with 10,000 access points. Hanaro also has plans to install 15,000 hotspots in Seoul.

3.3.4 Future Developments and Outlook

Future Developments. We see the future developments of WLAN in three directions.

- **WLAN/Wireless Wide Area Network Roaming**
  Seamless roaming between WLAN and Wireless WAN, like GSM, GPRS, WCDMA and CDMA2000, is expected to become the norm in the future. One of the earliest products that provide such a roaming architecture is ROAMMATE from NetSeal[36] . Another notable example is the Cisco Internet Mobile Office (CIMO) solution[37]. More recently, cell phone companies such as Qualcomm and Nokia have announced plans to integrate Wi-Fi features into their mobile chipsets. Cell phone companies view Wi-Fi as a way to boost the coverage reliability and usefulness of upcoming 3G networks. Further down the road, WLAN roaming across other disparate networks, nationally and internationally can be expected.

- **WLAN Billing**
  Another important development is in **billing**. The challenge is to provide the end user a single bill when he roams across several WLAN operators. Currently, different WLAN operators implement different billing solutions. The most popular billing solutions among WISPs are credit cards and pre-paid cards. Other alternative models include the use of a third party payment service provider like PayPal, leveraging on the payment solutions of WLAN hotspot aggregators like Boingo, and/or incorporating WLAN access as an item on the customers' bills. For example, a hotel guest will pay its WLAN access fees together with its hotel bills at the time of checkout. Transat and Intel are developing an interesting solution to this challenge. Their solution is to allow users of smart card enabled products, such as GSM mobile phones, to use the same card for advanced authentication on public WLAN "hotspots". The plan is for Intel-based PCs running on networks with Transat's embedded

36 http://www.netseal.com/

37 http://www.cisco.com/

software to roam across different wireless networks but receive only one bill at the end of the day. The roaming and authentication would be based entirely on that used by 3G/GSM mobile phones using smart cards embedded in the product accessing the network.

- **Ad-hoc WLAN Networks**
  WLAN can potentially be used to create ad-hoc networks in remote areas, bypassing the need for a cellular network infrastructure. Currently, most of the WLAN implementations use AP in infrastructure mode, where more than one client shares one AP to access the local area network. Another application of WLAN is in a point-to-point direct link transmission, where the signal can be transmitted across distance of up to 25km. Coupling these two modes of operation allows WLAN to create an ad-hoc network. In Chile, this mode of deployment was recently used to do volcanic monitoring.

Market Forecast. According to Juniper[38], revenue from the WLAN public hotspots market has reached US$278 million by 2002, of which US$219 million came from North America. By 2007, Juniper forecasts the market to be worth just under US$9.7 billion with the West Europe region overtaking North America to lead with approximately US$2.75 billion. On the other hand, the service revenue from the "last mile" WLAN[39] market has reached US$216 million by 2002, of which US$201 million came from North America. By 2007, Juniper expects the market to be worth just under US$5.5 billion. Juniper's figures show growth in all global regions with North America leading with approximately US$1.87 billion.

In another more optimistic projection, In-Stat/MDR[40] has projected that by 2005, worldwide sales of WLAN equipment will surpass the US$5 billion mark from US$1.78 billion in 2001. Other notable projections from In-Stat/MDR includes the number of hotspots that will reach approximately 41,000 worldwide by the end of 2006 and the number of WLAN chipsets for portable devices will be over 30 million by 2006, far exceeding the 8 million chipsets estimated for cellular access.

Outlook. WLAN have achieved huge success in many enterprise and home deployments. However, public WLAN "hotspots/hotzones" deployments in restaurants, coffee shops, shopping centers, airports and hotels, are expected to fuel its next-wave of growth. Much has been said about the standards and technology developments in trying to achieve seamless roaming. Currently, mobile operators like Nextel, British Telecom and NTT DoCoMo have jumped onto the Wi-Fi bandwagon.

38 http://www.juniperresearch.com/

39 This is defined as Wireless Internet Service Providers offering community connections, or full commercial services to businesses and residential customers.

40 http://www.instat.com/

Migration to the higher data rate 802.11a and 802.11g standards can also be expected to take off in the next 2 to 3 years. We believe the 802.11g standard will eventually become more popular than 802.11a mainly because it is backward compatiable with the popular 802.11b standard.

Over the next few years, the popularity of WLAN technology will also drive the chipsets supporting wireless access in portable devices, especially in equipments like notebook computers and PDAs. Recently, Toshiba, Panasonic and NEC have announced projectors with Wi-Fi connections. In future, electronic equipments with Wi-Fi connections will proliferate.

Another emerging area of growth is voice-over-WLAN (VoWLAN). Currently, voice-over-IP (VoIP) are implemented in many corporations. In the near future, the convenience of WLAN technology will make VoWLAN an attractive alternative telephony tool. According to Cahners In-Stat/MDR, VoWLAN handset shipments will increase to 80,000 in 2002, up from 20,000 in 2001. This will eventually reach 500,000 shipments units by 2006. Currently, major vendors in this area include Symbol and Spectralink.

Competing Technology - Ultra WideBand (UWB). Recently, there is talk about Ultra WideBand (UWB) as a potential replacement of WLAN and as a potential last mile access technology in the future 5 to 7 year timeframe. UWB is a wireless technology for transmitting digital data at extremely high-speed (between 50Mbps to 1Gbps) at low power levels (less than 0.5 milliwatts) for a short distance (up to 10m)[41]. The February 2002 Report & Order of FCC allowed for unlicensed marketing and operation of UWB in the US under certain restrictions. There is no standards yet for this technology, but the IEEE 802.15 SG3a working group is working towards defining a high-speed PHY enhancement amendment to the existing IEEE 802.15.3 Personal Area Network (PAN) standard. This standard is expected to be completed in 2004, implying that standards-based product for PAN may begin to roll-out in 2005.

Progress of UWB to become a last mile access technology is not feasible yet due to restrictions on its power emission level. This is because UWB can cause noise pollution over large span of frequency spectrum, potentially affecting Global Positioning System (GPS) and radar systems. Until UWB vendors can provide that their equipments can co-exist well with other technologies, it is unlikely that regulators like FCC will allow higher UWB emission levels.

