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ΟΙΚΟΝΟΜΙΚΩΝ ΚΑΙ ΚΟΙΝΩΝΙΚΩΝ ΕΠΙΣΤΗΜΩΝ

Last Mile Networking:

Technology, Case Studies, Economics and Applications

ΑΛΕΞΙΟΥ ΙΩΑΝΝΗΣ

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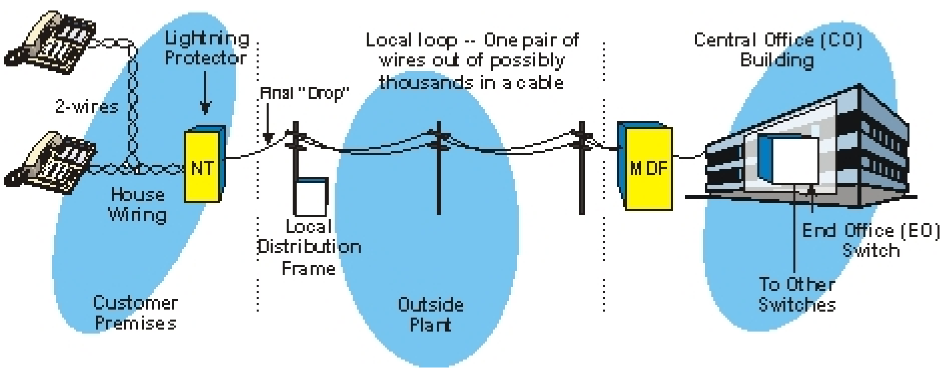

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ABSTRACT

In telecommunications, the local loop (also referred to as a subscriber line) is the physical link or circuit, that connects from the demarcation point of the customer premises to the edge of the carrier, or telecommunications service provider, network. The challenge that we face today is the same one we always faced and will face in the future, and that is the last mile of connectivity. That has always been the problem of most issues in terms of cost and reliability. Today it is where there are the highest costs and the least competition and the lowest bandwidth.

Nowadays, there wired and wireless last-mile connectivity solutions. Fiber optics can offer the highest bandwidth , but a cost. Copper and coaxial wires provide enough bandwidth with technologies like xDSL and Cable modems, at a reasonable cost for the provider. BPL , is a promising technology based on the usage of power lines as the last-mile of connectivity. On the other hand, WLL`s such as LMDS, WiFi and WiMAX offer xDSL 'like' bandwidth and can be used for low-density populated areas, where it is not profitable to create network infrastructure. Likewise, IoS, the satellite solution, offers broadband to much more difficult areas and not developed countries but is the most expensive of them all.

It is definite that in the future most last-mile networks will be hybrid and choices of last-mile technology to be used will be made under techno-economical aspects.

ΠΕΡΙΛΗΨΗ

Στις τηλεπικοινωνίες, ο τοπικός βρόχος αποτελεί το φυσικό μέσο διασύνδεσης του παρόχου τηλεπικοινωνιακών υπηρεσιών με τις εγκαταστάσεις του πελάτη. Η πρόκληση που αντιμετωπίζουμε σήμερα είναι αυτή που αντιμετωπίζαμε πάντα και θα αντιμετωπίζουμε στο μέλλον, και αυτό είναι ο τοπικός βρόχος. Αυτό ήταν πάντα το πρόβλημα των περισσότερων ζητημάτων από την άποψη του κόστους και της αξιοπιστίας. Σήμερα είναι το κομμάτι του δικτύου όπου υπάρχουν οι υψηλότερες δαπάνες και ο λιγότερος ανταγωνισμός και το χαμηλότερο εύρος ζώνης.

Σήμερα, υπάρχουν τεχνολογίες τοπικού βρόχου που βασίζονται στα ενσύρματα και στα ασύρματα μέσα μετάδοσης. Η οπτική ίνα μπορεί να προσφέρει το υψηλότερο εύρος ζώνης, αλλά με μεγάλο κόστος εγκατάστασης και συντήρησης. Ο χαλκός και τα ομοαξονικά καλώδια παρέχουν αρκετό εύρος ζώνης χρησιμοποιώντας τεχνολογίες όπως xDSL και Cable modem, με μικρότερο κόστος για τον προμηθευτή. Το BPL, είναι μια ελπιδοφόρος τεχνολογία βασισμένη στη χρήση των γραμμών μεταφοράς ηλεκτρισμού ως τοπικό βρόχο. Αφ' ετέρου, τα WLL`s όπως LMDS, WiFi και WiMAX προσφέρουν παρόμοια απόδοση με το xDSL και μπορούν να χρησιμοποιηθούν στις αραιοκατοικημένες περιοχές, όπου δεν είναι κερδοφόρο να δημιουργηθεί η υποδομή δικτύων. Επιπλέον, το IoS, η δορυφορική λύση, προσφέρει ευρυζωνικές υπηρεσίες στις δύσβατες περιοχές και μη αναπτυγμένες χώρες, αλλά είναι η ακριβότερη λύση.

Είναι προφανές ότι στο μέλλον τα περισσότερα δίκτυα τοπικού βρόχου θα είναι υβριδικά και οι επιλογές των τεχνολογιών που χρησιμοποιηθούν θα βασίζονται σε τεχνοοικονομικούς παράγοντες.

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Introduction

The increasing worldwide demand for rapid, low latency and high volume communication of information to homes and businesses has made economical information distribution and delivery increasingly important. As demand has escalated, particularly fueled by the widespread adoption of the Internet, the need for economical high speed access by end-users located at millions of locations has ballooned as well. As requirements have changed existing systems and networks which were initially pressed into service for this purpose have proved to be inadequate. To date, although a number of approaches have been tried and used, no single clear solution to this problem has emerged. This problem has been termed "The Last Mile Problem" also know as “local loop”.

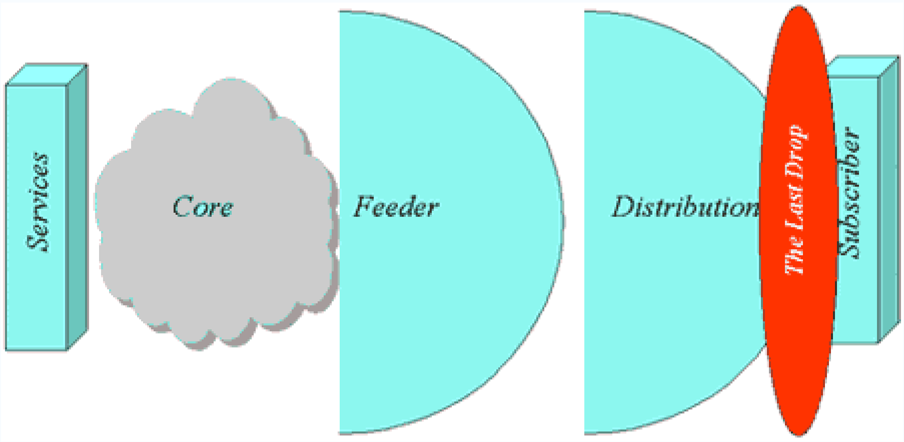


Figure : The Last Mile

- As expressed by Shannon's equation for channel information capacity, the omnipresence of noise in information systems sets a minimum signal power requirement in a channel, even when adequate spectral bandwidth is available. Since information quantity is the integral of rate with respect to time, this requirement leads to a corresponding minimum energy per bit. The problem of sending any given amount of information across a channel can therefore be viewed in terms of sending sufficient information-carrying energy, hereon abbreviated ICE. For this reason the concept of an ICE "pipe" or "conduit" is relevant and useful for examining existing systems.

In telecommunications, the local loop (also referred to as a subscriber line) is the physical link or circuit, that connects from the demarcation point of the customer premises to the edge of the carrier, or telecommunications service provider, network. At the edge of the carrier network in a traditional PSTN (Public Switched Telephone Network) scenario, the local loop terminates in a circuit switch housed in the CO (Central Office). Traditionally, the local loop was a twisted pair or coaxial cable from customer to central office. The local loop may terminate at a circuit switch owned by a CLEC (Competitive LEC) and housed in a POP, which typically is either an ILEC CO or a carrier "hotel". Making the local loop available, usually by law, to the owner's competitors, is referred to as local loop unbundling.

As the president of AT&T's network services group, Frank Ianna has had the mother of all networking jobs. He's spent the last 11 years running the world's largest voice and data network. SearchNetworking.com caught up with Ianna, who is retiring this fall, to discuss what he's learned in his time at the helm of AT&T's enormous network and to catch some parting words of wisdom.

Frank Ianna

What new networking technology will be the most challenging in the next two years?

Ianna: The challenge that we face today is the same one we always faced and will face in the future, and that is the last mile of connectivity. That has always been the crux of most issues in terms of cost and reliability. Today it is where there are the highest costs and the least competition and the lowest bandwidth. There are a number of technologies that can address those issues. There is power line technology, Gigabit radio, Wi-Fi and others. There is no silver bullet.

