Broadband Technology Overview

White Paper

Optical
Fiber

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Abstract:

We review the latest developments in the leading broadband access technologies and we assess the ability of those technologies to meet the future requirements of the broadband consumer. We compare and contrast those technologies to the advantages of fiber to the home to determine whether fiber continues to offer the ultimate in broadband connectivity.

1.0 Introduction

As the broadband revolution continues, the ever increasing competition in the broadband service market is forcing broadband service suppliers to plan their strategies for delivery of "triple play" services, with voice, data and video provided by a single connection. Over recent years, as the internet and intranets have evolved, increasing requirements for bandwidth intensive applications such as peer to peer file sharing and tele-working have resulted in relentlessly increasing demands for higher broadband bandwidth provisioning. However it is the bandwidth required by next generation TV and video services, such as Video on Demand (VoD) and, more significantly, high definition TV (HDTV) which have recently begun to place the most pressure on bandwidth provisioning in broadband networks. Even with the latest data compression techniques, HDTV requires in the order of 15 to 20Mbps of downstream bandwidth and this is testing the capabilities of a number of broadband technologies.

There are a myriad of competing technologies which can provide the bandwidth required to deliver broadband services, but each technology has its limits in terms of bandwidth, reliability, cost or coverage. Optical fiber offers almost limitless bandwidth capabilities, has excellent reliability and is becoming increasingly economical to install. Consequently fiber seems to be unsurpassed in its superiority over the other broadband technologies. However, many competitive copper and wireless technologies are developing at a significant pace and some technologies have so far managed to continually meet the ever increasing bandwidth requirements of the consumer.

We review the latest developments in the leading broadband access technologies and we assess the ability of those technologies to meet the future requirements of the broadband consumer. We compare and contrast those technologies to the advantages of fiber to the home (FTTH) to determine whether fiber continues to offer the ultimate in broadband connectivity.

2.0 Competing Broadband Technologies

In general broadband solutions can be classified by two groups: fixed line technologies or wireless technologies. The fixed line solutions communicate via a physical network that provides a direct "wired" connection from the customer to the service supplier. The best example of this is the plain old telephone system (POTS) where the customer is physically connected to the operator by a pair of twisted copper cables. Wireless solutions use radio or microwave frequencies to provide a connection between the customer and the operator's network; mobile phone connectivity is a prime example.

2.1 Fixed Line Technologies

Fixed line broadband technologies rely on a direct physical connection to the subscriber's residence or business. Many broadband technologies such as cable modem, xDSL (digital subscriber line) and broadband powerline have evolved to use an existing form of subscriber connection as the medium for communication. Cable modem systems use existing hybrid fiber-coax Cable TV networks. xDSL systems use the twisted copper pair traditionally used for voice services by the POTS. Broadband powerline broadband technology uses the power lines feeding into the subscriber's home to carry broadband signals. In general, all three aforementioned technologies strive to avoid any upgrades to the existing network due to the inherent implications for capital expenditure.

By contrast, fiber to the home (FTTH) or fiber to the curb (FTTC) networks require the installation of a new (fiber) link from the local exchange (central office) directly to or closer to the subscriber. Consequently, although fiber is known to offer the ultimate in broadband bandwidth capability, the installation costs of such networks have, up until recently, been prohibitively high.

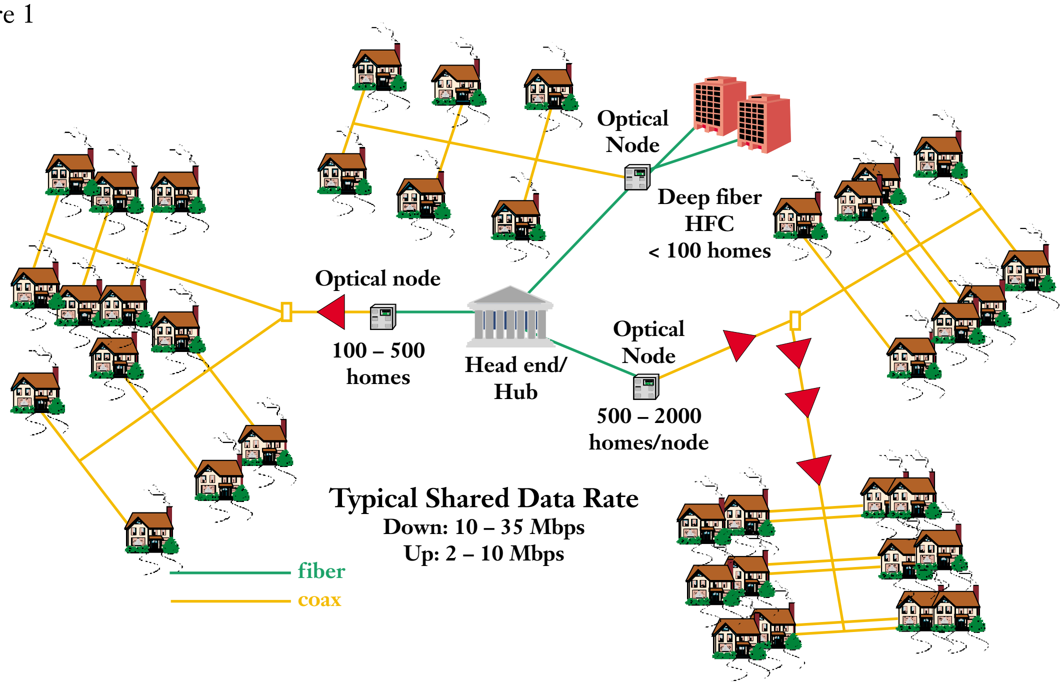
The fixed line technologies evaluated here include:

- Hybrid Fiber Coax: Cable TV & Cable Modems
- Digital Subscriber Line (xDSL)
- Broadband Power Line (BPL)
- Fiber to the Home/Curb

2.1.1 Hybrid Fiber Coax (HFC): Cable TV & Cable Modems

Digital cable TV networks are able to offer bi-directional data transfer bandwidth in addition to voice and digital TV services. Using a cable modem in the customer premise and a Cable Modem Termination System (CMTS) at the network's head-end, the well established HFC standard, DOCSIS 1.1, provides for a data transmission service with speeds of up to a 30 Mbps on one 8 MHz channel (6 MHz is used in the US) using QAM modulation techniques. The recently proposed HFC standard, DOCSIS 3.0, may be capable of 100 Mbps of bandwidth per channel in the near future. Data transmission over Cable TV networks has the advantage that where the coaxial cable is in good condition and RF amplifiers exist (or can be installed) to extend the network reach, relatively high bandwidths can be provided to the end user without distance limitations. However, a cable TV broadband service relies on a shared network architecture (see Figure 1); this results in the limitation that the amount of bandwidth delivered to the customer is dependant on how many people share the connection back to the head-end. Typically a service of 1 Mbps downstream and 128 kbps upstream is offered (more recently a 3-5 Mbps downstream service has become available), but up to 1000 users may share the connection to the head-end and so the actual bandwidth obtained can be lower due to excessive loading of the system by other users.