41 For more details, please refer to "The Connected Home" report.

3.4 Broadband Satellite

3.4.1 Overview of Broadband Satellite

Broadband satellite communications refer to two-way communications and broadcasting conducted via satellites orbiting around the earth. Broadband satellite systems can be broadly grouped into two categories: the Geostationary Earth Orbit (GEO) system and the Low-Earth Orbit (LEO) system. GEO satellites orbit at 36,000km altitude. Presently, GEO systems operate in the Ku-band, but Ka-band systems can be expected very soon (see Figure 9(a)). On the other hand, LEO satellites orbit at 700km to 1400km altitude. LEO systems require 40 to 300 LEO satellite constellations, with Ku-band or Ka-band transponders, spot-beams and inter-satellite links (see Figure 9(b)).

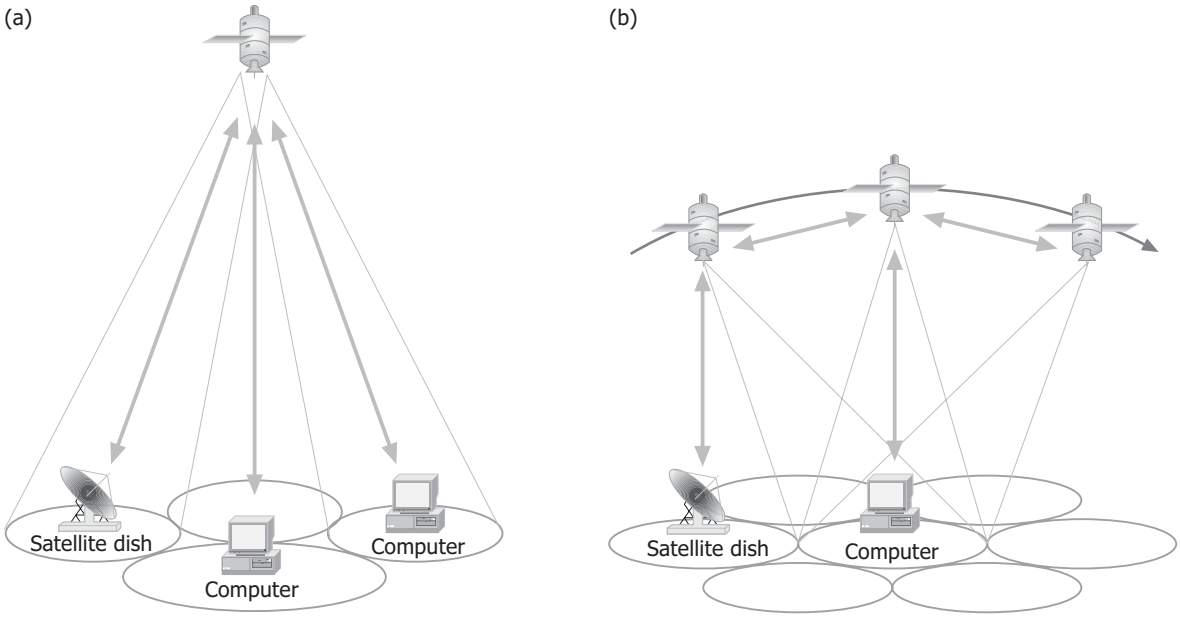

Figure 9. (a) Two-way Broadband GEO System (b) Two-way Broadband LEO System

There are several advantages associated with satellite. The key advantage is its ability to provide communications at virtually any granularity of speed to anywhere. The inherent broadcast architecture also makes it an excellent point-to-multipoint delivery. Furthermore, the ability of satellite to reach anywhere quickly allows it to provide non-broadcast service to locations not served by other means.

Two key factors have influenced the demand for broadband satellite solutions. Firstly, the use of broadband access and applications has increased and satellite solutions are a good broadband access technology for remote areas. Secondly, remote areas in countries, especially Asia, without an advanced telecommunications infrastructure are willing to employ satellite solutions in a bid to keep up in the high-tech race.

3.4.2 Standardization Activities

There are several standardization activities in the area of broadband satellite.

Digital Video Broadcast – Return Channel System (DVB-RCS). An initiative of the Digital Video Broadcasting Project (DVB)[42]. The DVB-RCS specification is a broadband satellite standard that adds a two-way interaction path to the established DVB-S broadcasting system. It uses the DVB-S[43] as a forwarding channel, with no changes to the coding and modulation specifications. Transparent satellite transponders at the Ku-band are assumed. Typical transmit capabilities for a terminal is in the order of a few hundred kbps to a few Mbps. Receive rates are as DVB-S receivers in the order of 40Mbps to 50 Mbps. The return link has the capability to adapt coding to individual requirements, and framing can be either MPEG (188 bytes) or ATM (53 bytes).

European Telecommunications Standards Institute (ETSI). The Satellite Earth Stations and Systems Technical Committee (TC SES), is the focal point in Europe for standardization activities of satellite systems[44]. There are several working groups relevant to broadband satellite systems, but the most notable one are: WG Ka Band and WG Broadband Satellite Multimedia (BSM). The Ka-band working group builds on the harmonized standards that are essential for the co-existence of several satellite systems, while the BSM work group works on issues related to Internet via satellite.

Internet Engineering Task Force (IETF). The TCP over Satellite Working Group was charged with addressing issues affecting TCP throughput over satellite links. The working group is closed and has produced two RFCs:

42 DVB is an industry-led consortium of over 300 broadcasters, manufacturers, network operators, software developers, regulatory bodies and others in over 35 countries committed to designing global standards for the delivery of digital television and data services. For more details, please refer to http://www.dvb.org/

43 DVB-S is the industry standard for satellite forward link. It was designed for video MPEG-2 transmission.

44 For more details, please refer to http://www.etsi.org/ses/

- Enhancing TCP Over Satellite Channels using Standard Mechanisms, RFC 2488.

- Ongoing TCP Research Related to Satellites, RFC 2760.

