SIDA Knowledge Transfer to Sri Lanka

“High Speed Communication”

Preface

The world of technology is ever changing, and communication is becoming a vital part of mans life. The discovery and deployment of telecommunication techniques has kept man on his toes.

But the richness of the technology is not what captures the markets acceptance and brings in the revenue. The market potential depends on the people who constitute it, their attitudes towards the development and most of all the reliability and robustness of its nature.

Man today seem to want everything, cost efficiency, university, adhocness, inter operability, flexibility and and most of all one which cators to his ever changing whim!

It's becom exceedingly difficult to find a single case within the past 50 years where a better technology won out in the market place against an inferior one. Beta lost to VHS, after all, and the sleek "RISC" microprocessors from companies like Sun Microsystems and MIPS lost out to Intel's technologically inferior Pentium chips. Ultimately, this battle will be won and lost on mundane issues like price and quality of service.

In this report I have only touched upon the market analysis of the technologies I have discussed. This report has been structured to cover in a comprehensive manner few of the broadband technologies existing in the market today.

My addendum to this report for the future would be to cover the market stratergies existing today and discuss new concepts of handling the market to provide the users the opportunity to be flexible as their free will would permit them, and to control the quality of service they receive.

1 Introduction

Ever since the conception of the Internet, the world has shrunk to a microcosm. But the insatiable need for more applications and services for daily human life has kept on a catapulting increase.

This meant provision for not only one type of signal but multiple signals being transported on the same medium. A migration from base band to broadband! Thus the world began its footsteps on the path to **'Broadband to All'**.

With the multitude of existing technologies, a cost effective competitive and non monopolistic infrastructure to provide the necessary bandwidth and services the end customers require and also a sustainable business model to attract service providers to penetrate the areas where traditional business models will not be inclined to invest has been some of the major hurdles in this journey.

This report describes the existing infrastructures for different types of user communities, its pros and cons and also explores methods on expediting broadband network deployment with an attractive business model for both incumbent and established operators.

Broadband technology was deployed to address the bottleneck for the **'last mile'** connections to home and small offices connected to high capacity usually optical backbone.

Today's need to transport voice, video and data on the same media has inspired service providers to push the limits of usable media bandwidth.

Bandwidth is a decisive factor when carrying high capacity application. Users are tired of waiting for web pages to download using dial-up modem internet access, and expect high capacity connections which can provide multimedia applications such as real time internet audio streaming, posting and displaying digital photographs for friends and families, movie trailers and taking a virtual tour through hotels and resorts before making a reservation are becoming few of the necessities of an average busy human. Since broadband access is **always on** unlike dialup modems there is no need to wait to connect to the internet. Which means the telephone lines are no longer tied up when accessing the internet, eventually saving the need to purchase a second telephone line and enables the users to talk to someone on the phone while accessing information from the web?

1.1 What is Bandwidth?

The capacity of information possible to handle on the medium is called Bandwidth of the medium or the transmittable Bandwidth.

Wave or Pulse…… what’s the difference?

1.2 Analog signals

The first TV, radio and telephone signals were sent through the air and over wires using electromagnetic waves. The waves were called "analog" because they took on the same shape as the light and sound waves produced at the sending end of a transmission — they were in proportion with the output.

So as the sound and light waves grow bigger and smaller, the electrical signals also grow proportionately bigger and smaller. The two sets of waves are analogous to each other — they are analog waves.

Analog bandwidth is a measurement of the amount of spectrum each signal occupies, regardless of the information the signal carries. It's measured in hertz, or cycles per second.

Analog signals have their limitations. Their fidelity to their source deteriorates the further they move from the source. Analog signals can be boosted. But when you boost an analog signal, you also boost the distortion or static along with the signal.

1.3 Digital signals

One way to preserve the fidelity of analog signals is to turn them into digital signals. That's done by sampling an analog signal, say 8000 times a second. The value of the signal at each interval is recorded as a base-two numeral (zeroes and ones). Then this binary information is sent through the network as a series of pulses of electricity or light.

Several advantages of digital signals:

- Digital signals decay just as analog signals do, as they travel away from their source. Here's how they're different: Since a digital signal is either on or off, it can be boosted without replicating the distortion. Digital signals can perfectly replicate their source at the receiving end.

- Digital signals can be sent at rapid speeds-as fast as the latest laser and laser detectors can transmit and receive.

- Digital signals are discrete, limited. When the pulse is on, it's on. When it's off, the pathway is not being used. That means different digital signals, at different rates, can be mixed on a digital path, so that the path can carry many different kinds of information simultaneously — one of the benefits of digital over analog transmission. Packets are separate and distinct chunks of data that are encoded and sent on their way along a network, where they are decoded at the end of the transmission.

Digital bandwidth measures how much information each signal carries, and is measured in bits per second. A bit is the smallest measure of data; in the binary language of computers, it's either a "0" or a "1". The more bits per second, the higher the bandwidth and the more information the signal carries.

The basic premise of bandwidth is that the higher the bandwidth of a particular transmission medium, the more information you can carry. A Plain-Old-Telephone-Service (POTS) call traveling over a copper wire voice circuit has a bandwidth of 3 kHz, or kilohertz. Expressed in digital terms, that voice telephone call has a bandwidth of 64,000 bits per second, or 64kbps. By comparison, a 28.8 modem can move some 28,000 bits per second, or about a page and a half of text. Broadcast video however, requires moving 10 million bits per second, or 10 Megabits (10Mbps).

Digital bandwidth offers some clear and compelling advantages over analog bandwidth. For example, it's flexible: you can't really force a high-bandwidth analog signal, like broadcast television, through a low-bandwidth channel. But you can send massive amounts of digital information through a low-bandwidth digital channel, like sending a digital television broadcast through a slow modem — it just takes longer. Regardless of how long it does take, once that digital content arrives at its destination and is reassembled, it can be viewed, listened to, read or processed in its original form.

1.4 Why Go Digital?

So, why is the world moving to digital communications? Consider two basic reasons. First, digital is the language of computers; and digital communications networks not only enable computers to talk to each other directly, and more efficiently, but also enable faster communications at greater bandwidth. If you can digitize it, you can send it. Digital information is also easier to store and transmit in or on a wide variety of media.

1.5 The Local Loop

What is this local loop we've all heard about? And why can't we get cable telephony and "always-on" internet access on it?

The local loop is the so-called "last mile" of the telephone connection between the telephone company's local switch, and your home phone or desktop. Most telephone traffic between that local switch, and virtually all other switches, is digital. It's only in the last mile where analog copper wire is the primary medium, and only now is that beginning to change.

Analog copper wire is great for low bandwidth voice phone calls. But even though copper wire can theoretically transmit up to 6 Megabits per second if you're within two miles of a central office, and up to 1.5 Mbps if you're within three miles, copper wire has problems at those higher bandwidths. Carrying data at those speeds over the local loop's copper wire requires specialized switches, signal repeaters and other equipment to get copper to carry more bandwidth than a telephone call. And copper picks up a lot of "noise," extraneous electromagnetic signals that interfere with the signal.

Anyone who's ever sat at a computer with a low-speed modem waiting for an Internet page to download knows all about the limitations of the analog local loop. Local phone companies now are beginning to deploy ADSL, or Asynchronous Digital Subscriber Line, to give the local loop the kinds of broadband capabilities that customers are increasingly demanding. But it's not widely available.

Consumers have had access to a broadband communications technology for the past five decades — cable television. Cable TV is a true broadband medium, but until very recently, it's been one-way only. Today IP packets are transported in duplex modes with speeds greater than standard dial up modems.

1.6 What is ‘Broadband’?

This is the Telecommunication technique that provides multiple channels of data over a single communications medium, typically using some form of frequency or wave division multiplexing.
DSL services, for example, combine separate voice and data channels over a single telephone line -- voice fills the low end of the frequency spectrum and data fills the high end.

Federal Full broadband lines are lines with information carrying capability in excess of 200 Kbps in both directions, simultaneously. One-way broadband lines are lines with information carrying capacity in excess of 200 Kbps in one direction (typically downstream) and less than or equal to 200 Kbps in the other direction (typically upstream).

There are many completing broadband access technologies brought to address the last mile connectivity.

- Cable Modem
- Digital Subscriber Line (xDSL)
- Fiber
- 2.5 and 3G cellular wireless
- Wireless Ethernet

2 Cable Modem

Cable modems are devices that allow high-speed access to information at a distant Server may it be Internet server or video on demand server, via a cable television network.

While similar to the traditional (analog) dialup modems, a cable modem is significantly more powerful, but capable of delivering data approximately 500 times faster.

2.1 Overview

The idea is simple - To use the existing cable networks to hook up to the net. This not only gave the subscribers an opportunity to experience new level of speeds of browsing the net but also eventually made it affordable. Along with this would come Video on demand and Media Home Platform (MHP).

Entrepreneurs immediately realized the immense revenue potential of this technology by the sheer number of subscribers that would be able to log on to the net via their already existing cables connections and make technologies like MHP a reality.