Local loop connections in this sense include:

- Broadband over Powerline: **BPL**
- Coaxial Cable local loop: **Cable TV**
- Twisted pair local loop: **xDSL**
- Fiber Local Loop: **FTTN / FTTH**
- Wireless local loop (WLL): **LMDS, WiMAX, e.t.c**

- Satellite local loop: Internet over Satellite **(IoS)**

BPL

Despite the proliferation of broadband technology in the last few years, there are still huge parts of the world that don't have access to high-speed Internet. When weighed against the relatively small number of customers Internet providers would gain, the cost of laying cable and building the necessary infrastructure to provide DSL or cable in rural areas is too great. But if broadband could be served through power lines, there would be no need to build a new infrastructure. Anywhere there is electricity there could be broadband.

Like phone companies, power companies also have lines strung all over the world. The difference is that they have power lines in a lot more places than phone companies have fiber optics. This makes power lines an obvious vehicle for providing Internet to places where fiber optics haven't reached.

This is BPL. An emerging technology may be the newest heavy hitter in the competitive world of broadband Internet service. It offers high-speed access to your home through the most unlikely path: a common electrical outlet.

By slightly modifying the current power grids with specialized equipment, the BPL developers could partner with power companies and Internet service providers to bring broadband to everyone with access to electricity.

With broadband over power lines, or BPL, you can plug your computer into any electrical outlet in your home and instantly have access to high-speed Internet. BPL is a recently commercialized technology that allows broadband Internet (using Internet Protocol - IP) to be transported over the Grid at speeds ranging from 4Mbps to 145Mbps for delivery of IP data traffic and applications to homes and businesses on a shared basis.

When power leaves the power plant, it hits a transmission substation and is then distributed to high-voltage transmission lines. When transmitting broadband, these high-voltage lines are the first obstacle.

The power flowing down high-voltage lines is between 155,000 to 765,000 volts. That amount of power is unsuitable for data transmission. It's too "noisy."

As stated before, both electricity and the RF used to transmit data vibrate at certain frequencies. Since power lines are usually unshielded, in order for data to transmit cleanly from point to point, it must have a dedicated band of the radio spectrum at which to vibrate without interference from other sources

Hundreds of thousands of volts of electricity don't vibrate at a consistent frequency. That amount of power jumps all over the spectrum. As it spikes and hums along, it creates all kinds of interference. If it spikes at a frequency that is the same as the RF used to transmit data, then it will cancel out that signal and the data transmission will be dropped or damaged en route. BPL bypasses this problem by avoiding high-voltage power lines all together. The system drops the data off of traditional fiber-optic lines downstream, onto the much more manageable 7,200 volts of medium-voltage power lines.

Once dropped on the medium-voltage lines, the data can only travel so far before it degrades. To counter this, special devices are installed on the lines to act as repeaters. The repeaters take in the data and repeat it in a new transmission, amplifying it for the next leg of the journey.

In Current Communications Group's model of BPL, two other devices ride power poles to distribute Internet traffic. The BPL injector allows the data on the line to bypass transformers.

The transformer's job is to reduce the 7,200 volts down to the 240-volt standard that makes up normal household electrical service. There is no way for low-power data signals to pass through a transformer, so you need a coupler to provide a data path around the transformer. With the coupler, data can move easily from the 7,200-volt line to the 240-volt line reaching the last-mile.

The diagram below (BPL Architecture) shows IP data from the Internet being injected at the HV/MV substation, travelling through the electrical grid and being accessed by consumers using a BPL modem at their premises.

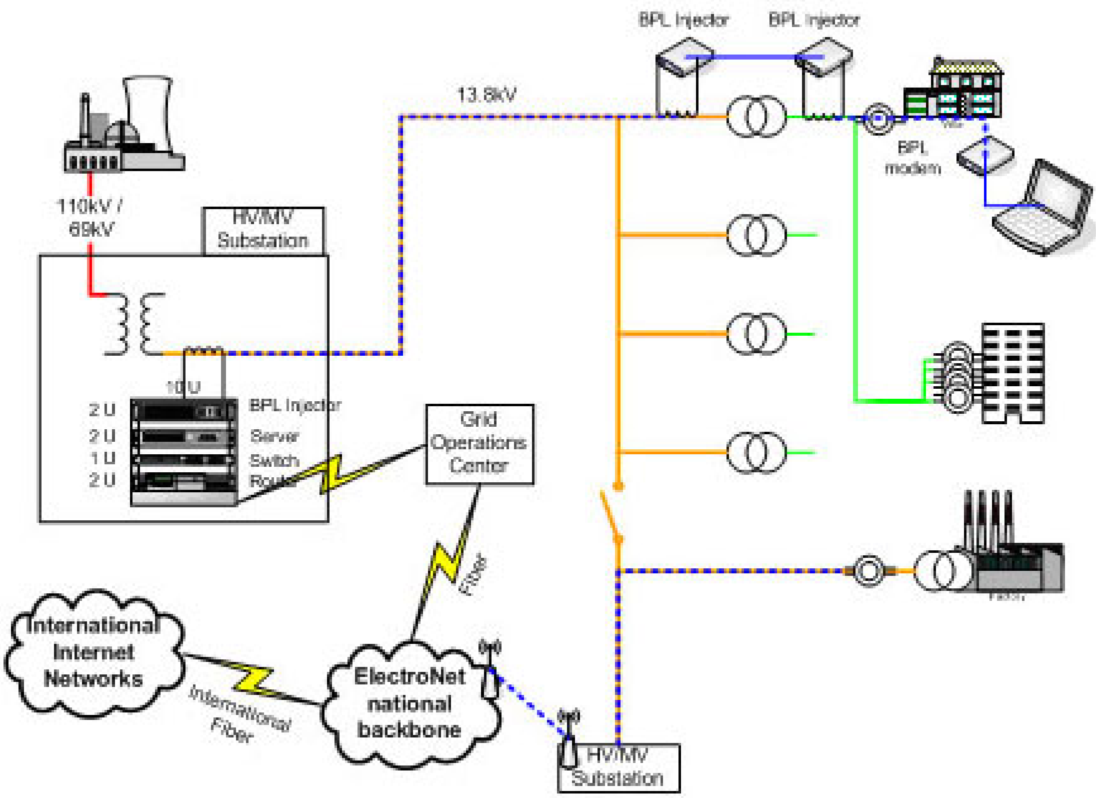
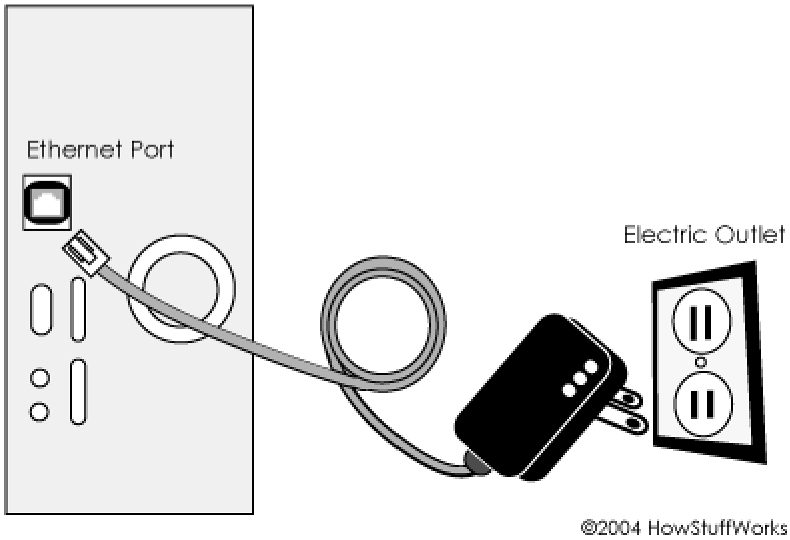


Figure : BPL network architecture

BPL Modems

BPL modems use silicon chipsets specially designed to handle the work load of pulling data out of an electric current. Using specially developed modulation techniques and adaptive algorithms, BPL modems are capable of handling powerline noise on a wide spectrum.



The BPL modem simply plugs into the wall and then into your computer. These modems are capable of speeds comparable to DSL or cable modems.

A BPL modem is plug and play and is roughly the size of a common power adapter. It plugs into a common wall socket, and an Ethernet cable running to your computer finishes the connection. Wireless versions are also available.

Future Challenges

On April 23, 2003, the FCC put forth a Notice of Inquiry to the public supporting the potential of the BPL technology and seeking to set standards in practice for its implementation. Immediate opposition came from the American Radio Relay League (ARRL) and the Federal Emergency Management Agency (FEMA). Both entities claim that BPL will cause serious interference issues.

A BPL modem is considered an unlicensed device, like a cordless phone or garage door opener. All unlicensed devices are governed by the FCC's Part 15 rules. Part 15 mandates that all electronic devices sold in the United States must meet FCC radio-frequency emissions limits. These limits are in place to secure against interference with important transmissions like CB communications, air-traffic control and government channels. ARRL and

FEMA are concerned about the interference caused by BPL signals transmitted on exposed medium-voltage power lines.