Telecommunications Industry Association (TIA). The TIA of US has two sub-committees looking into standards development of satellite communications: TR-34.1 and TR-34.2[45]. TR-34.1 looks into issues such as interoperability among satellite and terrestrial systems and among satellite systems and services. While, TR-34.2 looks into the efficient use of spectrum and orbit resources for satellite communications systems. The work of TR-34.2 includes both space and earth segments of satellite communications systems and networks.

International Telecommunications Union (ITU). Both ITU-T and ITU-R has relevant projects in the satellite area[46]. The most notable project is the ATM via Satellite, which defines "Performance for B-ISDN ATM via Satellite" and "Satellite Link Performance for Transmission of IP".

3.4.3 Global Deployment

For over fifteen years, satellite access has been offered through Very Samll Aperture Terminal (VSAT) technologies. Currently, two players dominate the VSAT industry: Hughes Network Systems (HNS)[47] and Gilat Satellite Networks[48]. Each uses its own proprietary equipment, and each company is increasingly focused on services instead of equipment sales. As the installed base of VSAT subscribers strains the limits of existing systems, both HNS and Gilat are actively researching ways to cost-effectively extend the platform capabilities to address the consumer access market. Although these vendors have alternative solutions for extending forward-channel (from a central site to the remote users) data rates, they are still working on a corresponding extension of return channel capabilities. Current implementations are limited to 256kbps return channels, each shared by multiple subscribers.

Currently, the use of satellite as a broadband technology is slowly gaining traction. Existing Ku-band broadband Internet providers, DIRECWAY and StarBand Communications announced approximately 100,000 and 40,000 broadband satellite service subscribers respectively at the end of year 2001.

45 For more details, please refer to http://www.tiaonline.org/standards/sfg/scope.cfm

46 For more details, please refer to http://www.itu.int/home/index.htm

47 http://www.hns.com/

48 http://www.gilat.com/

In the Asia-Pacific region, two projects that may point the way to satellite's future in the broadband world are the pending launches by New Skies Satellite[49] and Shin Satellite[50]. New Skies Satellite expects to launch its new bird, NSS6, in late November or early December this year. The new satellite has 60 Ku-band transponders in six spot beams and is tailored towards multimedia services. Shin Satellite plans to launch its iPSTAR satellite in 2003. So far, it has managed to convince a number of operators in the region of the merits of iPSTAR. Former Indian incumbent Videsh Sanchar Nigam Limited (VSNL) has signed a MoU to provide an Internet backbone and international private leased circuits. China's newest telecommunication carrier, China Railway Communications, has inked a deal for 20% of iPSTAR's capacity. Shanghai VSAT Network Systems (SVC) has also signed an agreement to become an iPSTAR national service provider in China.

3.4.4 Future Developments and Outlook

Future Developments. The next generation broadband satellite technology lies in the Ka-band systems. Ka band is a new frequency band that enables higher bandwidth communications. It operates in the 17.7 GHz, 21.2 GHz, 27.5 GHz and 31 GHz spectrums and is widely seen as the optimal spectrum for delivering two-way broadband satellite Internet services. Presently, commercial roll-out of Ka-band systems are expected in 2003. A significant drawback is that the Ka band is more weather sensitive. Areas subject to extreme rain or snow may have difficulty receiving satellite signals under those conditions.

Market Forecast. According to Northern Sky Research[51], global broadband satellite subscribers are expected to reach 4.35 million in 2007 from a base of 0.59 million in 2002. The Asia market will be increasingly more important, with huge opportunities in large market such as India and China. Specifically, the Asia share of the global satellite market is expected to rise from 11.1 % from 2002 to 20.4 % in 2007. In terms of revenue, global broadband satellite service revenues are forecast to reach US$4.3 billion in 2007 from US$1.05 billion in 2002. Out of this pie, the Asia market will account for 23.1 % in 2007, up from 15.6 % in 2002.

Future Outlook. Overall, we feel that the market for broadband satellite lies in areas of **providing Internet access in remote areas with poor or no wireline telecommunications infrastructure.** This is because wireline broadband access

49 http://www.newskies.com/

50 http://www.thaicom.net/

51 http://www.northernskyresearch.com/

technologies, like DSL and cable, can offer higher bandwidth without the latency problems inherent ot GEO satellite systems. In addition, the CPE and monthly subscription cost for DSL and cable are generally cheaper than those for satellite. Therefore, present broadband satellite systems cannot compete effectively with wireline broadband alternatives. However, most parts of the world still do not have a high capacity backbone telecommunication infrastructure. With increasing urbanization in many parts of the world, especially in China and India, satellite communications will become increasing relevant over the next few years.

On the horizon, we believe another emerging market for broadband satellite lies in **offering Internet services on planes.** Currently, European-based international carriers British Airways and Lufthansa have announced plans to launch Connexion, a broadband Internet service developed by Boeing. Lufthansa will begin offering the service on a trial basis in January 2003, while British Airways has begun a three-month trial in February 2002. Connexion uses satellites to send and receive data from transceivers mounted on airplanes. The in-flight broadband technology offers Internet services via Ethernet. According to Boeing, American, Delta, and United Airlines are also committed to delivering broadband onboard service, but could not say when these airlines might be offering the service.

4 Singapore Landscape

4.1 Local Telecommunication Cluster

4.1.1 Overview of Industry

Despite the global economic downturn and the exit of several players, the telecom industry continues to see an increase in the number of Facilities-Based Operators (FBOs) and Services-Based Operators (SBOs) over last year. There are about 35 FBOs and 620 SBOs licensees. Among the players are global names such as MCI WorldCom, Reach and France Telecoms Long Distance.

In terms of international connectivity, Singapore has become one of the most connected cities in the world. Singapore has direct internet connections to over 30 countries with more than 90Mbps to each key regional markets, such as Australia, China, Hong Kong, India, Japan, South Korea and Taiwan, making us one of the most connected business capitals around. Singapore has an extensive submarine cable network comprising of pan-Asian cables like APCN2, C2C, EAC2, and i2i, among others. Singapore's total cable capacity is over 21Tbps.

Singapore has around 20 Internet Data Centers (IDCs) in operation. Content and service providers can choose from a wide range of competitively priced services. Some of the leading IDCs have regional and international points of presence and use Singapore as a gateway to the region. NTT Communications, for example, launched its S$23.5 million IDC in Singapore in Jul 2001. The center is an integral part of NTT's global IDC network.