2.2 The Technology

Cable modem technology brings high-speed broadband networking to the home and small business user through cable television lines.

A “Cable Modem” is a device that allows high-speed data access (such as to the Internet) via a cable TV network. It operates over the ordinary TV network cables. The subscriber just connects the Cable Modem to the Cable TV outlet at his end and the cable TV operator connects a Cable Modem Termination System (CMTS) in his end. (the Headend.)

A data service is delivered to a subscriber through channels in a coaxial cable or optical fiber cable to a cable modem installed externally or internally to a subscriber's computer or television set. One television channel is used for upstream signals from the cable modem to the CMTS, and another channel is used for downstream signals from the CMTS to the cable modem.

When a CMTS receives signals from a cable modem, it converts these signals into Internet Protocol (IP) packets, which are then sent to an IP router for transmission across the Internet. When a CMTS sends signals to a cable modem, it modulates the downstream signals for transmission across the cable to the cable modem. All cable modems can receive from and send signals to the CMTS but not to other cable modems on the line.

At the cable provider's head-end, the CMTS provides many of the same functions provided by the DSLAM in a DSL system. The CMTS takes the traffic coming in from a group of customers on a single channel and routes it to an Internet service provider (ISP) for connection to the Internet.

At the head-end, the cable providers will have, or lease space for a third-party ISP to have, servers for accounting and logging, Dynamic Host Configuration Protocol(DHCP) for assigning and administering the IP Addressed of all the cable system's users, and control servers for a protocol called CableLabs Certified Cable Modems -- formerly Data Over Cable Service Interface Specifications (DOCSIS), the major standard used by U.S. cable systems in providing Internet access to users.

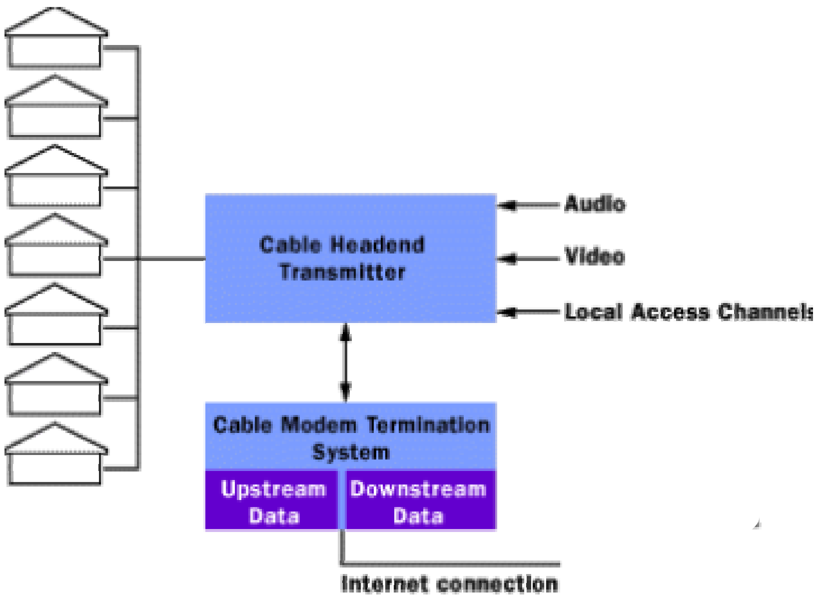


Figure 2-1

The downstream information flows to all connected users, just like in an Ethernet network -- it's up to the individual network connection to decide whether a particular block of data is intended for it or not. On the upstream side, information is sent from the user to the CMTS -- other users don't see that data at all.

The narrower upstream bandwidth is divided into slices of time, measured in milliseconds, in which users can transmit one "burst" at a time to the Internet. The division by time works well for the very short commands, queries and addresses that form the bulk of most users' traffic back to the Internet.

A CMTS will enable as many as 1,000 users to connect to the Internet through a single 6-MHz channel. Since a single channel is capable of 30 to 40 megabits per second (Mbps) of total throughput, this means that users may see far better performance than is available with standard dial-up modems. The single channel aspect, though, can also lead to one of the issues some users experience with cable modems.

If you are one of the first users to connect to the Internet through a particular cable channel, then you may have nearly the entire bandwidth of the channel available for your use. As new users, especially heavy-access users, are connected to the channel, you will have to share that bandwidth, and may see your performance degrade as a result. It is possible that, in times of heavy usage with many connected users, performance will be far below the theoretical maximums. The good news is that this particular performance issue can be resolved by the cable company adding a new channel and splitting the base of users.

A benefit of the cable modem for Internet access is that, unlike ADSL, its performance doesn't depend on distance from the central cable office. A digital CATV system is designed to provide digital signals at a particular quality to customer households. On the upstream side, the burst modulator in cable modems is programmed with the distance from the head-end, and provides the proper signal strength for accurate transmission.

A cable modem will typically have two connections, one to the cable wall outlet and the other to a computer (PC) or a set top box. Most cable modems are external devices that connect to the PC through a standard 10Base-T Ethernet card (or 100Base-T Ethernet card) and twisted-pair wiring. Alternatively they could be connected via the Universal Serial Bus (USB) or may be available as internal PCI modem cards.

The Tele Vision signals are usually spread in the 50 MHz to 750 MHz spectrum. With each TV Channel occupying 6 MHz. In the same way as we receive MTV or CNN or BBC as a channel. All of these occupy 6 MHz bandwidth. Similarly the Internet services via the cable (downstream and upstream separately) occupy a 6 MHz channel too.

We will now discuss the difference in these channels (data channels) with the conventional analog channels and what are the issues involved and differences in the downstream channels and upstream channels.

A cable modem sends and receives data in two slightly different fashions, In the downstream direction, the digital data is modulated and then placed on a typical 6 MHz television channel, somewhere between 50 MHz and 750 MHz. Currently, 64 QAM † is the preferred downstream modulation technique, offering up to 27 Mbps per 6 MHz channel.

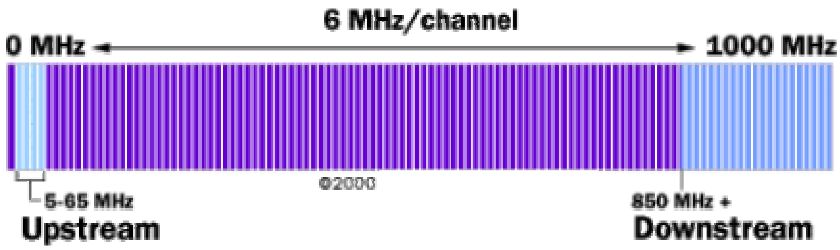


Figure 2-2

The upstream channel is more complex. Typically, in a two-way activated cable network, the upstream (also known as the reverse path) is transmitted between 5 and 42 MHz. This tends to be a noisy environment, with RF interference and impulse noise.

Additionally, interference is easily introduced in the home, due to loose connectors or poor cabling. Since cable networks are “tree and branch” networks, all this noise gets added together as the signals travel upstream, combining and increasing. Due to this problem, most manufacturers use QPSK ‡ or a similar modulation scheme in the upstream modulation techniques in a noisy direction, because QPSK is more robust scheme than higher order environment. The drawback is that QPSK is “slower” than QAM.

2.3 Speed

Cable modem speeds vary widely, depending on the following parameters

- Cable modem system
- Cable network architecture
- Traffic load

In the downstream direction (from the server to the user or from CMTS to user Cable Modem), network speeds can be up to 27 Mbps. This is an aggregate amount of bandwidth that is **shared** by users. Only a few user systems will be capable of connecting at such high speeds. A more realistic number is 1 to 3 Mbps. In the upstream direction (from user system to network), speeds can be up to 10 Mbps. However, most modem producers have selected a more 200 Kbps and 2.5 Mbps.

An asymmetric cable modem scheme is most common. The downstream channel has a much higher bandwidth allocation (faster data rate) than the upstream; this suit the common usage of cable modems viz., **video on demand and Internet applications** since they tend to be asymmetric in nature.

Activities such as World Wide Web (http) navigation and newsgroups reading (nntp) send much more data down to the computer than to the network.

Mouse clicks (URL requests) and e-mail messages are not bandwidth intensive, (which are primarily in the upstream direction). Image files and streaming media (audio and video) are very bandwidth intensive, (which are primarily in the downstream direction).