Cable TV operators get around the interference problem by shielding all of their cables. "Coaxial cable" used by cable TV operators has a braided metal shield that surrounds the signal wire. Telephone cables are also shielded. Power lines, on the other hand, have no shielding. In many cases, a power line is a bare wire, or a wire coated in plastic. The lack of shielding is where the interference concern comes from.

Depending on the bandwidth the FCC allots for BPL, interference with other radio services may be a problem. Currently, the frequency band breaks down as follows:

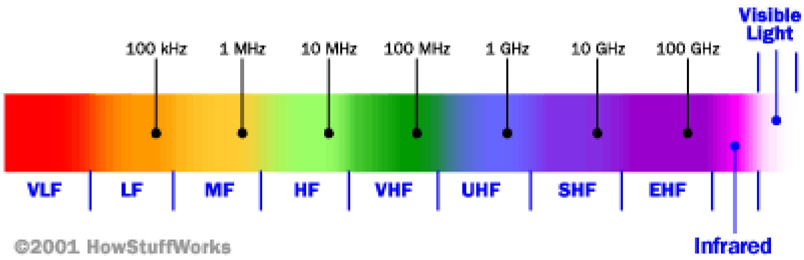


Figure : Frequency band

- AM radio - 535 kilohertz to 1.7 megahertz
- Short-wave radio - 5.9 megahertz to 26.1 megahertz
- Citizens-band (CB) radio - 26.96 megahertz to 27.41 megahertz
- Television stations - 54 to 88 megahertz for channels 2 through 6
- FM radio - 88 megahertz to 108 megahertz
- Television stations - 174 to 220 megahertz for channels 7 through 13

While FEMA is wiling to allow the FCC to seek a compromise, the ARRL claims that compromise is not possible because the bandwidth needed for BPL will directly interfere with ham radio and short-wave radio transmissions. Developers of BPL say that these interference issues have been solved. Only tests and time will tell. Until then, the advancement of BPL moves forward slowly as it waits for standards and logistics to be decided by regulating bodies.

CABLE TV (COAXIAL CABLE)

Coaxial cables have been used to construct the cable TV distribution network. Because TV channels are located at high-frequency bands, coaxial cables are used to construct the cable TV distribution network.

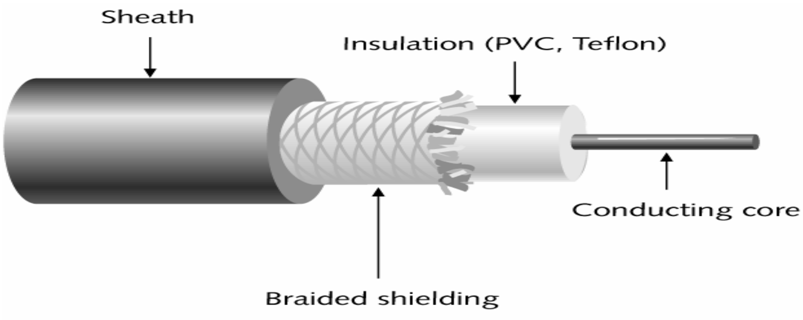


Figure : A coaxial cable

A coaxial cable consists of an inner copper conductor and an external aluminum wrap overlaid with another shield of copper or aluminum braid. There are also nylon form insulations between the inner conductor and the aluminum wrap and a plastic cover over the metal braid. The TV signal is carried over the inner conductor while the aluminum wrap and the metal braid are connected to electrical ground. The electromagnetic shielding effect of coaxial cables is pretty effective especially at high-frequency bands where TV channels are located.

The cable TV distribution network is constructed following a tree and branch structure. The cable TV signal from a main hub is first brought to an optical node through a glass optical fiber where the cable TV signal is Amplitude Modulated (AM) to an optical carrier frequency. After demodulation using Optical-Electronic (O/E) devices in the optical node, the cable TV signal is carried over a few branches of coaxial cable network to every subscriber. The root of each tree and branch distribution network is at the optical node. The main branch of the distribution network consists of distribution coaxial cables. The common types of distribution coaxial cables are 500-F and 625-F. The distribution cable is connected to subscribers through a device called a

Tap and drop coaxial cables. A Tap device is inserted by connecting one end of the cut distribution cable to its input port and the other end of the cable to its output port. The insertion of a Tap device will reduce the signal level on the distribution cable by a small amount. The captured signal is distributed to multiple drop cable ports on a Tap device. The common drop cable types are RG-6 and RG-59. Drop cables are also used for in-house TV signal wiring.

The in-house TV signal wiring has not been widely publicized as a transmission medium for home networking for several reasons.

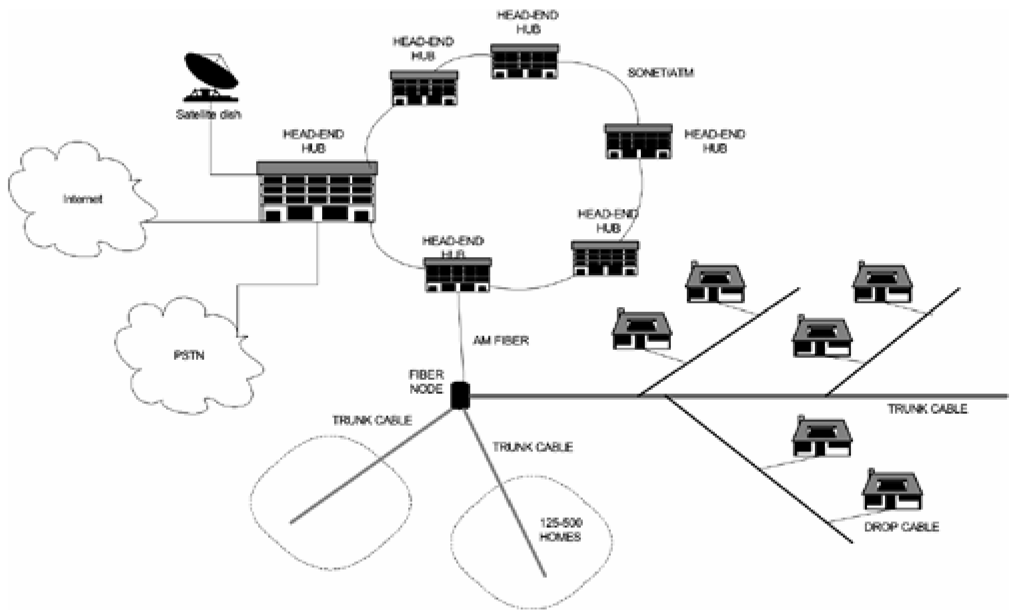


Figure : CATV network architecture

First, for most households where the coaxial cables are installed by cable TV companies as an extension to their cable TV network, there are usually not many cable connections, and the cable TV company owns the wiring infrastructure.

Cable Modems

A subscriber can continue to receive cable television service while simultaneously receiving data on cable modems to be delivered to a personal computer (PC) with the help of a simple one-to-two splitter.

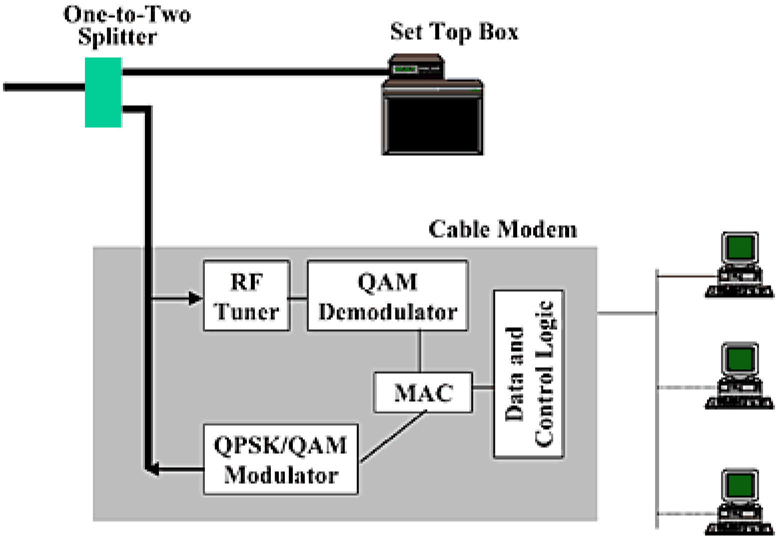


Figure : Cable modem block diagram

Cable Data Network Architecture

Cable data network architecture is similar to that of an office LAN. A CMTS provides an extended Ethernet network over a WAN with a geographic reach up to 100 miles. A CMTS is an important new element for support of data services that integrates upstream and downstream communication over a cable data network At the cable headend, data from individual users is filtered by upstream for further processing by a cable modem termination system (CMTS). The number of upstream and downstream channels in a given CMTS can be engineered based on serving area, number of users, data rates offered to each user, and available spectrum. A cable headend combines the downstream data channels with the video, pay-per-view, audio, and local advertiser programs that are received by television subscribers. The combined signal is then transmitted throughout the cable distribution network. At the user location, the television signal is received by a set-top box, while u ser data is separately received by a cable modem box and sent to a PC.