Wireline Broadband Access Technologies. ADSL and cable modem access are the dominant broadband access technologies in Singapore. SingNet (together with SingTel Magix) is the leader in the ADSL market, followed by Pacific Internet. On the other hand, StarHub Cable Vision (formely known as Singapore Cable Vision) is the only player offering broadband cable Internet access through MaxOnline. In recent months, competitive pricing has boosted the growth of the broadband subscriber market. Unlimited accesses bundled with a range of value-added services are the norm now. According to SingNet, ADSL has overtaken cable as the dominant broadband access technology at first-half of 2002[52].

SP Telecom, a subsidiary of Singapore Power, has embarked on a extensive market trial at 14 different sites in Singapore to test out the actual technical and commercial aspects of PLC.

52 Leo Kee Chye, "Broadband sales seen pipping dial-up", Business Times, 19 Sep 2002

The market trial, serving some 300 users, aims to gather feedback from users from various segments of the markets, ranging from HDB, Private Apartments, Landed Properties, JTC and HDB Industrial Users, Commercial Building Users, on any interference caused by the use of the technology or safety issues they may have when used within their home or offices. This market trial will also be used to provide a real operational environment for SP Telecom to test the PLC based network as an open and neutral access platform for Service Providers to reach their customers.

Optical fibre access service has been offered in Singapore since late 2000, but has not really taken off. SingTel has the GigaWave and MegaPOP service, while Starhub has the StarHub IP.Q.

Wireless Broadband Access Technologies. Fixed Wireless Access services have not been commercially launched in Singapore. There was much enthusiasm initially with a number of service providers participating in LMDS trials conducted in 2000. However, when a spectrum auction was launched in Sep 2001, there were no takers. Technical issues of LMDS coupled with the economic downturn played an important part in lack of takers. Recently, IDA successfully conducted a FSO trial. Results were positive and future broadband services based on FSO technology is expected to take-off.

The number of WLAN hotspots available in Singapore has doubled to more than 40 in the last year. And the number of public WLAN service providers has increased to eight, up from one last year. According to a recent study by Frost & Sullivan, Singapore's WLAN market will be worth more than US$15 million in 2002. Wireless broadband service provider Bluengine launched managed WLAN services since 2001. Currently, IDA is working with Bluengine, Pacific Internet, Starhub, GRIC Communications and other key industry players to develop a roaming platform for WLAN access in Singapore, so that users can utilize hotspots in various locations owned by various service providers, with the one single account through roaming agreements.

Satellite communications is not seen as an attractive access technology in Singapore due to the extensive wireline coverage of over 99%. Its usage remains limited to off-shore ships and planes.

4.1.2 Broadband Access Service Providers

The three dominant broadband access service providers (BASPs) in Singapore are SingNet, Pacific Internet, and Starhub.

SingNet. The incumbent telecommunication operator, SingTel, used to operate two BASPs in Singapore – SingNet and SingTel Magix. SingTel Magix has recently been merged into SingNet.

SingTel Magix launched its ADSL services in 1997, while SingNet launched its ADSL services in Oct 2000. After an initial head start in the broadband market, SingNet lost its lead in the broadband access market to Singapore Cable Vision (SCV), now known as StarHub Cable Vision. Over the last 12 months, SingNet has been cutting their prices for broadband access services and has successfully regained the market leadership position. Unlimited access has now become the standard broadband service package. Equipment is typically bundled in for free and value-added services such as content filtering (for residential subscribers) and security services and IP-VPN or WLAN networking are offered to corporate subscribers. SingNet also offers broadband access packaged with video-on-demand services.

SingTel also offers optical fibre broadband access service through GigaWave and MegaPoP IP suite of services. These service target the larger companies, while the less expensive ADSL offerings target the SME market.

On the wireless front, SingTel has announced the launched of SingTel's *Outdoor Wireless Surf* service in Sep 2002. This means that more than 300,000 SingNet users and over one million SingTel Mobile postpaid customers in Singapore can now enjoy immediate and convenient wireless broadband Internet access at over 100 wireless surf zones nationwide. SingTel will have at least 150 wireless surf zones by the end of 2002. This WLAN infrastructure will also be offered to other operators and ISPs on a wholesale basis.

StarHub Online. StarHub has an FBO license to operate fixed and mobile telecommunications services in Singapore. With the recent acquistion of Singapore Cable Vision (SCV), it now has two arms offering broadband access: StarHub Internet and MaxOnline.

StarHub acquired its first Internet arm through the purchase of Cyberway Ptd Ltd on 21 Jan 1999 and rebranded its Internet Services under the StarHub Internet banner. StarHub has over 16,000km of fibre network across the island. As early as Nov 2000, they have launched a metro Ethernet service, called StarHub IP.Q, over their own fibre network. The service targets corporate customers. Depending on the requirements, bandwidth ranging up to 1Gbps is available for large corporations. StarHub also offers ADSL services called "WebSpeed", including unlimited broadband Internet access to corporate subscribers.

Recently, StarHub acquired SCV, and renamed it StarHub Cable Vision Ltd on 1 Oct 2002. SCV MaxOnline, the broadband cable modem Internet service, was renamed MaxOnline. SCV was Singapore's only cable modem service provider and pay television service provider. StarHub Cable Vision has a cable network that covers over 99% of all residential properties in Singapore. This broadband network was completed in Sep 1999, costing S$600 million. The cable modem service, MaxOnline, was launched in Dec 1999 with residential users as the primarily target.

The service offers unlimited broadband access for a flat fee of S$76 per month. Additional discounts are given to their cable TV subscribers. As of Jun 2002, cable remains the most popular residental broadband Internet access technology in Singapore. StarHub Cable Vision will be launching cable telephony services in 2003, and has upgraded their cable network to DOCSIS 1.1. Cable Open access is also expected in 2003.