2.4 Cable TV Distribution Infrastructure

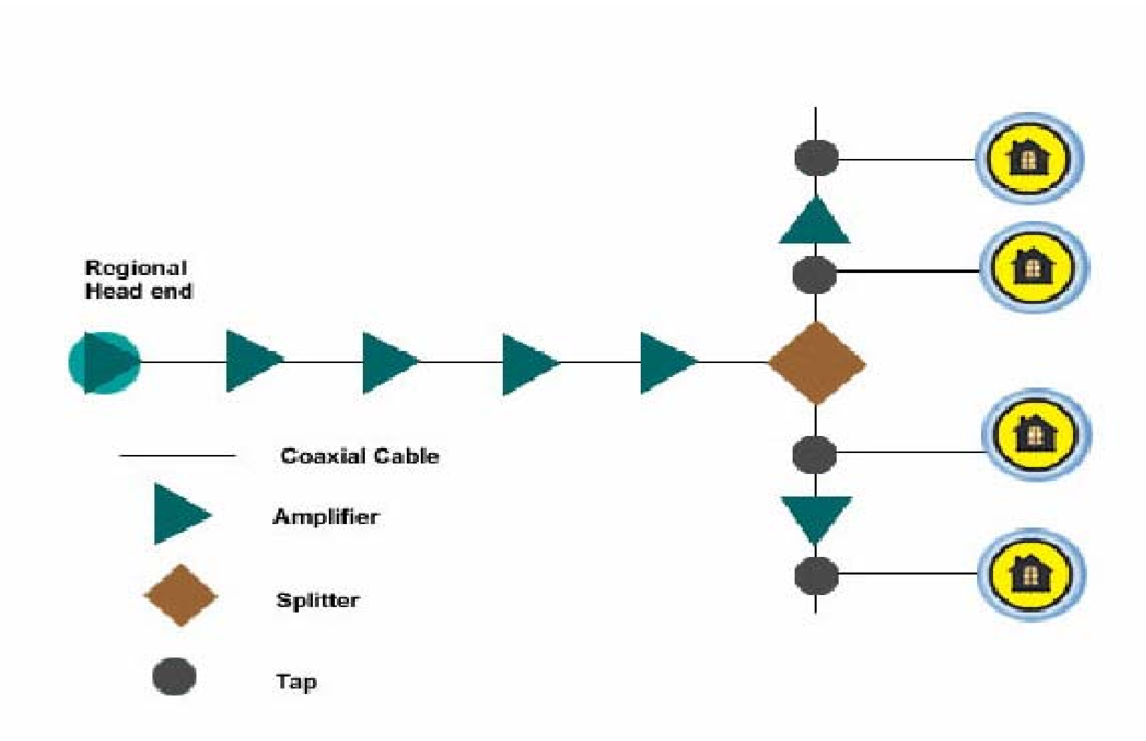
What would be the difference of the infrastructure from the existing one? Well let us discuss it in this section.

2.4.1 Traditional Cable System

Each TV cable box listens to all the downstream transmissions (that is, transmission coming “down” from the network (CMTS). Each transmission, or TV channel, is transmitted at a different frequency. The original cable system was based on coaxial cable, end to end.

The cable TV head end takes video feeds from various sources and introduces the signal onto the coax cable. Within the coax cable system signal level the amplifiers are placed at regular intervals in the system. There may be as many as 35 amplifiers cascaded between the head end and the subscriber station. The following

Figure 2-3 illustrates a conventional cable system.

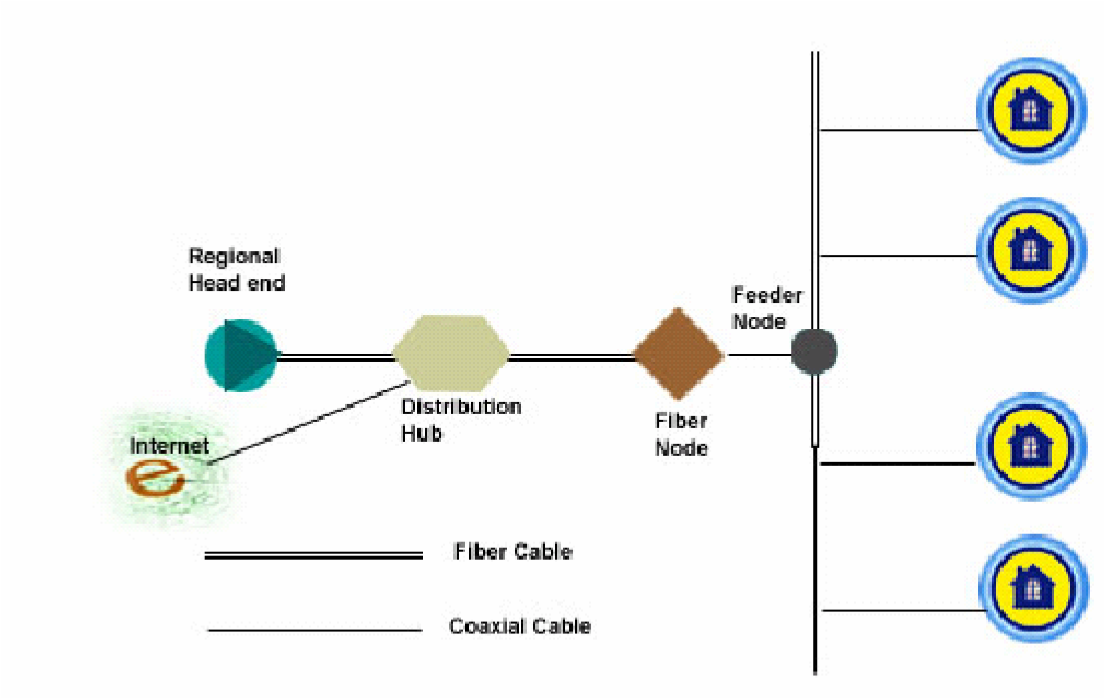


2.4.2 Hybrid Fiber Coaxial System

Currently cable operators are in the process of modifying the cable infrastructure by introducing fiber optic cables, replacing the analog signals with digital transmissions, and replacing the amplifiers so that the system becomes a two-way system.

The new infrastructure is referred to as Hybrid Fiber Coaxial (HFC) system. With HFC, the cable TV head end has a fiber interface instead of conventional coaxial interface, and with the introduction of fiber, many of the characteristics of a conventional cable network change. Most importantly, the fiber optic amplifiers are capable of regenerating signals rather than simply amplifying it. Also, base band filter RF amplifiers replace the conventional echo cancellation amplifiers.

These filters allow a certain frequency range to traverse the network in one direction and a different frequency range to traverse the network in the opposite direction. Thus, the new HFC system is a two-way system. Note that upgrading to HFC is a nontrivial task. It is essentially a complete rebuild of a significant portion of the cable system. Fortunately, the last drop, from the fiber node to the neighborhoods and into the homes, does not change, it is still coax based.



--------------------------------HFC cable system ---------------------------------
Figure 2-4

2.4.3 Types of Cable modems

The are several different cable modem products in the market, the most common 3 configurations are:

- External Cable modem
- Internal Cable modem
- Interactive Set Top Box

2.4.3.1 External Cable Modem

The external Cable Modem is a small external box that connect to your computer normally through an ordinary Ethernet connection. The downside is that you need to add a (inexpensive) Ethernet card to your computer before you can connect the Cable Modem. A plus is that you can connect more computers to the Ethernet. The ailable Cable Modems work with most of the operating systems and hard-ware platforms, including Mac, UNIX, laptop computers etc.

Another possible interface for external Cable Modems is USB, which has the advantage of installing much faster (something that matters, because the cable operators are normally sending technicians out to install each and every Cable Modem). The downside is that you can only connect one PC to a USB based Cable Modem.

The following Figure 2-5 depicts an External Cable Modem.

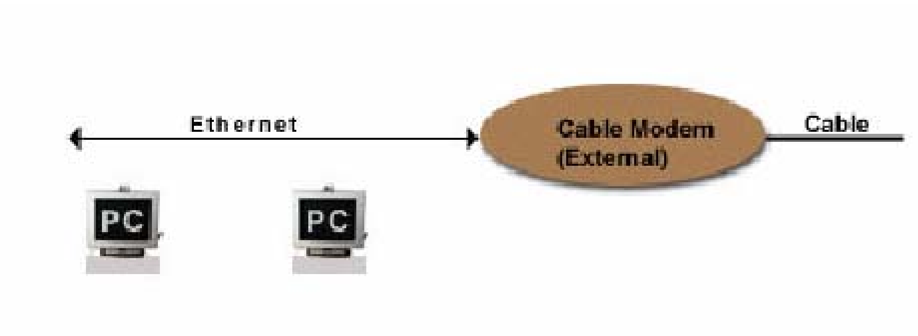


Figure 2-5

2.4.3.2 Internal Cable Modem

The internal Cable Modem is typically a PCI bus add-in card for a PC. That might be the cheapest implementation possible, but it has a number of drawbacks. First problem is that it can only be used in desktop PC's. Mac's and laptops are possible, but require a different design.

Figure 2-6

2.4.3.3 Interactive Set Top Box

The interactive set-top box is really a cable modem in disguise. The primary function of the set-top box is to provide more TV channels on the same limited number of frequencies. This is possible with the use of digital television encoding (DVB).

A Second problem is that the cable connector is not galvanic ally isolated from AC mains. This may pose a problem in some CATV networks, requiring a more expensive upgrade of the network installations.

Some countries and/or CATV Cable TV system) networks may not be able to use internal cable modems at all for technical and/or regulatory reasons.