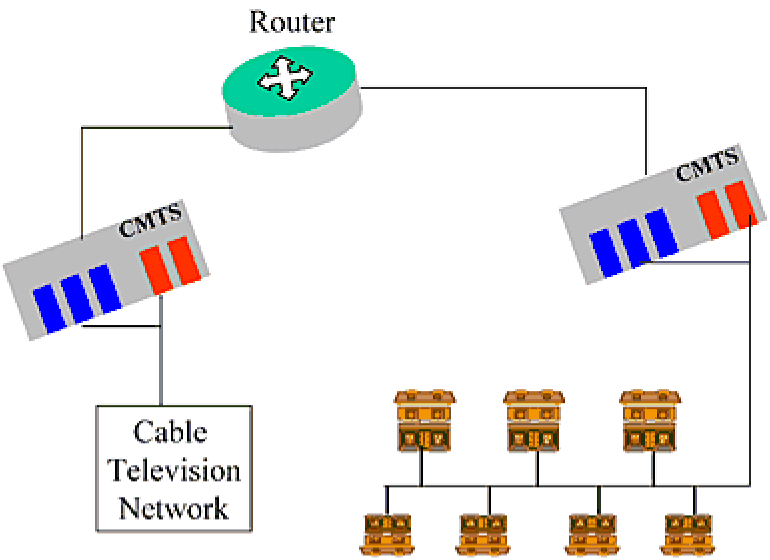


Figure : Distribution Network

A basic distribution hub is a minimal data network configuration that exists within a cable television headend. A typical headend is equipped with satellite receivers, fiber connections to other regional headend locations, and upstream RF receivers for pay-per-view and data services. The minimal data network configuration includes a CMTS system capable of upstream and downstream data transport and an IP router to connect to the super hub location .

MAC Layer

The MAC layer provides the general requirements for many cable modem subscribers to share a single upstream data channel for transmission to the network. These requirements include collision detection and retransmission. The large geographic reach of a cable data network poses special problems as a result of the transmission delay between users close to headend versus users at a distance from cable headend. To compensate for cable losses and delay as a result of distance, the MAC layer performs ranging, by which each cable modem can assess time delay in transmitting to the headend. The MAC layer supports timing and synchronization, bandwidth allocation to cable modems at the control of CMTS, error detection, handling and error recovery, and procedures for registering new cable modems.

Each modem transmits bursts in time slots, that might be either marked as reserved, contention or ranging.

- Reserved slots

A reserved slot is a time slot that is reserved to a particular Cable Modem. No other Cable Modem is allowed to transmit in that time slot. The CMTS (Head-End) allocates the time slots to the various Cable Modems through a bandwidth allocation algorithm (notice: this algorithm is vendor specific, and may differentiate vendors considerably).

Reserved slots are normally used for longer data transmissions.

- Contention slots

Time slots marked as contention slots are open for all Cable Modems to transmit in. If two Cable Modems decide to transmit in the same time slot, the packets collide and the data is lost. The CMTS (Head-End) will then signal that no data was received, to make the Cable Modems try again at some other (random) time.

Contention slots are normally used for very short data transmissions (such as a request for a number of reserved slots to transmit more data in).

- Ranging slots

Due to the physical distance between the CMTS (Head-End) and the Cable Modem, the time delay vary quite a lot and can be in the milliseconds range. To compensate for this all Cable Modems employ a ranging protocol, that effectively moves the "clock" of the individual Cable Modem forth or back to compensate for the delay.

To do this a number (normally 3) of consecutive time-slots are set aside for ranging every now and then. The Cable Modem is commanded to try transmitting in the 2nd time-slot. The CMTS (Head-End) measures this, and tells the Cable Modem a small positive or negative correction value for its local clock. The two time slots before and after are the "gap" required to insure that the ranging burst does not collide with other traffic.

The other purpose of the ranging is to make all Cable Modems transmit at a power level that makes all upstream bursts from all Cable Modems arrive at the CMTS at the same level. This is essential for detecting collisions, but also required for optimum performance of the upstream demodulator in the CMTS. The variation in attenuation from the Cable Modem to the CMTS can vary more than 15dB.

Privacy

Privacy of user data is achieved by encrypting link-layer data between cable modems and CMTS. Cable modems and CMTS headend controller encrypt the payload data of link-layer frames transmitted on the cable network. A set of security parameters including keying data is assigned to a cable modem by the Security Association (SA). All of the upstream transmissions from a cable modem travel across a single upstream data channel and are received by the CMTS. In the downstream data channel a CMTS must select appropriate SA based on the destination address of the target cable modem. Baseline privacy employs the data encryption standard (DES) block cipher for encryption of user data. The encryption can be integrated directly within the MAC hardware and software interface.

xDSL

The traditional telephone companies have an efficient means for delivering broadband Internet access. This is called Digital Subscriber Line (xDSL) service. There are several different types of DSL, the most common of which is Asynchronous DSL, or ADSL. ADSL also has many different appearances. Some of these are based upon equipment availability, cable distances, or even economic factors. In short, ADSL can support data rates up to 7 Mbps, but telcos typically are offering “fractional T1” services at downstream rates varying from 384 Kbps to 1 Mbps. Like cable modems, DSL service is asynchronous with residential upstream return paths supporting speeds of 224 Kbps or less. Unlike cable modems, the ADSL cables are not shared with other users, so the subscriber will be able to use the full bandwidth without contention.

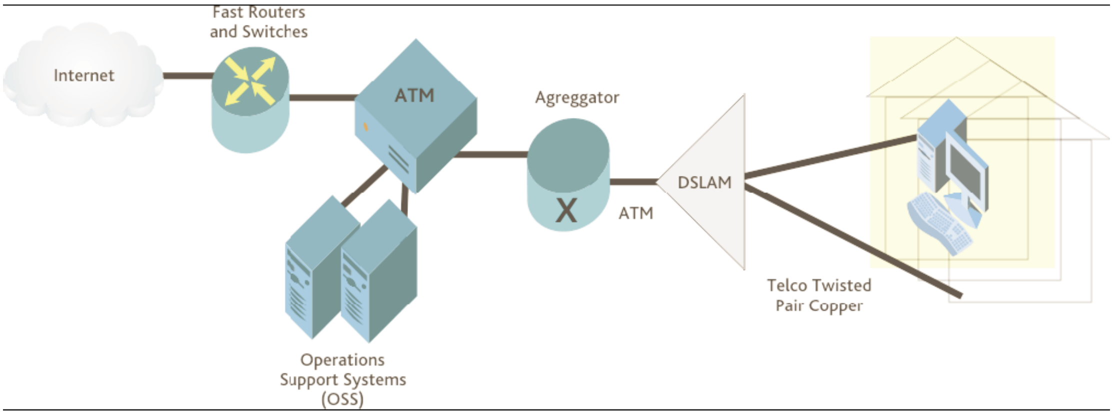


Figure : xDSL over ATM

The basic ADSL reference model is illustrated above. Following the diagram from the right (homes and business) to the left (the big Internet), ADSL starts with a user’s workstation attached to an ADSL modem called an ADSL Termination Unit – Remote (ATU-R). This modem is then connected to the end-user’s existing twisted pair copper telephone cables. An inexpensive line splitter can be installed in the wall-jack at the user’s location to permit concurrent voice and data support over the same twisted pair circuit (though some paradigms also provide for direct support of DSL-based telephone services). The twisted pairs from multiple locations are then grouped together at a telco Central Office (CO)

with a device known as a DSL Access Multiplexer (DSLAM) which combines all of the individual user sessions onto an ATM trunk. Next, the traffic from multiple DSLAMs is further combined at an aggregation point, typically located in a central office. From there the traffic is forwarded to a router,which in turn connects to the Internet.