On the wireless front, StarHub has launched in Aug 2002 the country's largest WLAN hotzone in Suntec City, covering over 180,000 square feet. Recently, they announced plans to launch another wireless broadband hub in Changi Airport, by end 2002. Travelers and visitors will be able to enjoy extended wireless broadband coverage throughout Terminals 1 and 2 of the airport, which includes the Arrival and Departure halls, all the airlines' lounges and all food and beverage outlets in the public area.

Pacific Internet (PacNet). The other significant ISP in Singapore, PacNet has the second largest ADSL subscribers behind SingNet. PacNet leases its capacity from SingTel. On the residential front, PacNet has been targeting the online gaming community. It has launched a "PAN Asia Gaming Network" and a "Singapore Online RPGer", building up a significant broadband subscriber base. On the corporate front, it is targeting SMEs and has pushed out a range of value-added services, such as web hosting and internet security services and applications.

4.1.3 Industry Associations

Association of Telecommunication Industry in Singapore (ATiS). ATiS was formed with the aim of becoming the voice for the telecommunication industry. ATiS is a member of ATIE (Asian Telecommunications Industry Exchange). Members include Radiance Communications, Motorola, XA Alliance and others.

Broadband Media Assoication (BMA). BMA was established in Jan 2001 to bring together players in the Broadband Media industry - technology, service, content and media providers – to build a business network, and forge alliances and partnerships in Singapore and the region. An industry driven initiative, BMA promotes the interests of the broadband media industry for the local and the regional market. To date, more than 50 key industry players from Singapore and the region have come under the association with the aim of spearheading developments in the Broadband Media Industry. Members include SingTel, Pacific Internet, i-STT Pte. Ltd., SPH Mediaworks, 1-Net Singapore, Cisco Systems and others.

4.2 Local Statistics

According to Gartner, Singapore will have about 223,500 broadband accounts, including individual subscribers and corporate users, by end 2002. This represents a 60% increase over last year's figures. This boost in demand also means that revenues from broadband services will amount to S$86 million, a 56.4% increase over last year's figure. Gartner predicts that the number of broadband accounts will reach 561,900 by 2006, growing at a CAGR of 20%. In revenue terms, broadband accounts will gross S$196 million by 2006, growing at a CAGR of 18%.

According to IDC, total broadband subscribers in Singapore will grow at a CAGR of 55% (2001-2006) from 144,000 in 2001 to 1.289 million in 2006. Growth will be strongest in the corporate market, with a 92% CAGR compared to 48% for residential subscribers. Penetration rates will increase dramatically, from just 3% of the total population, or 11% of households (residential subscribers only) in 2001, to 28% of the total population or 69% of households in 2006. On the other hand, broadband access service revenue is expected to grow from US$48 million to US$343 million (2001- 2006) for the residential market, and US$26 million to US$656 million (2001- 2006) for the corporate market.

According to the latest "Survey on Infocomm Usage in Households" commissioned by the IDA, 2001 saw a double-digit growth of broadband subscription among the household users in Singapore. Broadband access in Singapore households has risen to 17.7% from 8.0% in 2000. Access via ADSL and Cable modem has risen sharply from 2.3% and 4.4% to 8.9% and 7.% respectively in year 2001.

The actual broadband users in Singapore are higher as most schools and offices have broadband access. In particular, all schools have broadband connections ranging from 512kbps leased line to 5Mbps ATM Permanent Virtual Circuit. The survey of broadband users in Singapore 2001 commissioned by the IDA, and conducted by Precision Research Services, shows that 950,000 Singapore residents are on broadband. This means that approximately one-third of Singapore residents are using broadband.

4.3 Government Initiatives

4.3.1 Singapore ONE

Singapore ONE is a national initiative, which delivers a new level of interactive, multimedia applications and services to homes, businesses and schools throughout Singapore. Singapore

ONE comprises two distinct but integrated levels. The first is a broadband infrastructure level of high-capacity networks and switches. The second is a level of advanced applications and services that take advantage of the infrastructure's high-speed and high-capacity capabilities. Currently, the broadband infrastructure consisting of high capacity ATM networks and switches, covers over 99% of the island with access via ADSL, cable, wireless, and fibre to the curb. It carries voice, data, audio, and video information simultaneously and at high speed to homes, businesses, schools, and other public places throughout the country.

4.3.2 FastTrack Programme

FastTrack Programme is a programme under the Infocomm Development Authority of Singapore charge to help accelerate the development and growth of the broadband industry. It was launched back in 1998 to function as a one-stop service point for the Interactive Broadband Multimedia (IBBMM) companies. This programme facilitates the various industry developments through jumpstarting developments, enhancing capabilities, creating business opportunities, promoting and showcasing services and capabilities, providing marketing support and intelligence. To date, FastTrack Programme has facilitated and accelerated the development of over 200 businesses.

4.3.3 Free Space Optics Trial

An initative by IDA to provide the industry with an independent and thorough assessment of the FSO technology. Conducted in Feb 2002 over a period of three months, this trial is a technical evaluation of FSO technology in our rain/haze region for inter-building and last mile connectivity. The objectives of the trial are as follows:

- To highlight the issues and challenges of deploying FSO
- To study effective ways of deploying FSO
- To serve as an educational platform to help generate awareness and understanding of FSO technology amond the industry and public.

4.3.4 Next Generation WLAN Trial

Another initative by IDA to provide the industry with an independent and thorough assessment of the Next Generation WLAN (NGWLAN) technology. Conducted in May 2002 over a period of six months, this trial is a technical evaluation of the ability of NGWLAN to:

- Investigate the present WLAN limitations of security, interference, scalability and others.

- Evaluate issues arising from user roaming across different subnet in the same enterprise network, different enterprise networks, hotspot operator networks, and GPRS networks are made.

- Study into application layer issues such as security and roaming are made together with measurements of throughput and end-to-end delays with different applications area also presented. Issues and challenges that we may face during the deployment of the new technology and to ensure the migration from current deployment to next generation wireless network can be carried out smoothly.

5 Conclusion

In this report, we have examined global trends and future development of last mile broadband access technologies through the analysis of standards development, deployment status, and innovative developments in each access technology. Key drivers that have propelled this industry were also discussed.