Cable TV, Hybrid Fiber Coax (HFC) Architectures
Figure 1



2.1.2 Digital Subscriber Line (xDSL)

DSL technology uses the existing copper telephone infrastructure to facilitate high speed data connections. DSL equipment achieves this by dividing the voice and data signals on the telephone line into three distinct frequency bands. For example with Asymmetric DSL (ADSL), voice conversations are carried in the 0 to 4 KHz (3 KHz in U.S.) band (as they are in all POTS circuits), the upstream data channel is carried in a band between 25 and 160 KHz and the downstream data channel begins at 240 KHz and goes up to about 1.1 MHz. Complex data modulation techniques enable data rates of up to 12Mbps. DSL access modules (DSLAMS) are placed in the local exchange or at nodes in the access network to transmit and receive the data signals. However xDSL has the disadvantage that it is a distance-sensitive technology. As the connection length from the user to the DSLAM increases, the signal quality decreases and the connection speed goes down (see Figure 2).

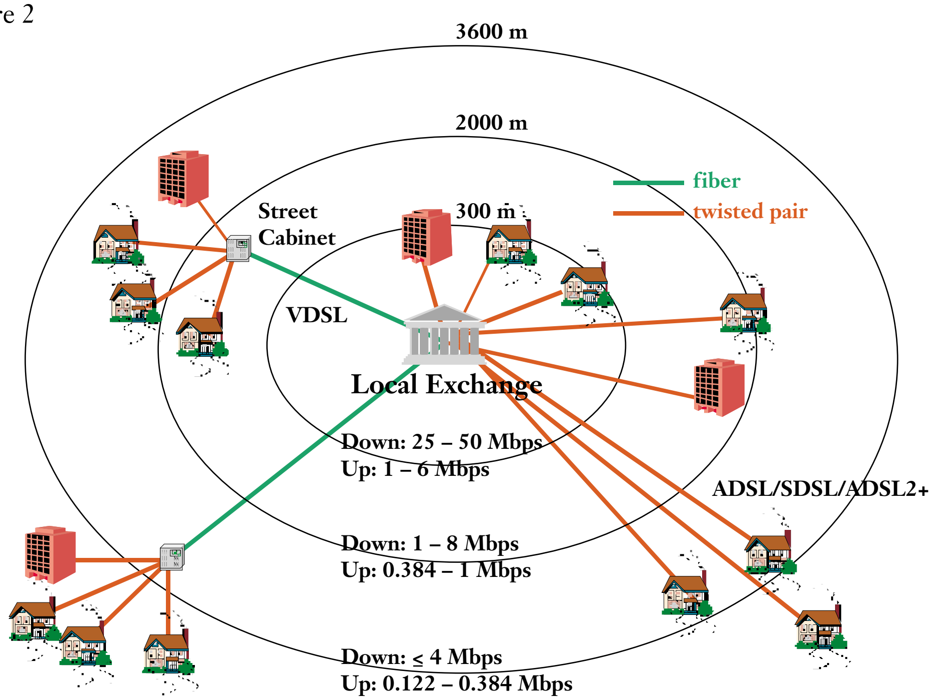
There a number of different DSL technologies, the key ones are ADSL, SDSL (symmetric), VDSL (Very high bit rate DSL) and ADSL2+. More recently, ADSL2++ has been introduced.

Table 1 shows that ADSL technology can provide maximum downstream speeds of up to 12 Mbps and upstream speeds of up to 640 Kbps at a distance of about 0.3 km. The ultimate distance limit for ADSL service is 5.4 km, but at this distance transmission speeds are limited to approximately 500 Kbps. In order to maximise network coverage out to the full 5.4 km, the ADSL speeds widely offered today in Europe are 500 Kbps downstream, with upstream speeds from 128 Kbps.

For business applications it is possible to get Symmetric DSL (SDSL) which allows high speed download and uploads, but again the maximum available bandwidth is around 3Mbps.

With VoD requiring at least 3Mbps and HDTV requiring approximately 15 to 20 Mbps, clearly neither ADSL or SDSL can meet the bandwidth requirements for HDTV and may well struggle to provide VoD and/or a basic video service over the full network.

Network architectures for various forms of xDSL, note the xDSL bandwidth is dependant on distance from the local exchange/central office or the remote street cabinet
Figure 2



However, VDSL and the more recently introduced ADSL2+ can offer bandwidths high enough to allow video services. VDSL can offer up to 52 Mbps, but only over very short distances. Therefore in order to offer VDSL to a significant proportion of the population the DSLAMs need to be relocated to street cabinets (closer to the subscriber) and fiber feeds installed to the street cabinets. The cost of this upgrade and laying fiber to the cabinets means that VDSL is prohibitively expensive relative to ADSL technology and VDSL deployments have been limited.

The latest technologies to emerge from the DSL family are ADSL 2+ and ADSL 2++. ADSL2++ is still in its infancy and is not yet supported by an appropriate standard. ADSL2+ however, is standardized and allows transmission of sufficient bandwidth for some video services, over greater distances than VDSL, without the need for DSLAM relocation. As a result ADSL2+ is becoming the upgrade path for operators wishing to improve upon their standard ADSL service offerings.

xDSL bandwidth versus distance capability. Note, the maximum data capacities shown are not available at the maximum distance. There is always a trade-off between distance and bandwidth.
Table 1

Technology	Max Upstream Capacity	Max Downstream Capacity	Max Distance	Downstream Capacity @ Max Distance	Frequency Range
ADSL	640 Kbps	12 Mbps (0.3km)	5.4 km	**1.5 Mbps**	Up to 1.1 MHz
SDSL	3 Mbps	3 Mbps	2.7 km	**2 Mbps**	Up to 1.1 MHz
ADSL 2+	1 Mbps	26 Mbps (0.3km)	3.6 km	**4 Mbps**	Up to 2.2 MHz
VDSL	16 Mbps	52 Mbps (0.3km)	1.3 km	**13 Mbps**	Up to 12 MHz