Family	ITU	Name	Ratified	Maximum Speed capabilities
ADSL	G.992.1	G.dmt	1999	7 Mbps down 800 kbps up
ADSL2	G.992.3	G.dmt.bis	2002	8 Mb/s down 1 Mbps up
ADSL2plus	G.992.5	ADSL2plus	2003	24 Mbps down 1 Mbps up
ADSL2-RE	G.992.3	Reach Extended	2003	8 Mbps down 1 Mbps up
SHDSL (updated 2003)	G.991.2	G.SHDSL	2003	5.6 Mbps up/down
VDSL	G.993.1	Very-high-data-rate DSL	2004	55 Mbps down 15 Mbps up
VDSL2 -12 MHz long reach	G.993.2	Very-high-data-rate DSL 2	2005	55 Mbps down 30 Mbps up
VDSL2 - 30 MHz Short reach	G.993.2	Very-high-data-rate DSL 2	2005	100 Mbps up/down

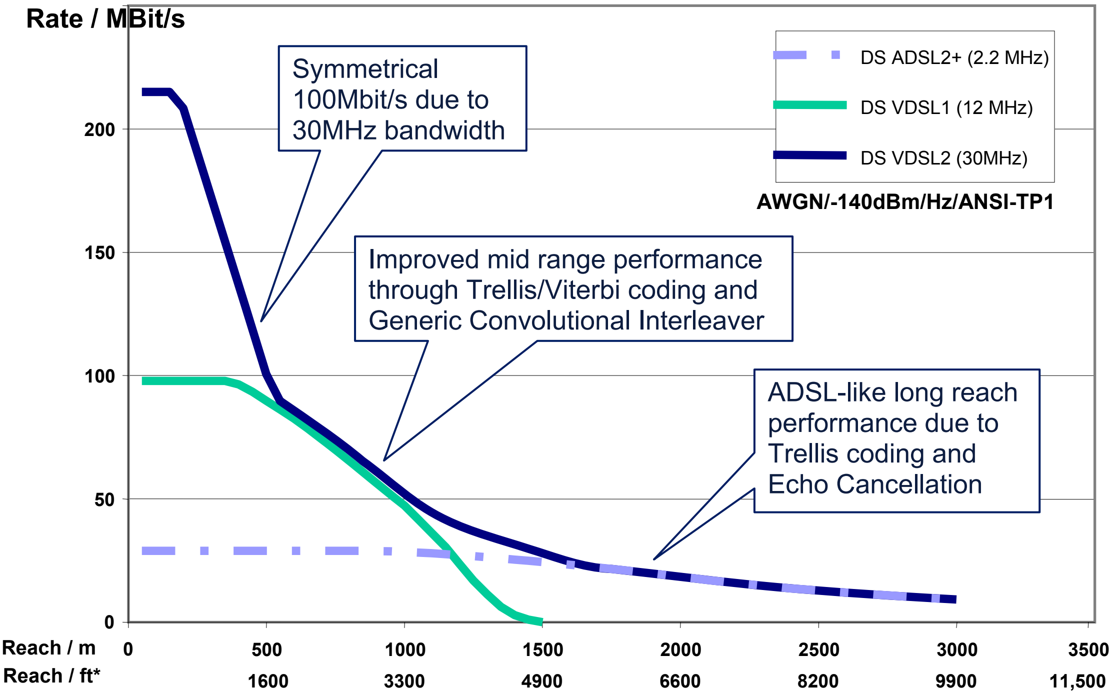


Figure : comparing xDSL technologies (Rate vs. Reach)

High Data-Rate Digital Subscriber Line (HDSL)

HDSL is simply a better way of transmitting T1/E1 over copper wires, using less bandwidth without repeaters. It uses more advanced modulation techniques to transmit 1.544 Mbps over lines up to 12,000 feet long.

Single-Line Digital Subscriber Line (SDSL)

SDSL is a single-line version of HDSL, transmitting T1/E1 signals over a single twisted pair, and able to operate over the plain old telephone service (POTS) so that a single line can support POTS and T-1/E-1 at the same time. It fits the market for residence connection which must often work over a single telephone line. However, SDSL will not reach much beyond 10,000 feet. At the same distance, ADSL reaches rates above 6 Mbps.

Asymmetric Digital Subscriber Line (ADSL)

ADSL is intended to complete the connection with the customer's premise. It transmits two separate data streams with much more bandwidth devoted to the downstream leg to the customer than returning. It is effective because symmetric signals in many pairs within a cable (as occurs in cables coming out of the central office) significantly limit the data rate and possible line length.

ADSL succeeds because it takes advantage of the fact that most of its target applications (video-on-demand, home shopping, Internet access, remote LAN access, multimedia, and PC services) function perfectly well with a relatively low upstream data rate. MPEG movies require 1.5 or 3.0 Mbps down stream but need only between 16 kbps and 64 kbps upstream. The protocols controlling Internet or LAN access require somewhat higher upstream rates but in most cases can get by with a 10 to 1 ratio of downstream to upstream bandwidth.

Figure : Outdoor DSLAM next to MDF

Comparing Cable Modem and DSL

The following table compares general characteristics between cable modem service and DSL service. Again, your choice of service may depend on what is available in your area. Note on fees and costs: Figures given here are for usual home rates (business rates are generally higher). Providers often offer special pricing for new subscribers, which may include free installation, discounts on monthly rates for the first few months of service, or free modems.

	Cable Modem	DSL
Installation Fee	$0-$200	$0-$200
Monthly Rates	$40-$50	$40-$200+
Pricing Specials	May get price break when combined with cable TV and phone service	May get price break when combined with cable TV and phone service
Connection Speed: Upload	128 kbps to 500 kbps	128 kbps to 1.5 mbps
Connection Speed: Download	1 mbps to 3 mbps	144 kbps to 9 mbps
Hardware Requirement	Ethernet card Cable modem (usually obtained from provider)	Ethernet card DSL modem (usually obtained from provider)
Set Up	Relatively easy set up	Set up can be difficult
Availability	More widespread than DSL	Sometimes difficult to determine if service is available
Performance	Line shared with others; speeds vary accordingly	Dedicated line, so speed is guaranteed; performance may depend on location

The major difference between these technologies is performance, which will play crucial role in the future , as more bandwidth is wanted by the market.

FIBER OPTICS

Fiber-To-The-Home

FTTP/FTTH/FTTB: Fiber to the Premises (FTTP),Fiber to the Home (FTTH), or fiber to the building (FTTB) is a broadband telecommunications system based on fiber-optic cables and associated optical electronics for delivery of multiple advanced services such as of telephone, broadband Internet and television across one link (triple play) all the way to the home or business. Current research forecasts that the total FTTP market for equipment, cable, and apparatus will reach $3.2 billion in 2009.

Two competing FTTP technologies are Active FTTP, also called Active Ethernet, and passive optical network (PON) architectures.

A **Passive Optical Network** (**PON**) is a fiber to the premises network architecture in which unpowered optical splitters are used to enable a single optical fiber to serve multiple premises, typically 32. A PON consists of an Optical Line Termination (OLT) at the service provider's central office and a number of Optical Network Units (ONUs)

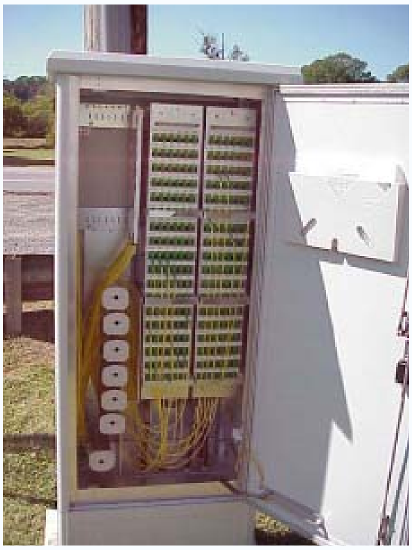
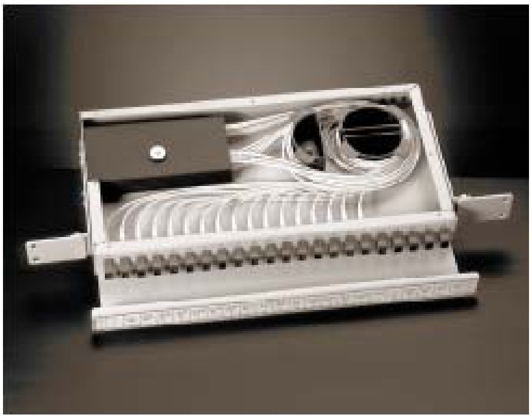


Figure: Optical Network Unit (ONU)



near end users. A PON configuration reduces the amount of fiber and central office equipment required compared with point to point architectures. Passive optical network (PON) FTTP networks avoid the placement of electronics in the field. PON networks use passive splitters to distribute fiber to individual homes. One fiber is optically split into 16, 32, or 64 fibers, depending on the manufacturer, which are then distributed to residential or business subscribers. In PON architectures, the switching and routing is done at the carrier's central office.. Optical signals, once received in the home, are processed by thin film filter technology or more recently with dispersion bridge planar lightwave circuit technology so that the signal can be properly routed to the appropriate component in the home (voice, video or data).

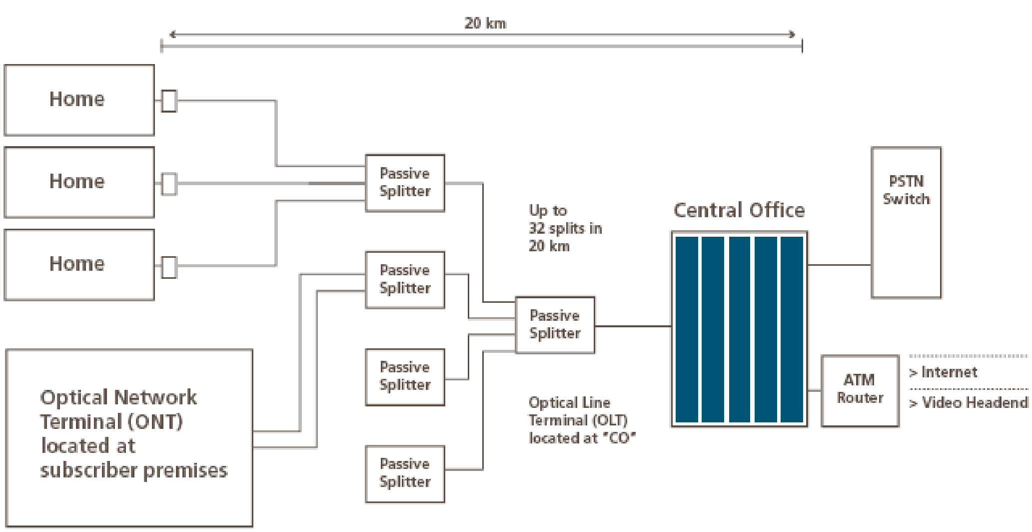


Figure : Passive Optical Network Architecture

Downstream signals are broadcast to each premises sharing a fiber. Encryption is used to prevent eavesdropping.