In Singapore, the broadband market has successfully crossed the chasm and have entered the early majority stage. In recent months, competition has driven down the subscription cost, significantly boosting the broadband take-up for ADSL and cable. Unlimited access bundled is the norm now, and various broadband access service providers (BASPs) are bundling value-added services to increase revenue and attract new customers. Over the next 5 years, we expect ADSL and cable to replace dial-up as the dominant means for accessing Internet. However, in the long run, they may no longer be considered "broadband". The advent of new interactive multimedia applications will make the effective access speeds offered by ADSL and cable insufficient. For example, a VOD with broadcast TV quality based on MPEG2 compression technology will require 6Mbps, which is higher than the effective bandwidth offered by cable and ADSL service providers[53]. Therefore, we believe the access speeds offered by VDSL and fibre will set the stage for the new definition of "broadband" in 2007.

On the end-user side, more people are beginning to see the productivity gains that can be reaped from having a broadband connection. An Internet access has gone beyond simple web-browsing and e-mail. Currently, popular Internet usage includes the download of MP3 music, playing online games, multimedia e-learning, and teleworking. In particular, teleworking applications like video conferencing, workflow application through corporate Virtual Private Network, and collaborative peer-to-peer type of applications and services will become common. On the horizon, new business models based on outsourcing such as application service provision and utility computing will also push the need for greater bandwidth and QoS. Therefore, broadband access characteristics of "always-on" will no longer be sufficient, and will evolve over the next 5 years to include QoS and symmetric downstream/upstream access speed.

Wireless broadband access technologies will continue to complement the wireline broadband access networks to offer even greater connectivity and mobility to end-users. In situations whereby a fast and/or temporary high bandwidth last mile connectivity is required, deploying FSO will be significantly cheaper and faster than deploying fibre. For the convenience of roaming, deploying WLAN will provide the necessary high-speed wireless connectivity. In

53 The effective bandwidth offered by cable and ADSL is normally lower than the rated bandwidth offered by the technology. The effective bandwidth that each cable modem subscribers gets is determined by the number of subscribers in the local loop. On the other hand, ADSL gets a delicated link back to a Central Office, but bandwidth sharing occurs from the Central Office to the broader Internet.

particular, we expect standards-based roaming to be available between WLAN-to-WLAN and WLAN-to-WWAN networks by 2005. Therefore, we believe there will be a surge in FSO and WLAN deployments in the coming years.

Overall, besides enhancing work productivity and lifestyle, having pervasive broadband access also improve the competitive advantage of a nation. Singapore is one of the first few countries to recognise the importance of having a broadband infrastructure through the construction of Singapore ONE. This effort has been successful in making Singapore one of the leading broadband nations in the world. Moving forward, compelling content and sophisticated broadband applications and services will drive the demand and eventual deployment of higher speed broadband access infrastructures.

2B1Q	Two-Binary One-Quaternary
2G	Second Generation
3G	Third Generation
ACTS	Advanced Communications Technologies and Services
ADSL	Asymmetric Digital Subscriber Line
AES	Advance Encryption Standard
ANSI	American National Standards Institute
AP	Access Point
APON	Asynchronous Transfer Mode Passive Optical Network
ATiS	Associatoin of Telecommunication Industry in Singapore
ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
BMA	Broadband Media Association
BPON	Broadband Passive Optical Network
BRAN	Broadband Radio Access Networks
BSC	Base Station Controllers
BTS	Base Transmitter Stations
CableLabs	Cable Television Laboratories, Inc.
CAGR	Compound Annual Growth Rate
CAP	Carrier Amplitude/Phase
CATV	Cable Television
CIMO	Cisco Internet Mobile Office
CMTS	Cable Modem Termination System
CPE	Customer Premises Equipment
DAVIC	Digital Audio Visual Council
DBA	Dynamic Bandwidth Assignment
DMT	Discrete Multi-Tone
DOCSIS	Data Over Cable Service Interface Specification
DSL	Digital Subscriber Line
DSSS	Direct Sequence Spread Spectrum
DTV	Digital Television
DVB	Digital Video Broadcasting
DVB-RCS	Digital Video Broadcasting – Return Channel System
E1	E-carrier system – Level 1
ECTA	European Competitive Telecommunications Group
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMS	Element Management Systems
EPON	Ethernet Passive Optical Network
ETSI	European Telecommunications Standards Institute
EU	European Union

EuroDOCSIS	European Data Over Cable Service Interface Specification
FBO	Facilities Based Operator
FCC	Federal Communications Commission
FDDI	Fibre Distributed Data Interface
FHSS	Frequency Hopping Spread Spectrum
FSAN	Full Services Access Network
FSO	Free Space Optics
FS-VDSL	Full Service Very High-Speed Digital Subscriber Line
FTP	File Transfer Protocol
FTTB	Fibre-to-the Basement
FTTCab	Fibre-to-the Cabinet
FTTC	Fibre-to-the Curb
FTTN	Fibre-to-the Neighbourhood
FTTO	Fibre-to-the Office
FWA	Fixed Wireless Access
GIS	Generic Interface Standard
GPON	Gigabit Passive Optical Network
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communications
HDSL	High-Speeed Digital Subscriber Line
HDSL2	Second Generation High-Speeed Digital Subscriber Line
HDTV	High Definition Television
HF	High Frequency
HFC	Hybrid Fibre Coaxial
HV	High Voltage
IAPP	Internet Access Point Protocol
IBBMM	Interactive Broadband Multimedia
IDA	Infocomm Development Authority of Singapore
IDSL	ISDN Digital Subscriber Line
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISM	Industry, Scientific and Medical
ISP	Internet Service Provider
ITR	Infocomm Technology Roadmap
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union – Radiocommunication
ITU-T	International Telecommunication Union – Telecom Standardization