2.1.3 Broadband Powerline (BPL)

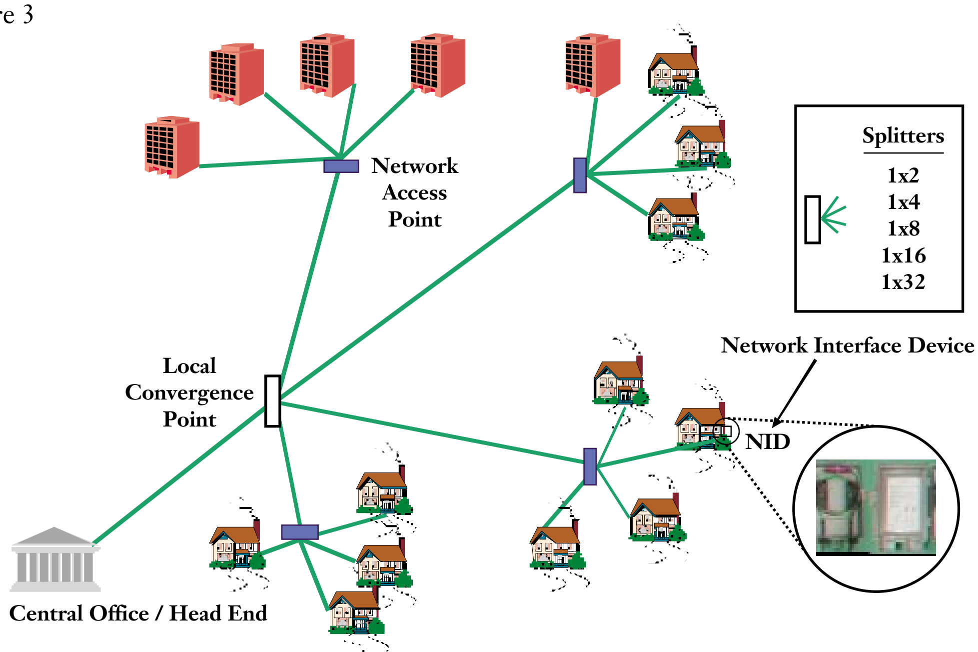
BPL systems allow for high speed data transmission over existing power lines, and do not need a network overlay as they have direct access to the ubiquitous power utility service coverage areas. BPL systems are being promoted as a cost-effective way to service a large number of subscribers with broadband. In a BPL system, the data is transmitted over the existing power line as a low voltage, high frequency signal which is coupled to the high voltage low frequency power signal. The frequency transmission band has been chosen to ensure minimum interference with the existing power signal. Typical data rates in current trials are 2 to 3 Mbps, but vendors have indicated that commercially systems offering up to 200 Mbps could eventually become available. However, there is no clear upgrade path to higher data rates. Most BPL systems at present are limited to a range of 1km within the low voltage grid, but some operators are extending this reach in to the medium voltage grid. Experience has shown that BPL requires a high investment cost, to upgrade the power transmission network and bypass transformers, to support high speed and reliable broadband services. In addition, the frequencies used for BPL often interfere with amateur radio transmission and some BPL trials have consequently suffered considerable opposition. At present, given the cost and the lack of an upgrade path, it seems unlikely that BPL will emerge as a leading broadband technology, but will remain as a niche fixed-line broadband option.

2.1.4 Fiber to the Home/Curb

FTTx is a generic term for those technologies which bring fiber, a step closer to the subscriber. However, not all fiber solutions in access networks bring the fiber directly to the home/subscriber as shown in Figure 4. Some technologies in the access that rely on fiber, like VDSL, bring fiber from the local exchange (central office) down to a node in the access network or to the curb, where equipment is housed in a street cabinet to convert signals from optical to electronic, ready for the final hop to the subscriber over twisted copper pair. This level of fiber provision in the network would be called FTTC (fiber to the curb) or FTTN (fiber to the node). Other architectures include FTTB (fiber to the building) and FTTP (fiber to the premises) where the fiber is brought as far as the building and then distributed amongst the resident subscribers over twisted copper pair or using wireless technology. FTTH is the ultimate fiber access solution where each subscriber is connected to an optical fiber.

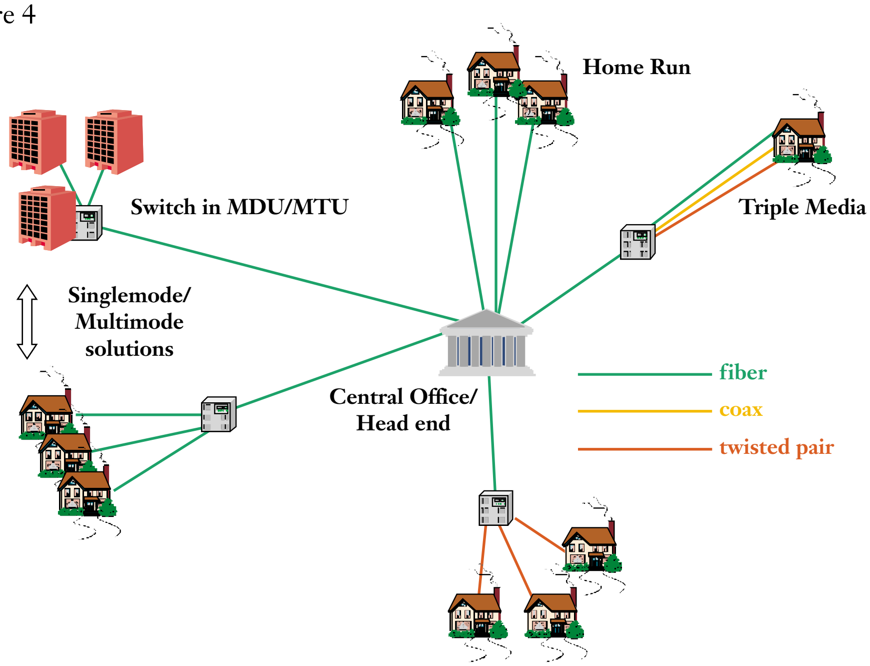
As FTTH has matured, applications have converged on to two consensus solutions. The first is the Passive Optical Network, or PON. PONs have been described for FTTH as early as 1986. In this architecture the main signal from the local exchange is passively split such that it is shared by between 16 and 32 subscribers (see Figure 3). Privacy is ensured by time shifting, and personal encryption of each subscriber's traffic. Upstream traffic is enabled by Time Division Multiple Access (TDMA) synchronization. Fixed network and exchange costs are shared among all subscribers. This reduces the key cost per subscriber metric. The PON solution benefits from having no outside-plant electronics. This reduces network complexity and life-cycle costs, while simultaneously improving reliability.