Upstream signals are combined using a multiple access protocol, invariably time division multiple access (TDMA). The OLTs "range" the ONUs in order to provide time slot assignments for upstream communication.

Active FTTP networks utilize powered (i.e. 'active') electronic equipment in neighborhoods, usually one equipment cabinet for every 400-500 subscribers. This neighborhood equipment performs layer 2/layer 3 switching and routing, offloading full layer 3 routing to the carrier's central office. The IEEE 802.3ah standard enables service providers to deliver up to 100 Mbit/s full-duplex over one single-mode optical fiber to the premises depending on the provider.

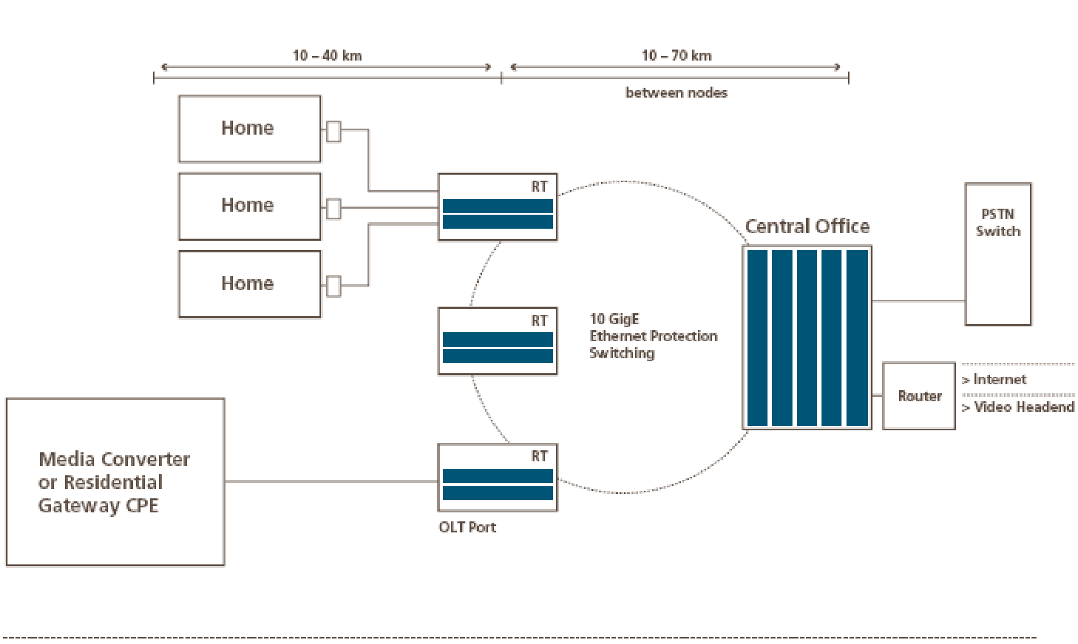


Figure : Active star Ethernet

PON Comparison

	Downstream	Upstream	Standard
APON	155 Mb/s 622 Mb/s	155 Mb/s 155 MB/s	ITU-T (FSAN)
BPON	155 Mb/s 622 Mb/s	155 Mb/s 622 MB/s	ITU-T G.983 (FSAN)
EPON (ETFM)	10-1000 Mb/s	10-1000 Mb/s	IEEE 802.3ah (EFM)
GPON	1.244 Gb/s 2.488 Gb/s	155 Mb/s 622 Mb/s 1.244 Gb/s 2.488 Gb/s	ITU-T G.984.1, G984.2, G984.3 (FSAN)

EPON Benefits

While Ethernet over point-to-point optical fiber offers the highest bandwidth at reasonable cost, Ethernet over point-to-multipoint optical fiber offers relatively high bandwidth at a low cost. Depending on the optical split ratio, Ethernet over passive optical network (EPON) can support subscriber bandwidths of 30 Mbps and, with service-level agreements, an EPON could enable bursting of 100 Mbps or more. EPON offers multiple economic advantages. The aggregation device, called the optical line terminator (OLT), supports 16 to 32 subscribers per port by means of a passive optical splitter. Thus, the Ethernet PON minimizes the number of fibers that need to be managed in the service provider's point of presence or central office, minimizes the number of central office transceivers, and reduces the rack space required in the central office, compared with a point-to-point topology. EPON also enables a low-cost fiber infrastructure by reducing the number of fibers in a trunk fiber. This economic benefit is significant. Finally, the EPON topology reduces maintenance costs by removing the need for electrical power and active electronics in the field although the diagnostic and troubleshooting overhead is increased. In addition, passive optical splitters have no need for curbside batteries or environmentally protected enclosures.

Fiber-To-The-Node

Fiber To The Node (FTTN) is a broadband architecture that provides high speed internet and other services to the home by running fiber to the node .Fiber is pulled to a larger hub or ONU (q.v.), in which fiber is linked to multiple copper (xDSL) or coax lines (HFC), typically serving about 200 residential or small business customers with a radius of about 3,000 to 4,000 feet. This architecture is lower cost to deploy than the competing Fiber to the premices (FTTP) technology but in turn does not bring the full bandwidth capability of the fiber to the home. Data rates are limited to 100 Mbit/s. However,this technology minimizes the distance between the customer and the DSLAM enabling high xDSL datarates.

Ethernet over Point-to-Point Copper (EoVDSL)

Because almost all the installed media in the outside cabling plant in the local loop is voice-grade, single-pair copper and most of the installed media inside buildings is Category 1, 2, or 3 copper, there is a strong desire for the IEEE 802.3ah EFM Task Force to support point-to-point topologies on copper and define a physical layer for this voice-grade copper. Specifically, the EFM Task Force's goal is to specify a physical layer for single-pair, nonloaded, voice-grade copper that reaches distances of at least 2,500 feet and speeds of 10 Mbps.

Cisco expects the task force to adopt Ethernet over very-high-bit-rate digital subscriber line (VDSL). That means using an Ethernet Media Access Control (MAC) layer on top of an ANSI VDSL physical layer (PHY). This kind of adoption of a proven physical layer is consistent with the philosophy and practice of the Ethernet industry to borrow existing PHYs. For example, Fast Ethernet (IEEE 802.3u) borrowed portions of the ANSI Fiber Distributed Data Interface (FDDI) physical layer and Gigabit Ethernet (IEEE 802.3z) borrowed the ANSI Fibre Channel physical layer. Table below summarizes the rates and reach of ANSI VDSL.

Figure : An outdoor IP DSLAM could be placed next to an ONU to provide EoVDSL

Very-High-Bit-Rate Digital Subscriber Line (VDSL)

ANSI T1E1.4 standard
Targets both fiber-to-the-curb and in-building (MxU) applications
High downstream bandwidth for distances up to 1.5 km
50/30 Mbps up to 300 meters
36/12 Mbps up to 1000 meters
15/3 Mbps up to 1500 meters
Runs on voice-grade, twisted-pair cabling

The Ethernet-over-VDSL (EoVDSL) technology is an ideal solution for delivering 15-36 Mbps performance over existing Category 1, 2, and 3 cabling. With 10-Mbps Ethernet performance that reaches up to 1.5 km, EoVDSL enables simultaneous voice, video, and data applications, such as high-speed Internet access, video streaming, and IP telephony. EoVDSL technology enables network designers to build high-performance access networks for multiunit building (MxU) and enterprise campus environments. MxU buildings include hotels, residential multidwelling units (MDUs), and commercial multitenant units (MTUs). Data rates in these environments are suitable for multiple channels of video service in addition to voice and data applications. Ethernet over VDSL is also ideal for network access to residential customers from curbside distribution boxes or nodes. Both of these infrastructure topologies, when combined with optical solutions allow end users to be coupled to the metropolitan NGN cost-effectively.

FTTH – FTTN Comparison

The use of IP over Ethernet in subscriber access applications eliminates unnecessary network layers. The elimination of network layers reduces the number of network elements in a network, and that reduces equipment costs, operational costs, and complexity. At the edge of the last mile, simpler architectures are always easier to manage. In the last mile, native Ethernet on copper or fiber will offer significant cost-performance advantage over competing technologies. These IP/Ethernet networks will of course coexist with time-division multiplexing (TDM) and SONET/SDH services. For example, for business customers, T1 and fractional T1 might be provisioned over Ethernet on optical fiber. Also, in many cases the service provider might backhaul data, voice, and video to a SONET/SDH network.