An interactive set top box provides a return channel - often through the ordinary plain old telephone system (POTS) - that allows the user access to web browsing, email etc. directly on the TV screen. Though this technology is now obsolete and the latest set top boxes allow the return path via the cable itself.

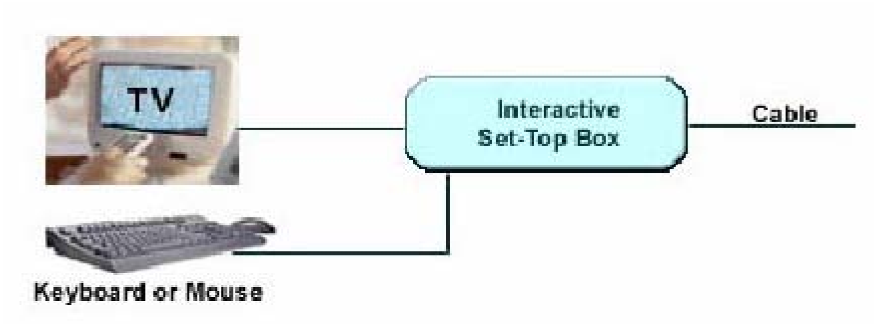


Figure 2-7

3 Digital Subscriber Line (DSL)

This is a copper-loop transmission technology for transmitting high speed data over ordinary telephone wires. A DSL modem is installed at the Central Office (CO) and the customer premise.

Different DSL technologies exist to address the different networking environments and trade-offs. The primary trade-off with DSL is reachable distance.

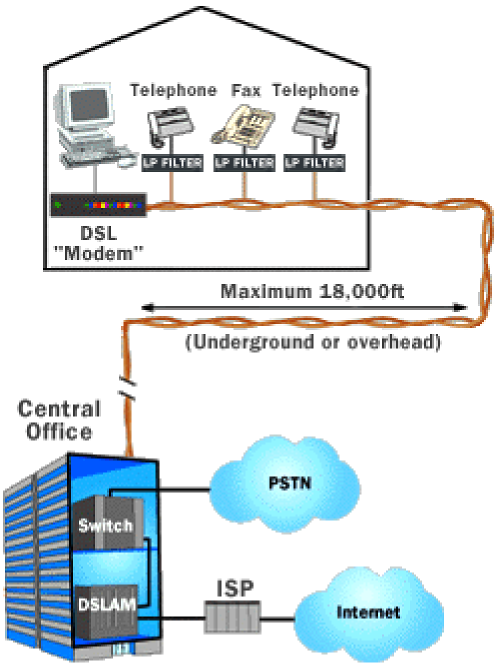


Figure 3-1

Here are some advantages of DSL:

You can leave your Internet connection open and still use the phon line for voice calls.

- The speed is much higher than a regular modem (1.5 Mbps vs. 56 Kbps)
- DSL doesn't necessarily require new wiring; it can use the phone line you already have.
- The company that offers DSL will usually provide the modem as part of the installation.

But there are disadvantages:

- A DSL connection works better when you are closer to the pro vider's central office.
- The connection is faster for receiving data than it is for sending data over the Internet.
- The service is not available everywhere.

Plain Old Telephones (POT) have been around for more than a century, carrying analog voice calls to homes and offices. But astonishingly the voice frequency occupies only a fraction of the copper cables bandwidth. By using the unused bandwidth, multiple services can be run on the copper loop at high speeds.

Human voice in normal conversational tone is within a frequency range of about 3400 Hz, but the wire has capacity to handle several million Hz.

Thus by splitting the wires frequency into many smaller voice bands, a large number of phone calls can be made on the same phone line.

Traditional phone service was created to let you exchange voice information with other phone users and the type of signal used for this kind of transmission is an “analog” signal. An input device such as a phone set takes an acoustic signal (which is a natural analog signal) and converts it into an electrical equivalent in terms of volume (signal amplitude) and pitch (frequency of wave change).

Since the telephone company's signaling is already set up for this analog wave transmission, it's easier for it to use that as the way to get information back and forth between your telephone and the telephone company. That's why your computer has to have a modem - so that it can demodulate the analog signal and turn its values into the string of 0 and 1 values that is called “digital” information.

Because analog transmission only uses a small portion of the available amount of information that could be transmitted over copper wires, the maximum amount of data that you can receive using ordinary modems is about 56 Kbps (thousands of bits per second). (With ISDN which one might think of as a limited precursor to DSL, you can receive up to 128 Kbps.)

DSL is a distance-sensitive technology: As the connection's length increases, the signal quality and connection speed decrease. ADSL service has a maximum distance of 18,000 feet (5,460 m) between the DSL modem and the DSLAM, though for speed and quality of service reasons, many ADSL providers place an even lower limit on the distance.

At the upper extreme of the distance limit, ADSL customers may experience speeds far below the promised maximums, whereas customers close the central office or DSL termination point may experience speeds approaching the maximum, and even beyond the current limit in the future.

You might wonder why, if distance is a limitation for DSL, it's not a limitation for voice telephone calls, too. The answer lies in small amplifiers, called loading coils, which the telephone company uses to boost voice signals. These loading coils are incompatible with DSL signals because the amplifier disrupts the integrity of the data. This means that if there is a voice coil in the loop between your telephone and the telephone company's central office, you cannot receive DSL service.

The ability of your computer to receive information is constrained by the fact that the telephone company filters information that arrives as digital data, puts it into analog form for your telephone line, and requires your modem to change it back into digital. In other words, the analog transmission between your home or business and the phone company is a bandwidth bottleneck.

Digital Subscriber Line is a technology that assumes digital data does not require change into analog form and back. Digital data is transmitted to your computer directly as digital data and this allows the phone company to use a much wider bandwidth for transmitting it to you.

Meanwhile, if you choose, the signal can be separated so that some of the bandwidth is used to transmit an analog signal so that you can use your telephone and computer on the same line and at the same time.

3.1 Splitter-based vs. Splitterless DSL

Most DSL technologies require that a signal splitter be installed at a home or business, requiring the expense of a phone company visit and installation. However, it is possible to manage the splitting remotely from the central office. This is known as splitterless DSL, "DSL Lite," G.Lite, or Universal ADSL and has recently been made a standard.

When DSL was first implemented Verizon would install a splitter on the outside of your house that separated the voice and data channels on your telephone line. Then they would wire the data channel to a special phone jack in your house for DSL. They stopped doing that after the first year or so, now both phone companies use a splitterless design.

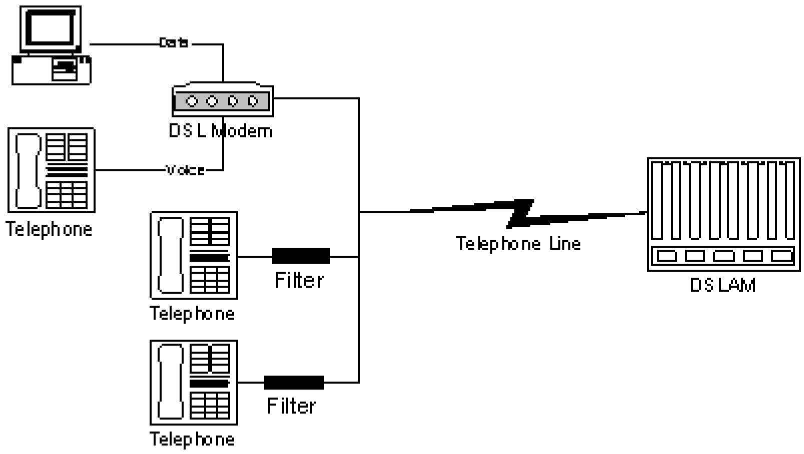


Figure 3-2

Instead of installing a special splitter on the outside of your house, or in your wiring closet, the splitter is now built into the DSL equipment provided by the phone company. This has cut the installation cost of the equipment, and most users find that the DSL signal doesn't interfere with their regular phone lines.

If you do hear some additional static or noise on your lines it's a good idea to install the filters that came with your DSL equipment. (Don't install a filter on the DSL line going to your modem, this will filter out the DSL signal and break your connection to the Internet).
More information about Equipment:

- Qwest (US West) Equipment

- Verizon (GTE) Equipment

The Internet light on the Actiontec, the WAN LNK light on the Cisco modems, Modem light on the Fujitsu modems and the connection indicators only tell you whether your not your DSL modem is 'trained' or synchronized with the DSLAM (DSL Area Multiplexer) -- the device that translates the DSL signal at the telephone company. This is the first part of your connection to the Internet, and it's the only part of the connection that uses DSL technology.

If your connection lights indicate that your DSL is working, but you can't get to the Internet, the problem can be with your computer; in the connection to ISP; or in the connection from ISP to the Internet.