Passive Optical Network (PON) Architecture
Figure 3



The second common FTTH architecture is a point-to-point (P2P) network (see Figure 4), which is often referred to as an All Optical Ethernet Network (AOEN). In this solution, each home is directly connected by optical fiber to the local exchange. This provides a dedicated line of connection to the operator for each subscriber, which is the main advantage of P2P networks over PONs. The dedicated connection lines of a P2P network facilitate subscriber specific service supply, higher subscriber bandwidth with improved traffic security, and simple provision of symmetric services. The P2P network architecture is similar to the common enterprise Local Area Network (LAN) design and so has the advantage of being able to use existing components and equipment, which helps to reduce system cost. However, P2P networks require actives in the field which can increase installation, operating and life-cycle costs and also reduce reliability.

Architectures for various point to point (P2P) networks, including direct "home run" P2P fiber connections, fiber feed to VDSL (fiber to copper) street cabinet and a fiber feed to an all optical street cabinet
Figure 4



Standards are established for both PON and P2P networks and suppliers exist for both PON and P2P systems, offering either Asynchronous Transfer Mode (ATM) or IP/Ethernet transmission on either architecture type. As a result there are many vendors offering many increasingly competitively priced P2P or PON networking products.

Current Ethernet PON (EPON) systems can operate at up to 1 Gbps over distances of up to 20 km, which is 40 times greater bandwidth delivery than ADSL2+ can achieve at 1km. EPON systems will soon be offering 2.5 Gbps split between 64 users (although 32 users is more likely). Even with the EPON bandwidth shared amongst 64 consumers, the bandwidth offered to the FTTH consumer can greatly outstrip anything achievable by cable services or ADSL2+ over a radial coverage area of 20 km. In addition Wavelength Division Multiplexed PON (WDM PON) is now being explored. This technology, by bringing a single optical channel to each subscriber (eliminating bandwidth sharing), will further increase the bandwidth offered by PON systems. Therefore it is an unchallenged fact that fiber, as a communication medium, offers almost infinite bandwidth over far greater distances relative to all its competitors.

2.2 Wireless Technologies

Generally, wireless broadband refers to technologies that use point-to-point or point-to-multipoint microwave in various frequencies between 2.5 and 43 GHz to transmit signals between hub sites and an end-user receiver. While on the network level, they are suitable for both access and backbone infrastructure, it is in the access network where wireless broadband technology is proliferating. As a consequence, the terms “wireless broadband” and “wireless broadband access” are used interchangeably.

There are a wide range of frequencies within which wireless broadband technologies can operate, with a choice of licensed and unlicensed bands. Generally speaking, higher frequencies are advantaged relative to lower frequencies as more spectrum is available at high frequencies and smaller antennas can be used, enabling ease of installation. Most higher bandwidth systems use frequencies above 10 GHz. However, high frequency systems are severely attenuated by poor weather conditions (e.g. rain or fog) and therefore suffer from distance limitations.

Wireless technologies can be broadly categorized into those requiring line-of-sight (LOS) and those that do not. Point-to-point microwave, Local Multipoint Delivery System (LMDS), Free Space Optics (FSO), and Broadband Satellite all require line-of-sight for reliable signal transmission while cellular technologies like GSM, CDMA, 3G, WiFi, WiMax, and fixed wireless broadband technologies like Multipoint Multichannel Distribution System (MMDS) require no line-of-sight between the transmission hub and receiving equipment. Clearly, the non line-of-sight (NLOS) technologies provide advantages in terms of ease of deployment and wider network coverage.

This section gives an overview of each of these wireless technologies. The technologies evaluated here include:

- Microwave links
- MMDS (Multichannel Multipoint Distribution Service)
- LMDS (Local Multipoint Distribution Service)
- FSO (Free Space Optics)
- Wi-Fi (Wireless Fidelity)
- WiMax (Worldwide Interoperability for Microwave Access)
- Satellite
- 3G (Third Generation Mobile Network)