Metro access for business and residential subscribers with EFM technologies is one critical component of the larger metro solutions portfolio offered. FTTH – FTTN topologies being defined by IEEE 802.3ah will complement each other. Ethernet over VDSL on copper (FTTN) is the best fit for established neighborhoods, business parks, and MxUs because it can reuse the existing voice-grade, twisted-pair copper cable. For new residential developments and many business applications, Ethernet over PON will be the best fit because of its high bandwidth and long potential service life. For high-end commercial customers, Ethernet over point-to-point fiber (FTTH) may provide the best solution because it can scale to meet future bandwidth demands. Service providers will build hybrid networks especially when the distance between the central office and the subscriber exceeds a mile. In fiber-to-the-house and fiber-to-the-node applications, point-to-point optical fiber or EPON can be used as the interconnect technology to the central office, extending the reach of the Ethernet-over-VDSL solution.

LMDS

LMDS (Local Multipoint Distribution System) can be used to serve E-1 and 10-baseT Ethernet connections from the CO to the customer premices. An interesting last-mile method, used primarily by customers who demand broadband Constant bit-rate (CBR) access with low latency.

Another successful use of LMDS is the interconnection of customer buildings for reliable and bidirectional transmition of data and voice channels.

However, the LMDS systems at 28 GHz are most susceptible to rain effects causing a reduction in the signal level. Rainfall causes depolarization of the signals, leading to decreased signal level and decreased interference isolation between adjacent sectors and adjacent cell sites. Additional propagation issues relating to foliage also need further study.

Figure : LMDS highly directional antenna

The primary propagation issue in lower-frequency bands is multipath fading. At the LMDS frequencies, multipath fading should not be an important effect. First, LMDS frequencies are much more **line-of-sight (LOS)–dependent**, which means that shadowing and diffraction do not occur as often at lower frequencies. Second, cellular and personal communications service (PCS) systems typically have customer-premises locations within six feet of the ground, whereas LMDS systems have customer antennas located high on rooftops. The height of the customer-premises antenna plays a large role in reducing multipath effects. Third, the LMDS antennas are highly directional (pointing to a single cell site), whereas the cellular and PCS antennas have either omnidirectional or loosely sectorized characteristics. Using directional antennas reduces multipath effects. Fourth, in cellular and PCS systems the customer antenna may be moving, whereas LMDS antennas are fixed on a rooftop. Once an antenna becomes fixed, installers can choose better case locations on the rooftop, leading to improved performance.

WiMAX

Historically, proprietary BWA systems have been predominantly line of sight (Just like wi-fi,LMDS e.t.c), which is costly and finicky. However, WiMAX's ability to address link budget and NLOS issues may finally make BWA affordable and practical for the masses.

Figure : WiMAX CPE installed in Trikala,Greece

BWA has been with us in one form or another for the past ten years or more. During that time, one of the biggest drawbacks to its widespread acceptance has been not only the cost of the SS or CPE, but the installation costs as well. Historically, proprietary broadband wireless access systems have been predominantly LOS, requiring highly skilled labor and a truck roll to install and "turn up" a customer. As a result, the combined cost of the CPE plus professional installation costs have relegated BWA to the small SME access market, where fees of several hundred dollars per month are acceptable and can support a business plan with those equipment and installation costs.

Moving forward, one of the target markets for BWA is the residential access market, which until now has not been a viable market for BWA. Systems composed of IEEE 802.16-based WiMAX-certified CPEs will address the cost or price of the end user equipment, leaving the issue of professional installation to be addressed. The concept of a self-installed CPE has been the Holy Grail for BWA from the beginning. With the advent of 802.16 and WiMAX, the question arises: what can or will these new technologies bring to the table in delivering on the promise of self-installation? With today's BWA systems, almost 100% of the CPEs are installed outside by professionals striving to achieve a LOS link to BS, a common requirement. This necessitates CPE antennas mounted on poles 20 or 30 feet tall and placed on the roof. As a result, installation can be complex and expensive.

One way to reduce these customer acquisition costs is to reduce the cost of the CPE, and this will happen as a natural result of standardization. The other element to focus on is lowering the installation cost by reducing the installation complexity, or even eliminating it completely, with self-installed indoor devices that can sit on a desktop. The barrier to the indoor CPE has been the large amount of signal loss and reflections, or multipath, which occurs when penetrating the exterior wall of a dwelling. Up until now, systems could only support an indoor installation for those customers very near the BS, approximately 0.25 km or less. Some systems were able to support an indoor install at greater ranges, but at the cost of bandwidth. In these systems, the data rate often falls to a few hundred kb/s.

WiMAX and NLOS

At a very high level, the IEEE 802.16 standard has two key features: the ability to support NLOS operation and the ability to implement and enforce QoS in mixed media traffic. In terms of the self-installed CPE, it is the NLOS feature that bears discussion.When NLOS deployments are considered, there are two factors that determine how well a system will work and whether or not a customer will be able to receive service: propagation or amount of signal received and multipath or RF reflections. WiMAX-based systems, at their core, employ a waveform called OFDM, which by its very nature addresses the multipath component of NLOS. The amount of multipath a system can tolerate is referred to as the delay spread, or how much time passes between the primary signal being received and the reflected signal. In WLAN environments, this value is typically less then 150 ns due to the shorter distances involved. In the BWA environment, delay spread anywhere from 1 to 15μs or even more must be accounted for. With OFDM, the larger the number of sub-carriers or tones translates directly into the amount of delay spread it can tolerate. This is the primary difference between the OFDM used in IEEE 802.11a (64 sub-carriers) and IEEE 802.16 OFDM (256 sub-carriers).

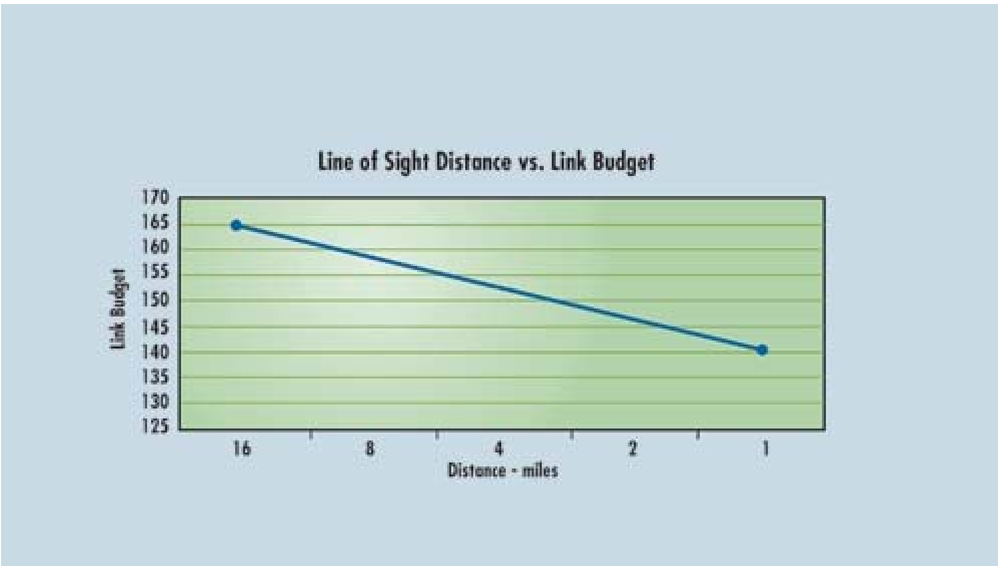


Figure : LOS vs Link Budget

When it comes to addressing the signal propagation factor of NLOS, 802.16 and WiMAX address this with a combination of mandatory and optional features. On the mandatory side, WiMAX BWA systems will support techniques such as dynamic modulation and dynamic error correcting code. These techniques do not add to the link budget, they merely help the system to adapt.

Typical RF paths can be broken into three primary types:

• LOS — clear path between CPE and BS. This includes an unobstructed Fresnel zone.

• Near LOS — this situation describes a link where the Fresnel zone is occluded but some direct path signal is received by the CPE. Anywhere from 9 to 12 dB may be lost via partial obstructions (see Figure 2).

• Non LOS — describes an RF path where the entire signal received by the CPE is reflected, i.e. there is no signal reaching the CPE on a direct path from the BS.