3.2 Modulation Technologies

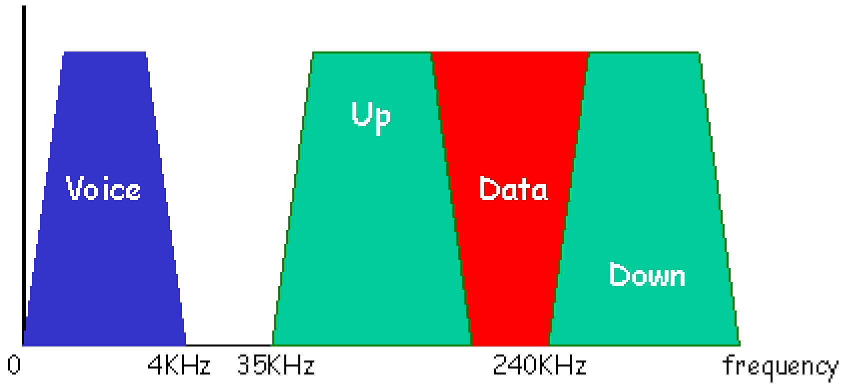


Figure 3-3

DSL takes advantage of the unused bandwidth on your copper phone line. The first 4KHz are reserved for voice data. DSL adds a second set of frequencies to your line in the upper part of the sound spectrum and uses that part of the channel for data. The image shows a sample of the frequencies that data can use.

There are many different types of DSL technology, and each type splits up the DSL signal differently, but most of them follow the same general rules given above. We generally call the device that translates the signal from a regular digital signal sent out by your computer into the high speed sound frequencies that communicate that signal over your phone line a modem, even though these devices are very different than analog modems.

Several modulation technologies are used by various kinds of DSL, although these are being standardized by the International Telecommunication Union (ITU). Different DSL modem makers are using either Discrete Multitone Technology (DMT) or Carrierless Amplitude Modulation (CAP). A third proprietary technology to paradyne, known as Multiple Virtual Line (MVL), is another possibility.

The official ANSI standard for ADSL is a system called **discrete multitone**, or DMT. According to equipment manufacturers, most of the ADSL equipment installed today uses DMT. An earlier and more easily implemented standard was the **carrierless amplitude/phase** (CAP) system, which was used on many of the early installations of ADSL.

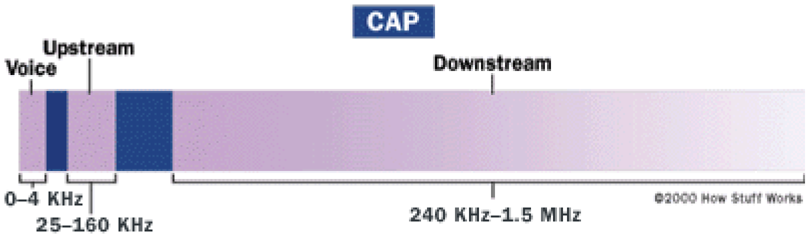


Figure 3-4

CAP operates by dividing the signals on the telephone line into three distinct bands: Voice conversations are carried in the 0 to 4 KHz (kilohertz) band, as they are in all POTS circuits. The upstream channel (from the user back to the server) is carried in a band between 25 and 160 KHz.

The downstream channel (from the server to the user) begins at 240 KHz and goes up to a point that varies depending on a number of conditions (line length, line noise, number of users in a particular telephone company switch) but has a maximum of about 1.5 MHz (megahertz).

This system, with the three channels widely separated, minimizes the possibility of interference between the channels on one line, or between the signals on different lines.

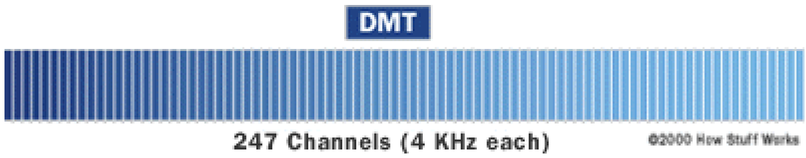


Figure 3-5

DMT also divides signals into separate channels, but doesn't use two fairly broad channels for upstream and downstream data. Instead, DMT divides the data into 247 separate channels, each 4 KHz wide. One way to think about it is to imagine that the phone company divides your copper line into 247 different 4-KHz lines and then attaches a modem to each one.

You get the equivalent of 247 modems connected to your computer at once! Each channel is monitored and, if the quality is too impaired, the signal is shifted to another channel. This system constantly shifts signals between different channels, searching for the best channels for transmission and reception. In addition, some of the lower channels (those starting at about 8 KHz), are used as bidirectional channels, for upstream and downstream information.

Monitoring and sorting out the information on the bidirectional channels, and keeping up with the quality of all 247 channels makes DMT more complex to implement than CAP, but gives it more flexibility on lines of differing quality and reliability.

MVL is based on CAP technology; it is a proprietary version of G.Lite. Now MVL is considered to be a competitor to G.Lite.

G.Lite is a standard based at-home version of ADSL. G.Lite approved by the ITU is slower than the full rate 16-64 Kbps upstream and 1.5-8 Mbps downstream, but is still 8 to 10 times faster than the ISDN.

G.lite has a standard rate of 256 kbps upstream and 1.5 Mbps downstream. G.Lite products are being successfully deployed by telcos. Telcos install a DSL Access Multiplexer (DSLAM) in the central office equipped with line cards that handle either G.Lite or Full ADSL. Compaq and Dell are also installing G.Lite compatible modems in their computers. This will make installations much easier for consumers.

An early trial of this splitterless design of MVL and G.Lite has showed that the consumer is successful in completing a self installation in 80-90 percent of the times.

Since G.Lite is rate adaptive it will allow the telco to provide tiered services at tiered costs. Rate adaptive means being more forgiving of variable line quality than found in laboratory conditions.

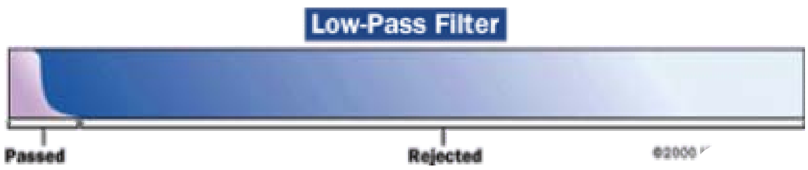


Figure 3-6

Because the high frequency digital signals that your computer sends with DSL can sometimes be heard on your telephone (and can interrupt your fax machine), it is a good idea to install filters between your wall jack and your telephone handset or fax machine.

CAP and DMT are similar in one way that you can see as a DSL user. If you have ADSL installed, you were almost certainly given small filters to attach to the outlets that don't provide the signal to your ADSL modem. These filters are **low-pass filters** - simple filters that block all signals above a certain frequency.

Since all voice conversations take place below 4 KHz, the low-pass (LP) filters are built to block everything above 4 KHz, preventing the data signals from interfering with standard telephone calls.

3.3 Factors Affecting the Experienced Data Rate

DSL modems follow the data rate multiples established by North American and European standards. In general, the maximum range for DSL without a repeater is 5.5 km (18,000 feet). As distance decreases toward the telephone company office, the data rate increases.

Another factor is the gauge of the copper wire. The heavier 24 gauge wire carries the same data rate farther than 26 gauge wire. If you live beyond the 5.5 kilometer range, you may still be able to have DSL if your phone company has extended the local loop with optical fiber cable.

3.4 The Digital Subscriber Line Access Multiplexer (DSLAM)

This separates the voice frequency from the data traffic and controls and routes the digital subscriber line traffic between the subscribers end user equipment (router ,modem, NIC) and the network service providers network.

To interconnect multiple DSL users to a high-speed backbone network, the telephone company uses a Digital Subscriber Line Access Multiplexer (DSLAM). Typically, the DSLAM connects to an asynchronous transfer mode (ATM) network that can aggregate data transmission at gigabit data rates. At the other end of each transmission, a DSLAM demultiplexes the signals and forwards them to appropriate individual DSL connections.

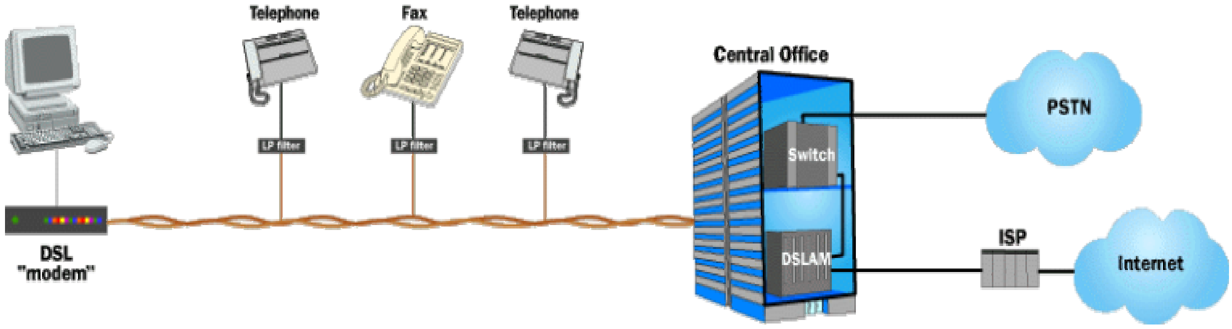


Figure 3-7

DSL can be broken up into three basic structures,

- The home or small office
- The network service provider or Telco central office
- The telco data network and Telco telephone network.