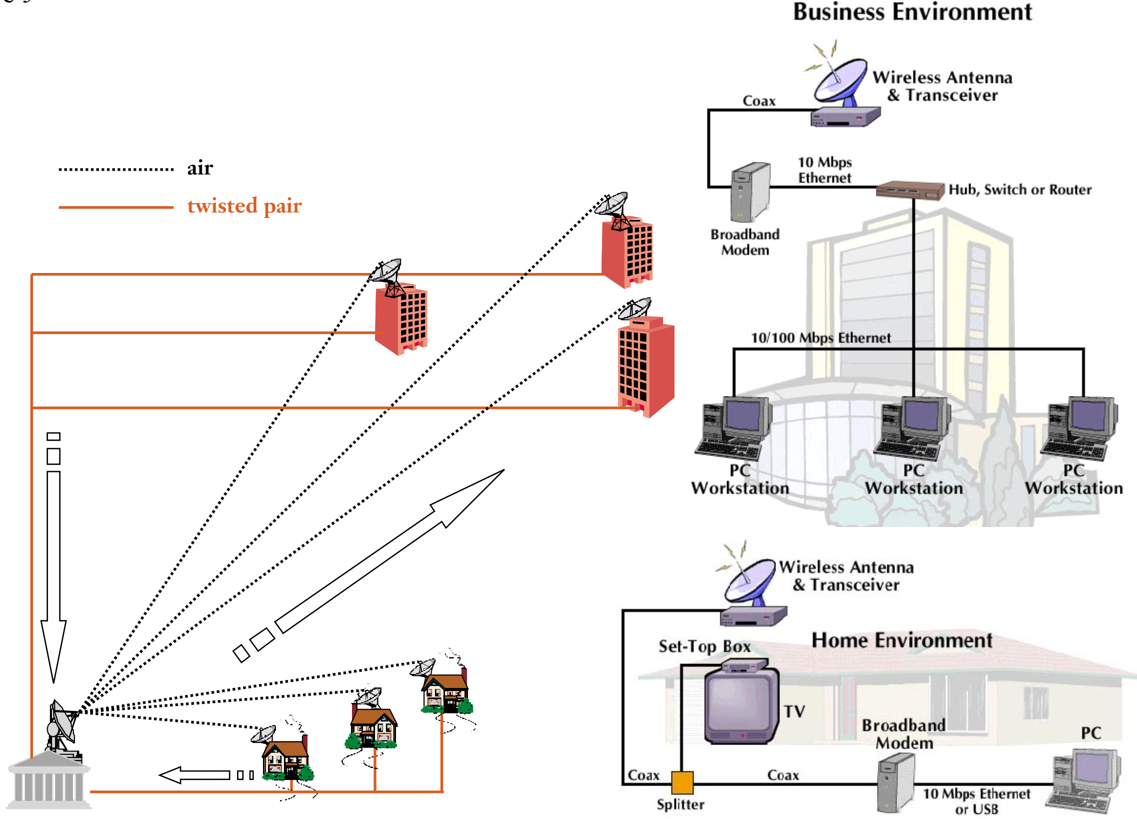
2.2.1 Microwave Links

Microwave links are the traditional workhorse of fixed-wireless broadband systems and were around long before the term wireless broadband was coined. It is the point-to-point LOS wireless transmission method for up to 155 Mbps (STM1 or OC-3), with a range of up to 5 km. Single channel microwave links are relatively inexpensive and simple to install. This is particularly true in areas of difficult (e.g. mountainous) terrain or of high population density where the installation costs of a traditional buried cabled network are prohibitively high. However, microwave networks have the great disadvantage of being limited by a very low data rate and are therefore of little use for high capacity links or for networks where it is essential to ensure that bandwidth capability is never outstripped by consumer bandwidth demand. Microwave capacity can be enhanced by installing more links, but deployment of additional links will soon push the overall cost of a microwave network to the point where it outstrips the cost of a much higher bandwidth traditional buried cables system. For networks with a low predicted capacity, microwave can be the lowest cost solution, but microwave will inhibit significant capacity expansion and in the longer term may result in lost business opportunity.

2.2.2 MMDS (Multichannel Multipoint Distribution Service)

For a wide coverage area, a microwave system will require a multitude of point to point links. MMDS allows the point-to-point antenna system used for microwave links to be replaced by a sector antenna in the transmitting base station which sends signals to multiple locations within a 60° or 90° angle sector (see Figure 5). By overcoming the point to point limitations of microwave links and enabling a wide coverage area, MMDS offers a microwave solution with a reduced cost per link. MMDS uses this point to multipoint architecture to deliver television signals and, more recently, telephone/fax and data communications.

Multichannel Multipoint Distribution Service (MMDS) network architecture
Figure 5

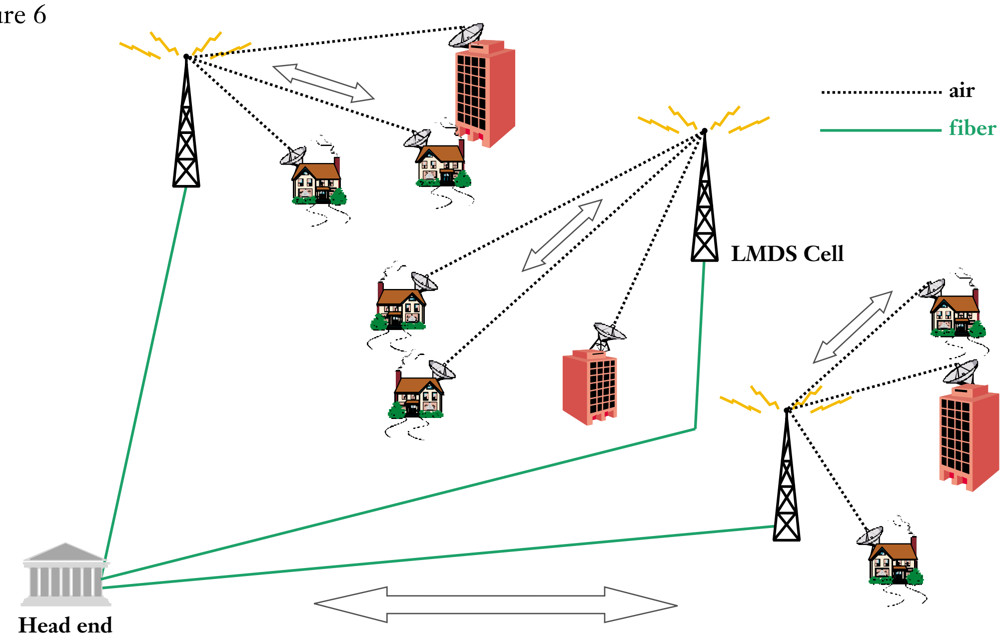


Initially referred to as wireless cable, MMDS has been around since the 1970s. MMDS was introduced as an alternative to Cable TV, to provide coverage in areas of remote or difficult terrain where the cost of cable installation were prohibitively high. MMDS service is delivered using terrestrial based radio transmitters that use frequencies in the lower end of the ultra-high frequency (UHF) range of the radio spectrum (between 2.1 and 2.7 GHz). The transmitters are sited at the highest location in the intended coverage area. Each subscriber receives MMDS using a small digital receiver placed at their location with line of sight to the transmitters. The workable range can reach up to 100 km in flat terrain but is significantly less in hilly or mountainous areas. MMDS channels are 6 MHz wide and run on licensed and unlicensed bands. In the US a bandwidth block of 200 MHz is allocated to a licensed MMDS carrier, which originally facilitated 33 analog TV channels of 6 MHz each. With the migration to digital services, the 33 analog channels were converted to 99 digital, 10 Mbps data streams, enabling full Ethernet connectivity and a total capacity of up to 1 Gbps. Capacity can be further increased by multiplexing the use of frequencies and sector cells. However, as a large number of users may share the same radio channels, data throughputs are typically much lower than they are for many other broadband wireless options, with practical data throughputs in the range of 500 kbps to 1 Mbps. Customers are protected from interference from other users when the provider uses licensed frequencies and due to the use of the lower frequencies on the UHF radio spectrum, rain, fog or snow do not affect performance. However, the ultimate limitation of MMDS is the limited number of licensed channels available. Only 600 MHz of bandwidth is available between 2.1 and 2.7 GHz and licensed MMDS is typically operated only in the 200 MHz section from 2.5 GHz to 2.7 GHz. This restricts the available bandwidth and thereby limits the data rate per subscriber or the total number of possible subscribers, making MMDS a broadband solution that is suited only to low data rate or localized services.

2.2.3 LMDS (Local Multipoint Distribution Service)

Like MMDS, LMDS uses a sector antenna at the base station to transmit in a point to multi-point fashion over a wide coverage area (see Figure 6). By operating in the higher UHF radio frequencies (27.5 GHz to 31 GHz), LMDS can offer much higher bandwidth but the range of the radio signals is limited to approximately 8 km, due to higher free space attenuation. Hence, it is a very localized service. In the US LMDS has been allocated the 27.5 to 29.5 GHz band and is currently intended to deliver digital TV services with each channel occupying 20 MHz of bandwidth. LMDS can also used to provide two-way broadband services such as voice, data, video and internet. Each LMDS channel is capable of 45 Mbps downstream (with an upper limit of 155 Mbps) but requires LOS between the base station and customer transceiver. Like MMDS, LMDS offers a more economical solution for wide area coverage than point to point microwave links. However, LMDS is distance limited and the ultimate subscriber capacity and their respective maximum data rate are also limited by the available radio spectrum.