LAN	Local Area Network
LMDS	Local Multipoint Distribution Service
LV	Low Voltage
MAC	Media Access Control
MAN	Metropolitan Area Network
MCNS	Multimedia Cable Network System Partners Ltd.
MEMS	Micro-Electro Mechanical Systems
MMDS	Multi-channel Multipoint Distribution Service
MP3	Moving Picture Experts Group-1 Audio Layer-3
MPEG	Moving Picture Experts Group
MSC	Mobile Switching Centres
MSO	Multi-System Operator
MV	Medium Voltage
NGWLAN	Next Generation Wireless Local Area Network
NMS	Network Management Services
OAM	Operations, Administration and Maintenance
OCAP	OpenCable Application Platform
OFDM	Orthogonal Frequency Division Multiplexing
OLT	Optical Line Terminating
OMCI	ONT Management and Control Interface
ONT	Optical Network Terminal
ONU	Optical Network Unit
PacNet	Pacific Internet
PAN	Personal Area Network
PHY	Physical Layer
PLC	Power Line Communications
PON	Passive Optical Network
POTS	Plain Old Telephone Service
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
R&D	Reserach and Development
RF	Radio Frequency
SBO	Services Based Operators
SCV	Singapore Cable Vision Ltd
SDSL	Symmetric Digital Subscriber Line
SHDSL	Single-Pair High-Speed Digital Subscriber Line
SME	Small and Medium Enterprise
SNR	Signal to Noise Ratio
TCPAM	Trellis Coded Pulse Amplitude Modulation
T1	T-carrier system – Level 1
TCP	Transmission Control Protocol

TIA	Telecommunication Industry Association
TKIP	Temporal Key Integrity Protocol
UMTS	Universal Mobile Telephone System
UK	United Kingdom
US	United States
USB	Universal Serial Bus
UWB	Ultra WideBand
VDSL	Very High-Speed Digital Subscriber Line
VOD	Video-on-demand
VoIP	Voice over Internet Protocol
VoWLAN	Voice over Wireless Local Area Network
VSAT	Very Small Aperature Terminal
VSNL	Videsh Sanchar Nigam Limited
WAN	Wide Area Network
WiFi	Popular term for IEEE 802.11 based Wireless Local Area Network
WDM	Wavelength Division Multiplexing
WECA	Wireless Ethernet Compatibility Alliance
WEP	Wired Equivalent Privacy
WG	Work Group
WISP	Wireless Internet Service Provider
WISPr	Wireless Internet Service Provider roaming
WLAN	Wireless Local Area Network
WWW	World Wide Web

IDA Technology Roadmap November 2002

Broadband Access

With active contribution from the industry and research community, IDA has launched the *Infocomm Technology Roadmap Release November 2002*. You have either attended the Roadmap Symposium or downloaded a copy of the Technology Roadmap document from our website. Your feedback is valuable to us to better our future services for you. We appreciate if you could spare a few minutes to fill up the following survey.

Please return the completed questionnaire to IDA:
via Fax: **+(65) 6211 2211 (Attention to Ms Saliza Mohd)**
or via Mail to the address on the previous page.

Company Name : _____

Your Name : _____

Designation/
Area of Expertise : _____

Email Address : _____

Contact Number : _____

Q1. With regards to the Roadmap Report Release November 2002 on "Broadband Access", please rate the following on a scale of 1 to 6.

Factors	Excellent					Poor
Usefulness of the roadmap	6	5	4	3	2	1
Completeness of coverage and contents	6	5	4	3	2	1
Ease of understanding	6	5	4	3	2	1
Usefulness of the Roadmap Chart 2002-2007	6	5	4	3	2	1
Relevance to you or to your business strategy/planning	6	5	4	3	2	1

Comments (if any):

_____

_____

_____

_____

Q2. Please indicate the accuracy (in terms of trend & development) of each topic in the Technology Roadmap Report. Please rate them on a scale of 1 to 6.

Area/Topic	Accurate			Inaccurate		
Wireline Broadband Access Technologies	6	5	4	3	2	1
Wireless Broadband Access Technologies	6	5	4	3	2	1
Singapore Landscape	6	5	4	3	2	1
Roadmap Chart 2002-2007	6	5	4	3	2	1

Comments (if any):

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_____

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_____

Q3. Do you have any suggestions for improvement on the Technology Roadmap?

_____

_____

_____

_____

Q4. If you are an industry player in Broadband Access, what are the strategic business areas and recommendations for future development that you deem appropriate for and unique to Singapore's competitiveness?

_____

_____

_____

_____

Q5. Would you like to be informed of our future Infocomm Technology Roadmap Seminar/ Reports? Yes / No

…. Thank You ….