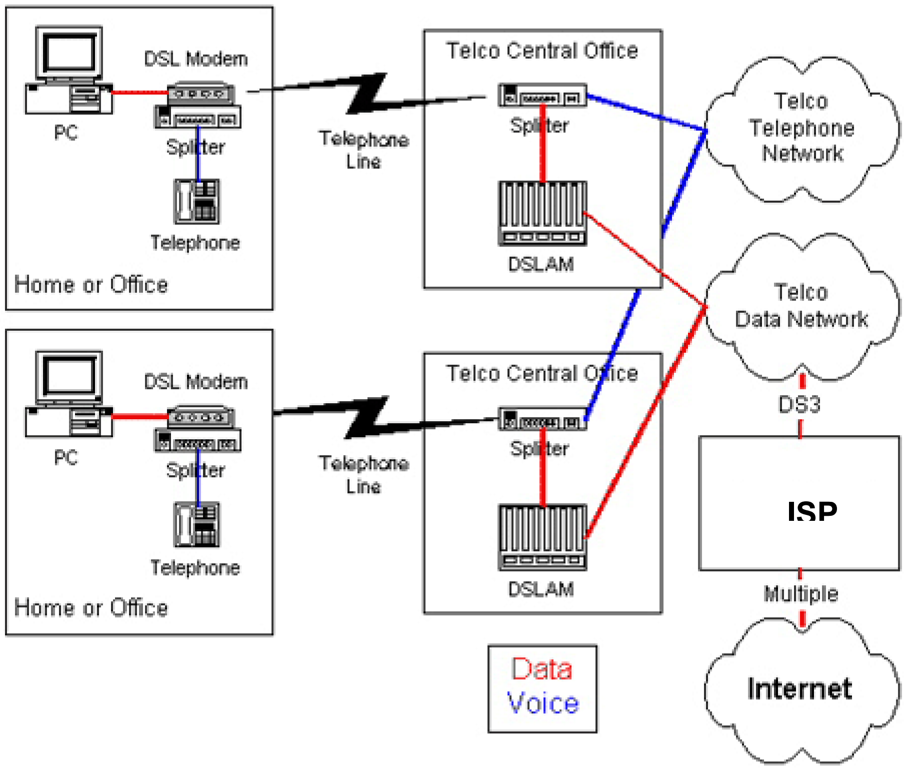


Figure 3-8

The quality of the DSL service that you can get depends upon the quality of the copper phone line between your house and the telephone company's Central Office (CO) where the DSL equipment is housed. This is a quick diagram of the different physical components in that connection:

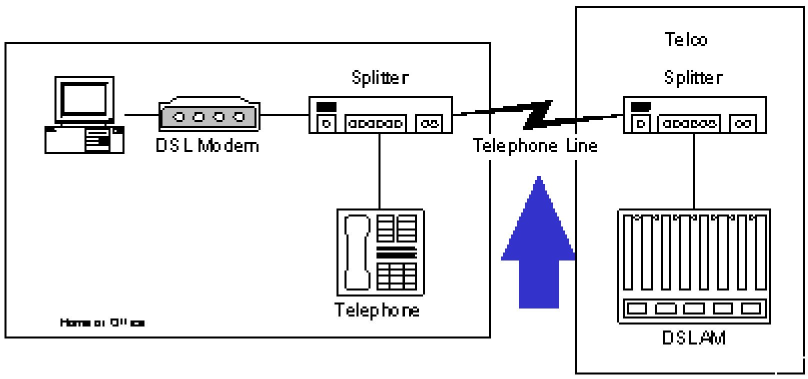


Figure 3-9

The phone line between your location and the DSLAM at the telephone company (Telco) must meet the following requirements:

- The line must be All Copper
- Only one phone number can be assigned to the line
- No Digital Loop Carrier (DLC) or fiber connection between your home and the local Central Office
- The distance must be less than 15,000 feet. (Current technology is increasing this distance, check with your telephone company what the limit is in your area.)
- No loads, bridges, taps or other phone company devices on the line.

DSL uses the same Plain Old Telephone Service (POTS) copper phone line to transmit data that your regular analog modem does, but uses a digital and not an analog signal. This technology works by bypassing the analog voice system (and its limitations) altogether.

With DSL you use a special DSL "modem" (also called a CPE) to send a digital signal from your computer, over the copper wire to another special DSL modem at your phone company's Central Office (the building where your phone line terminates).

At the Central Office, the regular voice and telephone data that you generate by using your phone normally is split off and sent normally through the Public Switched Telephone Network (PSTN), and the digital signal from your computer is translated at the DSL modem at the Central office (called a DSLAM) and routed through a separate Data Network to the ISP. At ISP the data traffic is routed out to the Internet.

In this diagram the splitter that separates the regular telephone signal from the DSL signal is shown as a different device, but in real life the splitter is usually built into the DSL equipment.

Because DSL is separated from your regular voice line, you can use your DSL to connect to the Internet, at the same time that you are talking on the phone or using your fax machine. If you have a phone line in your house that you use just for your modem, you may not need it any more!

DSLAM to ISP or Data network, and Data network to the Internet
This is a handy over simplification of the complicated nest of fiber and switching devices that take the data from your DSL line from the DSLAM and send it out to the Internet. The boundaries of the Service Provider network are surrounded by the green box. (Clouds are used whenever there are too many connections to draw them individually).

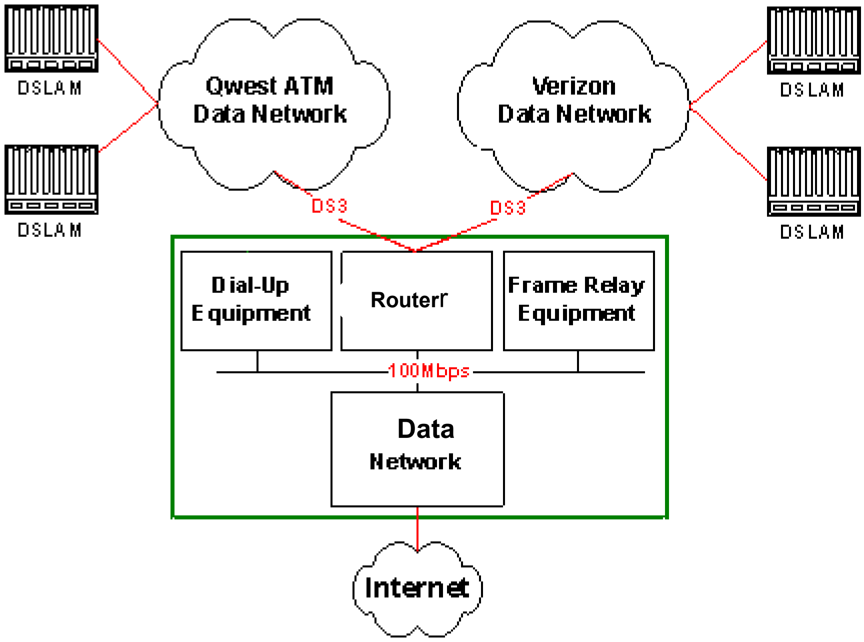


Figure 3-10

3.4.1 The "Path" (DSLAM to Data network)

In the DSLAM (DSL Area Multiplexer) the DSL signal is translated back into a regular digital signal and then forwarded through the telephone company's or private DSL provider's data network. After passing through the telephone company data network, the data from your DSL connection is sent through a DS3 to ISP. The path that your data takes from the DSLAM to ISP is often called the Permanent Virtual Circuit (PVC) -- phone company technicians often just call it "the path".

This part of your connection is largely invisible you and to ISP. Generally problems in this part of the network are found by sending a set amount of traffic through the data network and checking different points along the network to see if it makes it through to the other side.

It can be difficult to find problems in this part of your connection, and it frequently takes a 3 way conference call between ISP, the phone company's or private DSL providers repair, and the customer end of the connection to identify the problem.ISP to the Internet

At ISP the DS3 from the telephone company comes straight into the DSL router. (There may be multiple routers, but one customer’s connection only terminates in one of them). The IP of the DSL router is given as your Gateway on your Account Information, and it is the first piece of equipment that you can ping.

The DSL router uses your IP and your MAC address to authenticate your DSL connection (so you don't need to enter a username and password). As its name implies the DSL router sends your data through the data network to other routers that connect to mail and web servers, or to our upstream Internet connections.

3.4.2 ISP to the Internet

At ISP the DS3 from the telephone company comes straight into the DSL router. (There may be multiple routers, but one customer’s connection only terminates in one of them). The IP of the DSL router is given as your Gateway on your Account Information, and it is the first piece of equipment that you can ping.