Local Multipoint Distribution Service (LMDS) network architecture
Figure 6



2.2.4 FSO (Free Space Optics)

A FSO system employs the use of infra-red sources or lasers to support free-space data transmission rates of between 10Mbps and 1.25Gbps between a transmitter and a receiver over distances of up to 4km. LOS is required for such system, which operate at THz frequencies in the RF spectrum. The main advantages of FSO systems are the low installation costs and avoidance of radio spectrum licensing requirements as FSO systems use a light signal instead of a radio wave. However, due to the point-to-point nature of FSO systems, they are not cost effective for the wide area coverage required for competitiveness in today's broadband consumer market. In addition, free-space optics are susceptible to system outage in poor weather conditions. FSO systems are therefore primarily suited to private applications.

2.2.5 WiFi (Wireless Fidelity) and WiMAX (Worldwide Interoperability for Microwave Access)

WiFi is a highly localized adaptation of MMDS, which does not require LOS. Based on the IEEE 802.11x standard and transmitting in unlicensed spectrum at 2.4 GHz, WiFi operates in the low frequency area of UHF in a point to multi-point fashion. The increased penetration of signals at these frequencies allows WiFi transmitters to operate at low power and still achieve ranges of up to 30 meters in doors and up to 450 meters outdoors. The main application of WiFi is to provide highly local wireless radio links to end user communications equipment (e.g. PCs, VoIP phones) within customer premises/residences. The latest WiFi products support data rates up to 54 Mbps and encryption software is used to provide user security. WiFi "hotspots" are premises such as airports, and restaurants which have set up local WiFi connectivity to the internet. Although it is best suited to within building applications, in certain cities (e.g. Amsterdam) WiFi service providers have set up and are using multiple WiFi transceiver sites to provide city centre WiFi connectivity to individuals and private enterprises (e.g. hotels) over a radius of approximately 3 km. However, at present the 54 Mbps per channel capability limits the practical end user data rate to approximately 1 Mbps.

WiMAX is the latest wireless broadband technology which is designed to deliver WiFi type connectivity over a much greater range and thereby compete as a point-to-multipoint last-mile broadband wireless access solution. It is important to note that there are two types of WiMAX; line of sight (LOS) and non-line of sight (NLOS). The LOS WiMAX systems are point to point operation only while the NLOS WiMAX systems are point to multi-point.

Although the LOS systems have much better reach capabilities, they will not facilitate a large consumer service coverage area and so it is the much shorter reach NLOS systems which are being developed to offer an alternative large-scale consumer broadband service technology. WiMAX is based on the IEEE 802.16 standard and the latest amendment, to facilitate mobile services, has just been standardized. WiMAX equipment suppliers aim to provide fixed, nomadic, portable and, eventually, mobile wireless broadband connectivity without the need for direct line-of-sight with a base station within a given sector cell. In a typical cell radius deployment of 3 to 9 km, WiMAX Forum Certified™ systems aim to ultimately deliver capacity of up to 75 Mbps per channel, for fixed and portable access applications. Mobile network deployments are aiming to provide up to 15 Mbps of capacity within a typical cell radius deployment of up to 3 km. However, current practical bandwidth capabilities are much lower and as WiMAX is a shared bandwidth technology, the ultimate bandwidth delivered to a subscriber can be lower than the channel capacity and will depend on the customer per channel contention ratio.

For NLOS systems, there is a further choice between indoor self-install or outdoor customer premise equipment (CPE). The indoor self-install equipment will be favoured by the consumer market as it has the distinct advantages of simplicity of installation, but the reach is severely reduced as the signal is attenuated by the infrastructure of the building. There are also two grades of WiMAX network installations; standard and full-featured. Table 2 shows that the performance of WiMAX varies greatly and is a very complex function of the type of WiMAX deployed, be it NLOS or LOS, the consumer friendly indoor self-install or the outdoor equipment, a standard or a full-featured installation.

Reach and bandwidth performance that is achievable for current WiMAX systems (source: www.WiMAXforum.org); however current practical NLOS ranges are reported in the order of 3 – 5 km with maximum data rates of 2 to 10 Mbps.
Table 2

WiMAX System Type	**Reach Capability**	**Max. Downlink Bandwidth Per Sector**	**Max. Uplink Bandwidth Per Sector**	**Downlink Bandwidth Per CPE At Cell Edge**	**Uplink Bandwidth Per CPE At Cell Edge**
Standard					
LOS	10 – 16 km	8 – 11.3 Mbps	8 – 11.3 Mbps	2.8 – 11.3 Mbps	2.8 – 11.3 Mbps
NLOS	1 – 2 km 0.3 – 0.5 km (indoor self-install)	8 – 11.3 Mbps	8 – 11.3 Mbps	2.8 – 11.3 Mbps	2.8 – 11.3 Mbps
Full-Featured					
LOS	30 – 50 km	8 – 11.3 Mbps	8 – 11.3 Mbps	2.8 – 11.3 Mbps	2.8 – 11.3 Mbps
NLOS	4 – 9 km 1 – 2 km (indoor self-install)	8 – 11.3 Mbps	8 – 11.3 Mbps	2.8 – 11.3 Mbps	0.7 – 0.175* Mbps