BROADBAND ACCESS ROADMAP 2002 to 2007

	2002	2003	2004	2005	2006	2007
Wireline Technology and Market Trends	• Release of ADSL2 G.dmt.bis and ADSL2 G.lite.bis standard • Release of DOCSIS2.0 standard • Commercial deployment of PLC for "last mile" access in Europe • Release of ATM based Broadband-PON (BPON) standards adopted under ITU-T G.983.1 to G.983.7 • Limited deployment of BPON systems • HFC network upgrade to support DOCSIS 1.1 in Singapore • 14 site market trial of PLC for "last mile" access in Singapore by SPTel • ADSL replaces cable as the dominant broadband access technology in Singapore • Worldwide DSL broadband subscribers at 12.5 million [Pioneer Consulting] • Worldwide market opportunity for DSL broadband service at US$13.6 billion [Pioneer Consulting] • Worldwide residential cable broadband subscribers at 10.3 million [Pioneer Consulting] • Worldwide market opportunity for residential cable broadband service valued at US$5.9 billion [Pioneer Consulting] • 5.21 million cable telephony subscribers [Allied Business Intelligence] • 223,500 Singapore broadband subscribers [Gartner] • S$86 million revenue from Singapore broadband services market [Gartner]	• Release of G.shdsl.bis standard by ITU-T • Expected adoption of FS-VDSL standard by ITU-T • Increase global HFC networks upgrade to support DOCSIS 1.1 • Spectrum bands for access and in-home PLC systems resolved • Commercial deployment of PLC for "last mile" access in North America and Asia • Cable telephony services to be offered in Singapore • Cable Open Access in Singapore • Worldwide DSL broadband subscribers at 19.2 million [Pioneer Consulting] • Worldwide market opportunity for DSL broadband service at US$20.9 billion [Pioneer Consulting] • Worldwide residential cable broadband subscribers at 14.2 million [Pioneer Consulting] • Worldwide market opportunity for residential cable broadband service valued at US$7.8 billion [Pioneer Consulting]	• Release of new ADSL standard that is able to support 10Mbps at distances up to 3km • DMT chosen as the single line code modulation standard for VDSL • Release of ITU-T IP based FS-VDSL multimedia DSL architecture (Study Group 15, Q2) • Cable telephony to take off • European EMC/EMI standard for PLC • Release of IEEE 802.3ah (Ethernet First Mile), including Ethernet-over-DSL and EPON standards • ADSL/SHDSL to take off in Singapore's SME market • Worldwide DSL broadband subscribers at 52.9 million [Pioneer Consulting] • Worldwide market opportunity for DSL broadband service at US$54.0 billion [Pioneer Consulting] • Worldwide residential cable broadband subscribers at 35.9 million [Pioneer Consulting] • Worldwide market opportunity for residential cable broadband service valued at US$18.6 billion [Pioneer Consulting]	• DSL Forum targets 20% DSL penetration of global telephone lines, or 200 million DSL connections • Ethernet-over-DSL gains traction in Business market • Global EMC/EMI standards for PLC • Release of WDM-based Giga-PON (GPON) standards by FSAN, as an efficient means for scaling BPON capacity • Commercial deployment of VDSL in Singapore • Worldwide DSL broadband subscribers at 70.5 million [Pioneer Consulting] • Worldwide market opportunity for DSL broadband service at US$63.6 billion [Pioneer Consulting] • Worldwide residential cable broadband subscribers at 47.6 million [Pioneer Consulting] • Worldwide market opportunity for residential cable broadband service valued at US$23.4 billion [Pioneer Consulting]	• Ethernet-over-DSL to take off • Limited HFC networks upgrade to support DOCSIS 2.0 • Limited deployment of WDM-PON systems • Worldwide subscribers to cable broadband services at 48.7 million [Allied Business Intelligence] • Worldwide cable internet access subscriber revenues at US$22.2 billion [Allied Business Intelligence] • Worldwide PON equipment revenue will reach US$833.5 million in 2006 [In-Stat/MDR] • 561,900 Singapore broadband subscribers [Gartner] • S$196 million revenue from broadband services market [Gartner]	• VDSL to take off • Worldwide DSL broadband subscribers at 111.6 million [Pioneer Consulting] • Worldwide market opportunity for DSL broadband service at US$79.2 billion [Pioneer Consulting] • Worldwide residential cable broadband subscribers at 75.3 million [Pioneer Consulting] • Worldwide market opportunity for residential cable broadband service valued at US$33.5 billion [Pioneer Consulting] • 53 million cable telephony subscribers [Allied Business Intelligence]
Wireless Technology and Market Trends	• Release of IEEE 802.16 and IEEE 802.16.2 standard • Release of IEEE 802.16a and IEEE 802.16c standards • First commercial deployment of RF fixed wireless systems employing mesh networking (alternative to point-to-multipoint topology) • FSO transceivers with backup 60GHz link for areas with dense fog and moderate rainfall • Launch of Ka-band satellite systems • Trial of broadband satellite Internet services on plane • 54,500 broadband wireless connections worldwide, including unlicensed, LMDS and MMDS [Intex Mgmt Services] • Global public hotspots market at US$278 million [Juniper Research] • Global "last mile" WLAN access market at US$216 million [Juniper Research] • 0.59 million broadband satellite subscribers globally [North Sky Research] • Global broadband satellite service revenues at US$1.05 billion [North Sky Research]	• Vendors start shipping pre-802.16 compliant solutions • Worldwide licensed-spectrum deployments accelerate as second generation, non-line-of-sight solutions (mesh, smart antenna) ship in volume • Commercial deployment of point-to-multipoint FSO systems • FSO systems with 10Gbps (4 lambdas) bandwidth • Release of IEEE 802.11e (QoS), IEEE 802.11f (IAPP), IEEE 802.11g, and IEEE 802.11h (European compliant) standards • Standards-based roaming between WLAN and Wireless WAN • Commercial launch of broadband satellite Internet services on plane • Small-scale deployments of FSO links by operators in Singapore • Interoperable roaming between different WLAN hotspots and hotzones in Singapore	• Release of standards for IEEE Mobile Wireless MAN Study Group and IEEE 802.16 ad-hoc enhancements • Horizontal component suppliers to fixed wireless equipment makers (silicon and system management software) increase as industry converges to 802.16 • Commercial deployment of WDM-FSO systems expected • Release of IEEE 802.11i (security) standards • FSO deployment for cellular infrastructures in Singapore • Standards-based roaming between WLAN and Wireless WAN in Singapore	• Average sales price for fixed wireless CPE units are 50% less than in 2002 due to silicon integration and standards adoption • Release of IEEE 802.11j standard, which works on the convergence of IEEE 802.11 and HiperLAN standards in the 5GHz band • Over 2 million RF fixed wireless broadband connections worldwide [Intex Mgmt Services] • Global FSO market expected at US$215 million [Frost & Sullivan] • Global public hotspots market at US$3,390 million [Juniper Research] • Global "last mile" WLAN access market at US$2,201 million [Juniper Research] • Worldwide sales of WLAN equipment will surpass the US$5 billion [In-Stat/MDR] • 2.53 million broadband satellite subscribers globally [North Sky Research] • Global broadband satellite service revenues at US$3.5 billion [North Sky Research]	• Advances in CMOS radio integration enable cost-effective, multiple-input, multiple-output (MIMO) antenna technology for higher data rates and better non-line-of-sight performance in fixed wireless systems • Worldwide sales of FSO equipment at US$2 billion [Strategis Group] • Worldwide WLAN chipsets for portable devices will exceed 30 million [In-Stat/MDR]	• Majority of portable mobile devices, like notebook computers and Personal Digital Assistances, to be WLAN-enabled • Global LMDS subscriber at 3.6 million [Allied Business Intelligence] • Global MMDS subscriber at 14 million [Allied Business Intelligence] • Global public hotspots market at US$9,690 million [Juniper Research] • Global "last mile" WLAN access market at US$5,495 million [Juniper Research] • 4.35 million broadband satellite subscribers globally [North Sky Research] • Global broadband satellite service revenues at US$4.3 billion [North Sky Research]