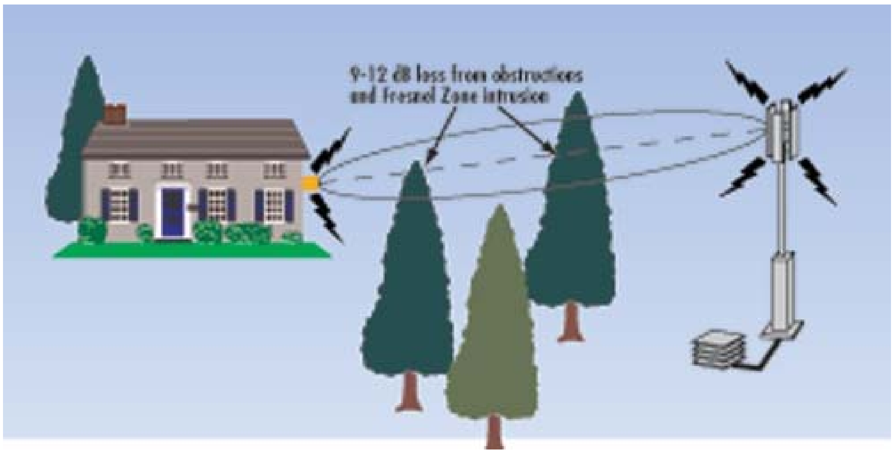


Figure : Near –LOS Wimax link

At the end of these three types of RF paths, near the subscriber, the scenario can be broken down further into those that have an outdoor mounted CPE and those that are self-installed indoor. Clearly, the hope and promise of WiMAX systems for the service provider is to support a NLOS, indoor installed scenario — the most challenging of all.

Beyond WiMAX

With a thorough understanding of the complexities and trade-offs for carriers in terms of BS range, data rates and total cost of ownership, it is clear that not only are the optional features within WiMAX required, but even more needs to be done. In short, chip vendors incorporating additional techniques can greatly extend the range of the indoor self-installed CPE. For example, a system which employs both sets of optional features mentioned above in a WiMAX chip, as well as taking it an additional step with support for more advanced signal processing and smart antenna techniques, will enhance propagation tremendously. Adding diversity combining using two RF chains within a single 802.16 ASIC, the link budget will improve by 14 to 15 dB when compared to a standard WiMAX system supporting only the mandatory features in a NLOS environment. Adding in other signal processing advantages can raise this to an average of 18 dB. This represents an additional 9 dB over the best results a standard WiMAX system, with optional range enhancing features employed (STC and turbo codes), can deliver.

The Self-installed CPE — Results

As noted previously, it is the first wall penetration that has historically been the primary barrier to self-installed indoor CPEs. Depending on frequency and type of wall, this signal loss can measure from 10 to 20 dB, averaging at 15 dB. For example, at 3.5 GHz with a 3.5 MHz channel size, an average of 16 dB is assumed for first wall penetration. This loss can be offset by the additional link budget generated by incorporating the techniques described above in the MAC/PHY WiMAX ASIC. This means systems employing WiMAX optional features will do well, and those employing diversity and more, on average, will be able to compensate for all of the first wall penetration losses! In a typical example (see Figure 3), a WiMAX standard system will be able to support an indoor installation in a suburban environment at a distance of < 0.5 km. A system supporting WiMAX options such as STC will be able to support an indoor CPE up to slightly less than 1 km. Advanced solutions can go as far as 1.5 km.

Figure : Self – installed CPE

In those situations where the distance is too much even for a SS with every option utilized to be installed indoors, the fully loaded SS with STC and diversity combining will still support up to approximately two to three times the range when compared to standard products. In the worst case where an outdoor installation is mandated, the carrier or service provider will be able to install the SS under the eaves of the house. This is a task that does not require a professional installation but can be done by a satellite TV technician.

Conclusion

For broadband wireless access to be truly successful, it must be able to serve the residential market. It is evident that for BWA to effectively address this market, the self-installed CPE will play a significant role in reducing the total customer acquisition costs, enabling the overall business case. WiMAX and its associated technologies go a long way to delivering on this promise when both mandatory and optional features are included. But for the best performance available driving installation cost towards zero, a solution which also incorporates advanced signal processing and range extending technologies makes the business case for the residential market work.

IoS (Internet over Satellite)

Figure : Hellas SAT 2 (OTE)

Satellite Internet

A broadband access to the internet can be achieved Internet over Satellite (IoS). Satellite Internet is offered for professionals, as well for home users who use internet for transmitting or receiving a large amount of data through the internet. Satellite Internet can support a large number of applications such as : e-learning, VoIP trunking, Web browsing, video broadcasting / multicasting over IP, sites interconnection, e-paging e.t.c,. The greatest advantage of Satellite internet is that it is unaffected by the weather conditions and the position of the subscriber. Especially for professionals whose activities lay beyond the borders of the advanced European countries, satellite internet can successfully substitute xDSL connections and provide satisfying bandwidth.

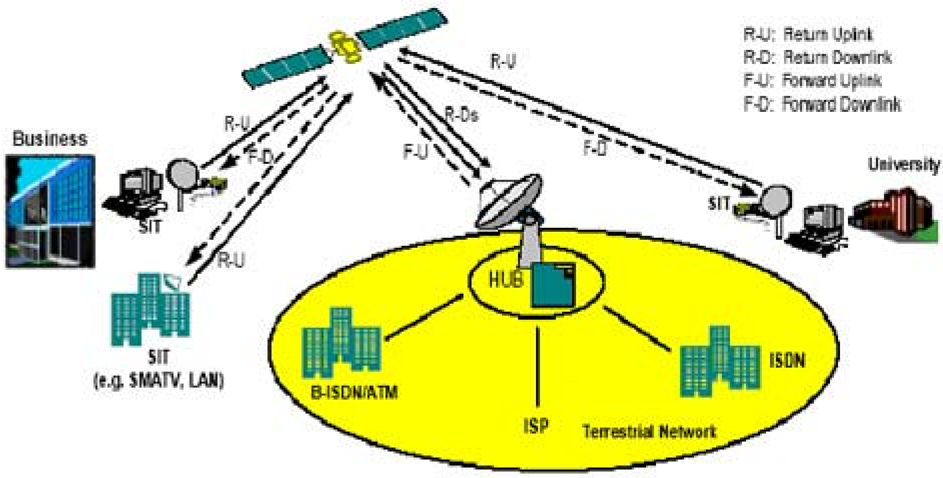


Figure: typical Internet over Satellite diagram

Technical Description

Customers , who wish to subscribe to bidirectional satellite services, have to buy their own equipment. This includes a satellite modem/IP router and a satellite antennae. On Hellas SAT 2, the user transmits data (upstream) over DVB-MPEG2 encryption protocol. The upstream broadcast takes place over the Ku band (13,75-14,5Ghz), with transmit power 2-4watts. The upsteam data rate is between 128Kbit/s and 8Mbit/s. The downstream takes place at (10,95-12,75Ghz) and the data rate is between 512Kbit/s and 54Mbit/s.

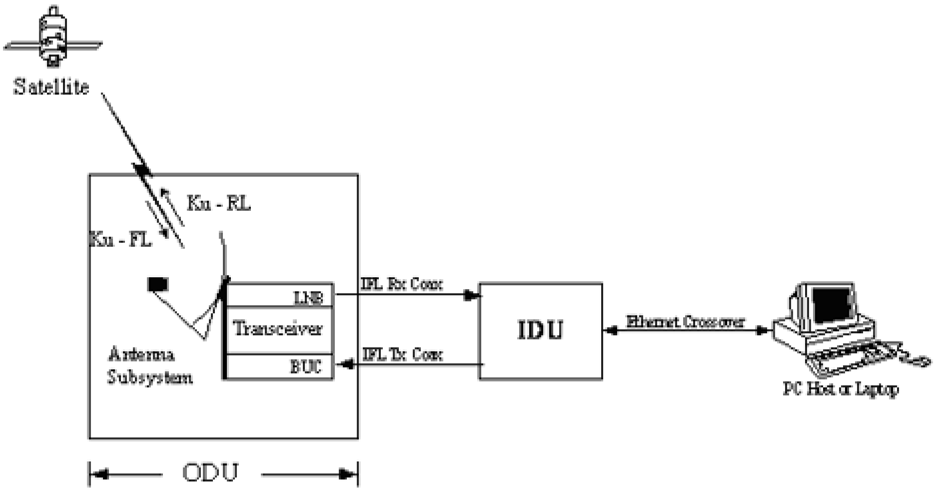


Figure : IoS block diagram

Advantages

A satellite, just like Hellas SAT 2 , can support broadband connections to places where there is no network connectivity and even typical wireless solutions are too expensive to implement.

With DVB-RCS , a multicast service, the same data can be sent to multiple users in order to achieve services such as: videoconference, VoIP conference, video on demand e.t.c. Although these types of services demand high bandwidth and low latency, Internet over Satellite can support them.

Disadvantages

From an economical aspect Internet over Satellite is the most expensive solution. Hence, low bandwidth is practically available. Also, Internet over Satellite connections have large latency , which is in the range of 700ms to 900ms or more , typically. Known latency-affected applications include interactive gaming, VoIP, and most non-TCP/IP applications.

Final Results

After an overview of the featured last-mile networking technologies, it is obvious that the challenge we face today is the same one we always faced and will face in the future. That has always been the problem of most issues in terms of cost and reliability. Today it is where there are the highest costs and the least competition and the lowest bandwidth.

It is definite that in the future most last-mile networks will be hybrid and choices of last-mile technology to be used will be made under techno-economical aspects.

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