*assumes only one subchannel is used to extend to edge of sector cell

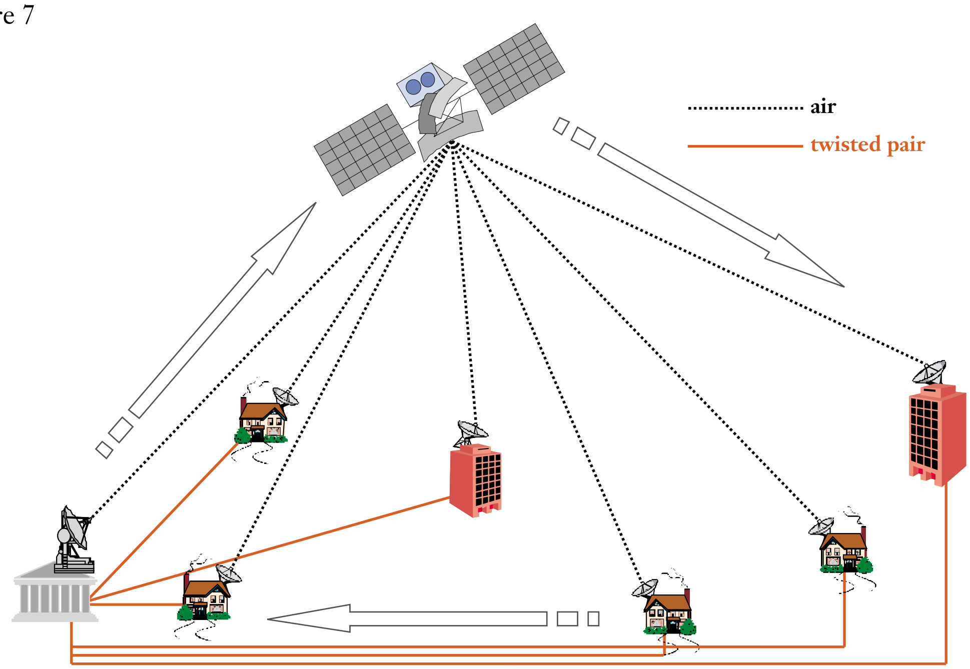
Table 2 shows that standard WiMAX equipment aims to deliver between 8 and 11 Mbps of upstream and downstream bandwidth per channel but only over a range of 1 to 2 km for NLOS operations. Equivalent indoor self-install standard WiMAX solutions aim to achieve similar bandwidths but only over 0.3 to 0.5 km of range. The latest generation of full-featured WiMax equipment aims to deliver a bidirectional bandwidth of up to 11 Mbps over 3 to 9 km with NLOS capability and the same bandwidth over a 1 to 2 km range for NLOS indoor self-install applications.

WiMAX has received much attention as the next generation wireless broadband solution for backhauling WiFi hot spots and even metro access coverage. However, pre-standard products from some vendors like Airspan and Alvarion reveal a practical NLOS cell radius of only 3 to 5 km with maximum bit rates of only 2 to 10 Mbps per customer premises equipment (CPE). Given the ultimate limitation of the bandwidth of the frequencies assigned to WiMax in the radio spectrum, it is unlikely that WiMax will ever be able to provide ubiquitous high data rate broadband services to a mass consumer base.

2.2.6 Direct Broadcast Satellite (DBS)

Primarily a direct-to-home digital TV broadcasting wireless solution, newer Direct Broadcast Satellite (DBS) services also provide two-way high-speed data transmission services. DBS uses geostationary satellites operating in the Ku band with a 12 GHz downlink and a 14 GHz uplink. Figure 7 shows the architecture of a DBS wireless broadband network, where the satellite relays the composite signal of digitized video and data services from a headend via an earth station and then broadcasts that signal to an area of targeted subscribers. Data rates of between 16 kbps and 155 Mbps can be obtained but the major drawback is that geostationary satellites being 22,300 km from the earth's surface introduce a 250 ms delay into the network. For most broadband services this latency is unacceptable. The use of a network of low-earth-orbit or LEOS satellites orbiting at only 1000 km will reduce this latency to 50 ms but such systems are not widely available as yet. However, satellites, like all other systems using the radio spectrum are limited in capacity by the bandwidth available. For satellites operating in the Ku band there a limit of 2 GHz of available bandwidth.

Direct Broadcast Satellite (DBS) network architecture
Figure 7



2.2.7 Mobile Phone Networks: 2G and 3G Networks

UMTS (Universal Mobile Telecommunications Services), which is also known as 3G, is the next generation high speed mobile system for the existing 2G and 2.5G digital cellular systems that are based on GSM (Global Systems for Mobile). Since the introduction of GPRS, mobile phones have had data transfer and internet connectivity and as a consequence can be considered as a broadband solution.

Standard digital GSM based mobile phone services of the 2G era offer voice and low data rates. GSM networks are circuit switched and use a combination of the TDMA (Time Division Multiple Access) and FDMA (Frequency Division Multiple Access) standards to enable multiple subscriber bandwidth access at data transfer rates of up to 14.4kbps. A more advanced mobile bandwidth access technology is CDMA (Code Division Multiple Access) but this was not adopted for GSM.

GPRS (General Packet Radio Service) is an additional technology which is applied as an overlay on GSM networks to facilitate higher data rates (up to 170 kbps) and transfer of larger data files. GPRS involves overlaying a packet-based air interface on the existing circuit switched GSM network. This gives the user the option to use a higher data rate packet-based data service. As GPRS introduces packet switching and IP to mobile networks, it therefore functions as an interim step for GSM networks on the route to 3G services. GPRS enables simultaneous voice and data handling. GPRS users can have always-on connectivity to the internet, high speed delivery of emails with large file attachments, web surfing using WAP (wireless access protocol) and access to corporate LANs (Local Area Networks).

For many operators the upgrade path from GSM-GPRS is 3G technology. However, the GSM Association is also pushing for EDGE (Enhanced Data for Global Evolution) as an interim step in the migration path from GPRS and GSM systems to 3G. EDGE takes the cellular community one step closer to 3G. Like GSM, EDGE uses a combination of FDMA and TDMA as the multiple access control techniques but EDGE uses a new modulation scheme called 8-phase shift keying (PSK) to enable a more efficient use of bandwidth and as a result data rates of up to 384 kbps.

The migration to 3G systems will enable mobile data transmission rates of between 384 kbps and 2 Mbps. The 3G mobile phone user will have access to high speed internet access, videoconferencing and even basic on-line video and TV services. 3G systems can use one of two international standards for its radio access technology, CDMA2000 and W-CDMA, as specified by ITU working group IMT-2000 (International Mobile Telephone). CDMA is a more advanced method for subscriber bandwidth sharing than either of the FDMA or TDMA systems used by GSM. W-CDMA is the upgrade path for operators with GSM while CDMA2000 is the migration path for the minority of operators with a cdmaOne legacy system.

Although 3G mobile phone services will ultimately offer up to 2 Mbps in broadband data transmission capability, this bandwidth is not sufficient for 3G to be considered as a major competitor in the broadband (to the home) technology market. Mobile 3G will be a service that is used in addition to mainstream broadband services.

3.0 Broadband Technology Comparison

Each broadband technology has its own unique characteristics, including advantages and disadvantages. In some deployment scenarios, the choice of technology is obvious, being driven by factors such as the nature if the terrain or expense of rights of way (ROW). However, in many other circumstances, the choice is not exactly simple, and it depends very much on the type of services to be provided, the penetration rate, the availability of alternatives, and other economical and technical considerations.

To assist in the difficult task of broadband technology selection, in Table 3 we compare the major broadband technologies on spectrum usage, capacity, coverage/reach, advantages and limitations.

Comparison of capabilities of Fixed Line and Wireless broadband technologies
Table 3

Technology	Spectrum Usage	Capacity Shared?	Capacity	Max Range	Advantages	Limitations
Fixed Line						
HFC	7 – 860 MHz (Typically 7-550 MHz) 6 MHz per channel	Yes (by up to 1000)	40 Mbps per channel, upgrade path to 50 Mbps proposed Typical bandwidth per user 0.5 – 3 Mbps	Amplifiers are installed to extend range. This is cost effective typically up to 100 km.	Uses existing cable TV network	Limited bandwidth per channel, bandwidth is shared by many users, asymmetric - very low upstream data rates
ADSL	Up to 1.1 MHz	No	12 Mbps @ 0.3 km 8.4 Mbps @ 2.7 km 6.3 Mbps @ 3.6 km 2 Mbps @ 4.8 km 1.5 Mbps @ 5.4 km	Max: 5.4 km	Uses existing POTS	Limited bandwidth which is distance sensitive, asymmetric - order of magnitude lower upstream rate.
VDSL	Up to 1.1 MHz	No	52 Mbps @ 0.3 km 26 Mbps @ 0.9 km 13 Mbps @ 1.3 km	Max: 1.3 km (from node)	Mainly uses existing POTS	Limited distance requires fiber feeds. Bandwidth is very distance sensitive
ADSL2+	Up to 2.2 MHz	No	26 Mbps @ 0.3 km 20 Mbps @ 1.5 km 7.5 Mbps @ 2.7 km	Max: 2.7 km (any further yields rates similar to ADSL only)	Uses existing POTS	Bandwidth is distance sensitive
BPL	1 – 30 MHz	Yes	Max: 200 Mbps Typical: 2 – 3 Mbps	1 to 3 km	Uses existing power lines	Expensive power line upgrades, with amateur radio
FTTH	THz	PON: Yes P2P: No	Up to 1 Gbps per channel per fiber	20 km	Relatively unlimited bandwidth	Requires new fiber access network overlay

Technology	Spectrum Usage	Capacity Shared?	Capacity	Max Range	Advantages	Limitations
Wireless						
Microwave	2, 4, 6, 21.3 – 23.6 GHz > 40 GHz UHF (Licensed)	Yes	Up to 155 Mbps per link	5 km	Quick setup	LOS Point-to-point
LMDS	26 – 13 GHz (Licensed)	Yes	Up to 155 Mbps per base station	4 km	Point to multipoint Large capacity	LOS Not standardized
MMDS	2.5 – 2.6 GHz (Licensed)	Yes	Up to 10 Mbps per base station	50 km	Point to multipoint NLOS Long range	Low capacity Not standardized
3G (WCDMA, CDMA200)	1.92 – 1.98 GHz 2.11 – 2.17 GHz (Licensed)	Yes	Up to 2 Mbps per mobile subscriber	Coverage area of host network	Mobile terminals Ride on existing cellular infrastructure	Costly spectrum Limited applications
FSO	Infra-red THz region of RF spectrum (Unlicensed)	No	Up to 2.5 Gbps per link	4 km	Low setup cost Unlicensed spectrum	LOS Performance is weather sensitive
WiFi	2.4, 5.7 GHz (Unlicensed ISM bands ISM: Industry, Scientific and Medical	Yes	11, 54 Mbps	Up to 100 m	Ethernet compliant Standardized 802.11 a/b/g	For LAN applications only Security issues
Standard WiMAX	3.5 GHz	Yes	2.8 to 11.3 Mbps per downlink per CPE[1] 2.8 to 11.3 per uplink per CPE	LOS- 10 to 16 km NLOS- 1 to 2 km Indoor self-install NLOS 0.3 – 0.5 km	NLOS to be standardized (except for first version 802.16)	Practical bit rate is 2 Mbps per subscriber and maximum NLOS cell size limited to 1 – 2 km
Full Featured WiMAX	3.5 GHz	Yes	2.8 11.3 Mbps per downlink per CPE[2] 0.17 to 0.7 Mbps per uplink per CPE (at sector cell edge)	LOS- 30 to 50 km NLOS- 3 to 8 km Indoor self-install NLOS 1 – 2 km	NLOS to be standardized (except for first version 802.16)	Practical bit rate is 2 Mbps per subscriber and indoor self-install NLOS cell size limited to 1 – 2 km
Satellite	Ku-, Ka-, C-, L- and S-band 1.5~3.5, 3.7~6.4, 11.7~12.7, 17.3~17.8, 20~30 GHz (Licensed)	Yes	Up to 155 Mbps per downlink	Large coverage area of up to 1000 – 36,000 km	Large coverage Suitable for multicast applications	Expensive to build Limited capacity per subscriber

[1] CPE: Customer Premise Equiptment

4.0 Conclusions

In order to remain competitive as the broadband market evolves, broadband service suppliers must have a strategy to be able to offer a triple play service at some point in the future; that is, voice, data and video. Of these three, video service is the most challenging as it requires most bandwidth.

There are a myriad of fixed-line and wireless broadband solutions available, with each technology having its own merits and demerits. Those fixed-line technologies operating over existing copper, coax or power lines are bandwidth limited by the nature of the transmission medium. Free space or wireless technologies that use the radio spectrum are also bandwidth limited, but in their case, by the amount of available licensed radio spectrum. Of these, WiMAX is the most promising technology for metro-based broadband provision. However the NLOS and indoor self-install system capabilities that are necessary features to attract and reach a widespread consumer base, place significant restrictions on WiMAX's data rate and reach performance.

It is an unchallenged fact that fiber as a communication medium offers almost infinite bandwidth relative to all its competitors. Fiber has other highly advantageous benefits such as a much higher level of security and reliability than copper/wireless networks provided by its immunity to electro-magnetic interference. The unsurpassed reliability of optical systems also leads to low operating costs. As consequence, direct fiber connections, to each and every home, are a very desirable concept. Up until recently, the cost of customer premise equipment (CPE) has been prohibitively high. However, the recent favorable FCC ruling, which provides competitive protection for fiber to the home (FTTH) builds in the US, has opened up a mass market for FTTH products. The economies of scale, associated with the resultant increase in the US FTTH market size, have driven the cost of CPE equipment down to new much more affordable levels. However, FTTH network deployments still require the installation of fiber optic cables throughout the access network, and the inherent cost of such cable installation is the major concern of many operators considering FTTH deployment. Nonetheless, the ultimate bandwidth capability, high reliability, security and low operating costs of FTTH systems, coupled with the new affordability of FTTH equipment is beginning to drive further deployment of FTTH in regions of the world outside the US.