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4 DSL End to End Architecture with Cisco

4.1 End to End architecture

Cisco 828 or SOHO 78 G.SHDSL Routers Deployed in a Back-to-Back

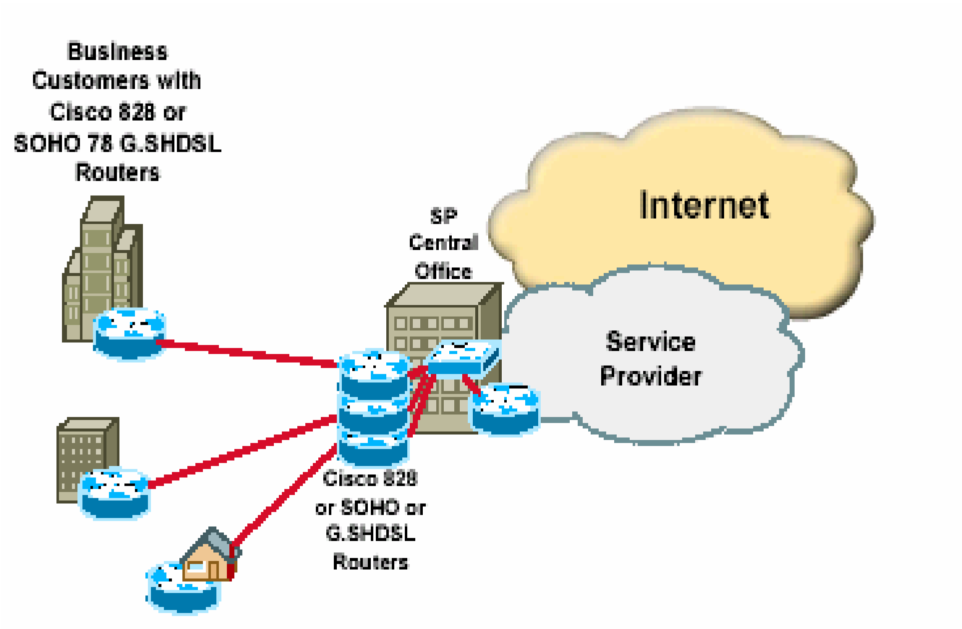


Figure 4-1

G.SHDSL solutions typically are deployed by service providers connecting G.SHDSL routers with DSL Access Multiplexers (DSLAMs) or IP multi service switches that contain corresponding G.SHDSL line cards.

However, the technical specifications for the G.SHDSL standard allow two G.SHDSL routers to directly connect with copper wiring in a back-to-back configuration. This back-to-back scenario allows two Cisco 828 or Cisco SOHO 78 G.SHDSL routers to connect without a DSLAM or IP DSL Switch between the units.

4.1.1 Environment by a Service Provider

Customers can deploy a back-to-back configuration to take advantage of existing copper wiring in a building, campus, or neighborhood where DSLAM aggregation equipment is not deployed or where a DSLAM investment and the corresponding infrastructure are not part of the business plan.

Applications for a back-to-back deployment may include:

- A service provider wanting to service only a few select customers in a metropolitan area.
- An enterprise or educational institution that wants to connect campus buildings through telephone wiring.
- A high-rise building where a limited number of tenants require broadband.
- A business wanting to connect two offices inside a building that has unused copper telephone lines
- Temporary installations such as trade shows or construction sites
- Government or local agencies with the right of way for using or deploying copper wiring including environments such as train stations or airports.

4.1.2 Service provider Deployment

Service providers can deploy Cisco 828 or SOHO 78 G.SHDSL routers to serve customers with a high-speed DSL WAN service where a DSLAM has yet to be deployed.

These customers could include those in a metropolitan area with copper lines connecting a service provider's central office (CO) location and an end customer site. G.SHDSL routers can be set up between locations in which a limited number of customers are to be served in this particular geography and the purchase and deployment of a DSLAM is not cost-effective.

The Cisco 828 or SOHO 78 G.SHDSL Router in the CO would be connected through the Ethernet LAN port to a service provider's network with each G.SHDSL port connecting the two sites with copper wiring.

If an increase in potential customers for G.SHDSL service warrants the installation of a DSLAM, the existing customers can continue to use their Cisco 828 or SOHO 78 routers, and their WAN links can be moved from the back-to-back deployment to a connection on a DSLAM line card.

The routers that were formerly used in the CO can then be redeployed to new customers or to other locations in the service-provider network. Additionally, service providers looking to turn on a high-speed service very quickly can simply provide a Cisco 828 or SOHO 78 Router to the end customer and add an additional router at the other end of the line to turn on the service.

A pool of Cisco 828 or SOHO 78 Routers could be kept on hand to immediately support customers where a DSLAM has yet to be deployed for quicker customer service and an immediate path to revenue.

For service-providers who wish to serve a limited number of customers who are beyond the reach of other DSL services, Cisco 828 or SOHO 78 routers can be deployed in the same CO to serve this limited customer set.

4.1.3 Enterprise Campus Deployments

When an enterprise customer has several buildings on a campus connected by copper wiring, hose buildings can be linked with Cisco 828 and SOHO 78 routers. Again, if the enterprise owns or leases the copper-wiring infrastructure, these connections can be used to provide inter building connections with speeds up to 2.3 Mbps. Each LAN within the building would connect with the Cisco 828 or SOHO 78.

Cisco 828 or SOHO 78 G.SHDSL Routers Deployed in a Back-to-Back Environment at an Enterprise Campus

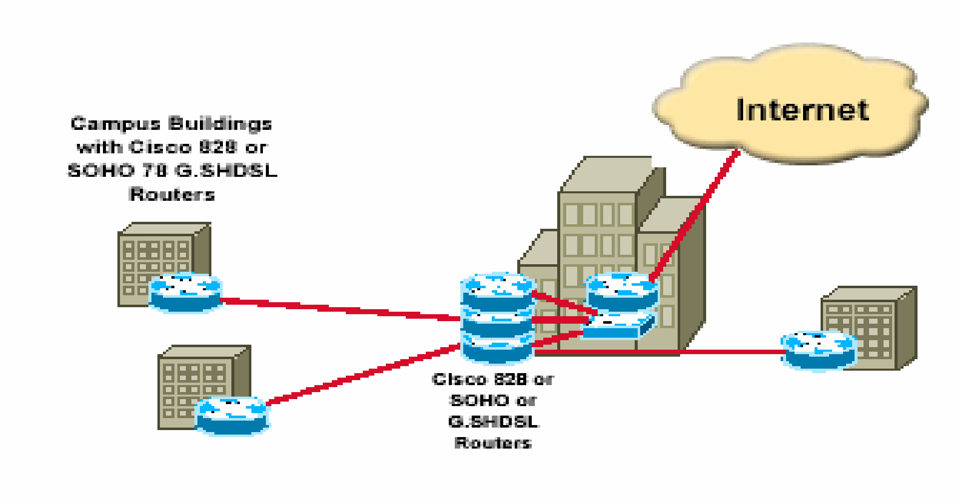


Figure 4-2

4.1.4 Enterprise Office Building Deployments

Another example of a back-to-back application is a business located within a high-rise or office building. If the business has access and ownership of the copper-wiring infrastructure within the building, offices not connected with existing Ethernet cabling can take advantage of the copper connections between the offices for inter-office connectivity.

Cisco 828 or SOHO 78 G.SHDSL Routers Deployed in a Back-to-Back Environment at an Enterprise Office Complex

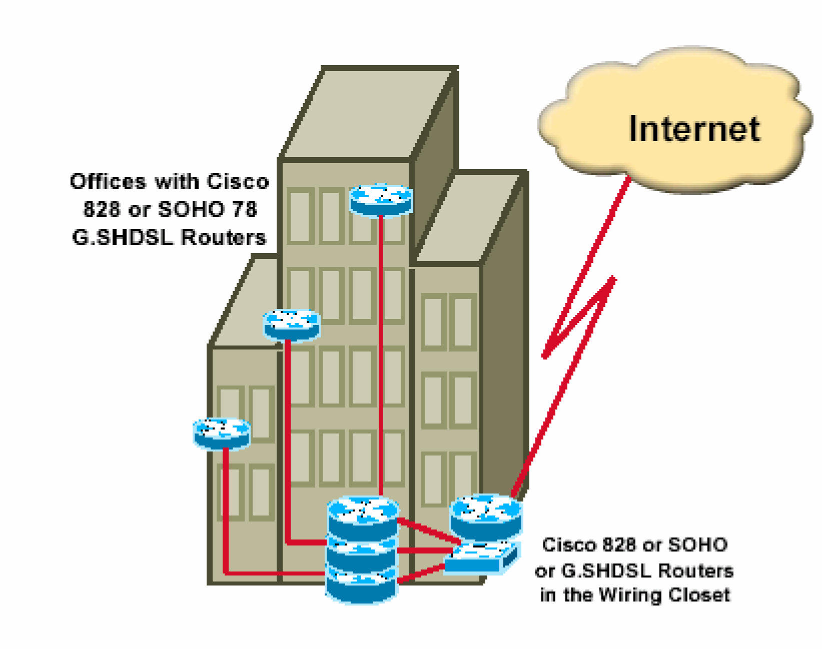


Figure 4-3

4.2 Benefits of G.SHDSL Back-to-Back Deployments

The benefits of using G.SHDSL in a back-to-back router deployment include low-cost, fast installations of high-speed service. In all instances, ownership and access to the copper wiring must be available to the customer, and the wiring must meet the technical requirements as stated in the G.SHDSL standard. Both Service Providers and Enterprise Customers can benefit from the following:

- Low cost broadband solution with minimal infrastructure cost and no DSLAM required
- Simple deployment for rapid service turn on by Service Providers or Enterprises
- Centralized, secure WAN or Internet connection rather than having individual connections at offices or buildings in Enterprise environments
- Service for a small customer base prior to deploying a DSLAM by Service Providers

4.3 Easy Deployment with Cisco 828 G.SHDSL Routers

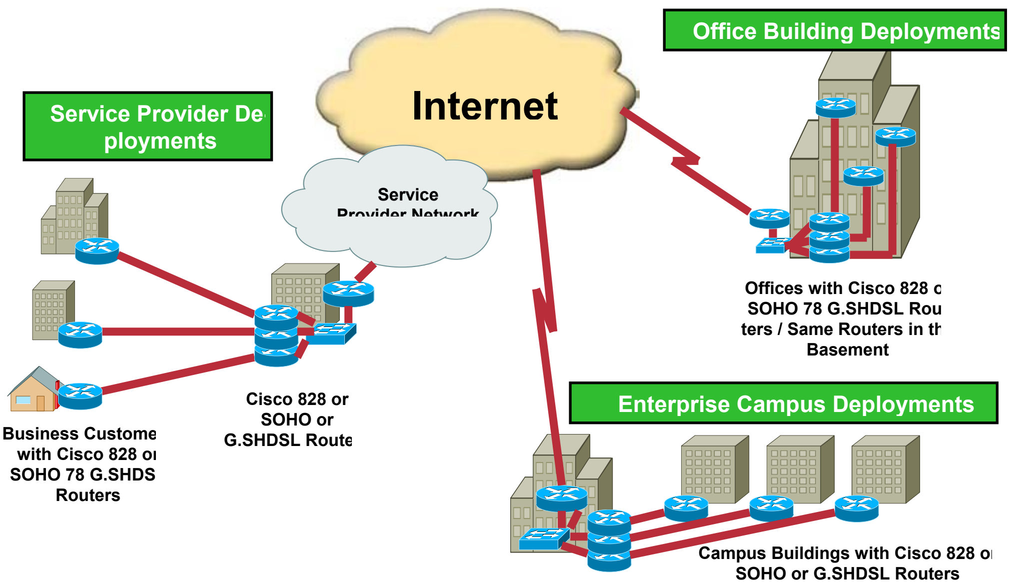


Figure 4-4

The Cisco 828 G.SHDSL Router offers small-office and teleworkers business-class features such as a stateful inspection firewall, support for virtual private networks (VPNs) with IP Security Triple Digital Encryption Standard (IPSec 3DES), and quality of service (QoS) features for voice and video applications.

The Cisco SOHO 78 provides affordable multiuser access with a single WAN connection. Both products offer an integrated four-port hub, and through the power of Cisco IOS Software, offer business-class reliability and remote management capabilities.

Technicians with knowledge of Cisco IOS Software can easily configure both models, and users without knowledge of Cisco IOS Software can use the Cisco Router Web Setup tool, which is a Web-based graphical user interface (GUI) that allows for quick router setup.

4.4 Back to Back router Configuration as CPE and CO

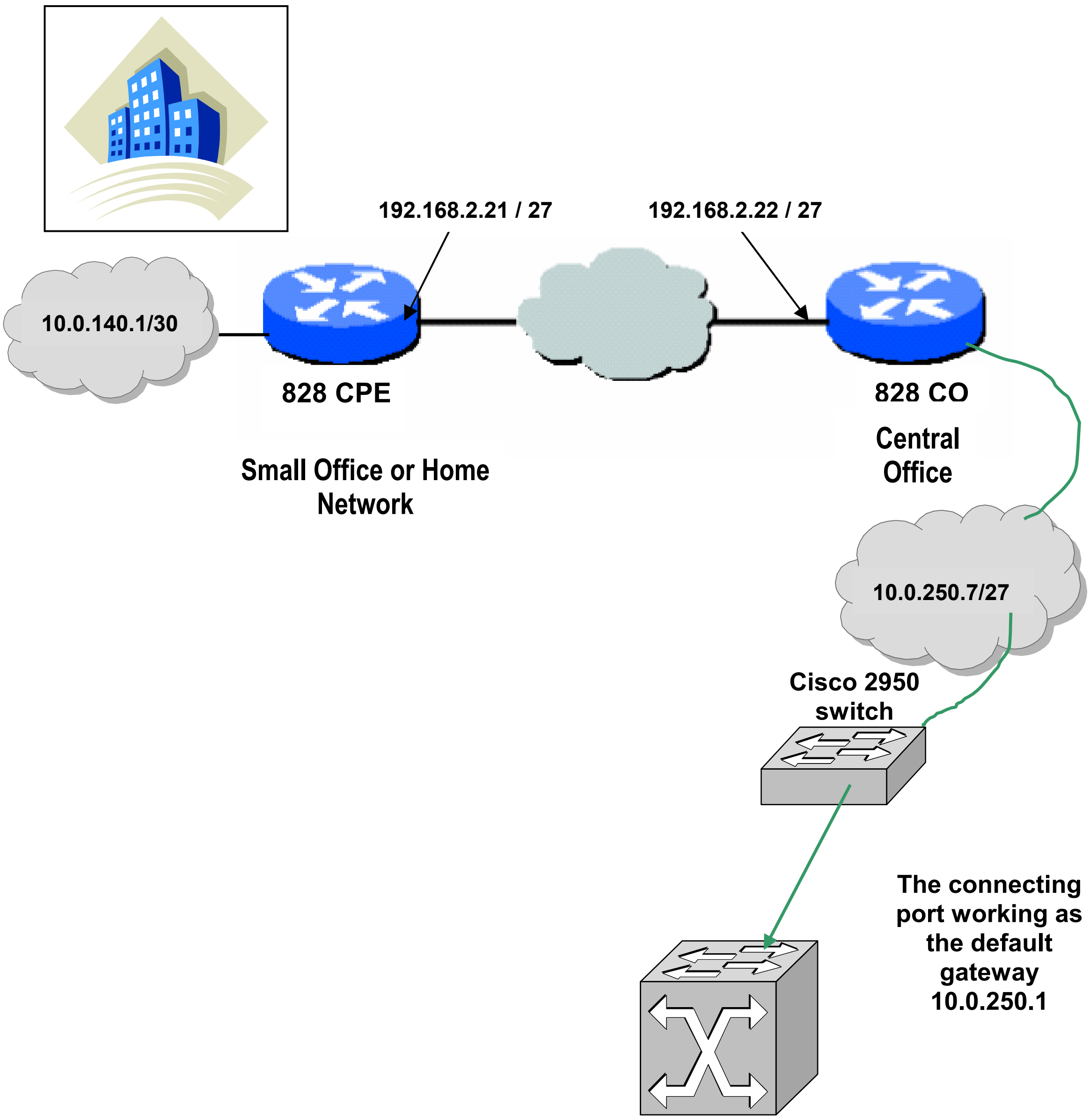


Figure 4-5

CPE Configuration:

```
router# hostname gshdsl_cpe
gshdsl_cpe# show running_configuration

!
version 12.2
no service pad
service timestamps debug uptime
service timestamps log uptime
service password-encryption
!
!
hostname gshdsl_cpe
!
!
username dilerium privilege 15 password 7
 1301051308090A2B
username dataservice privilege 15 password 7
06151F244F5A1B1851
ip subnet-zero
no ip domain-lookup
!
!
!
!
interface Ethernet0
 ip address 10.0.140.1 255.255.252.0
 hold-queue 32 in
 hold-queue 100 out
 no shutdown
!
interface ATM0
 ip address 192.168.2.22 255.255.255.252
 no atm ilmi-keepalive
 pvc 0/67
 encapsulation aal5snap
!
 dsl equipment-type CPE
 dsl operating-mode GSHDSL symmetric annex B
 dsl linerate AUTO
 no shutdown
!
ip classless
```

```
banner motd C
__________________________________________________________

Welcome
This Router is for PRIVATE use ONLY
BORDERLIGHT NETWORK
Management by: Borderlight AB
Switch: $(hostname), Line: $(line)
__________________________________________________________ C
!
line con 0
exec-timeout 30 0
login local
stopbits 1
line vty 0 4
exec-timeout 30 0
login local
!
scheduler max-task-time 5000
```

CO Configuration:

```
router# hostname gshdsl_co
gshdsl_co# show running_configuration
!
!
version 12.2
no service pad
service timestamps debug uptime
service timestamps log uptime
service password-encryption
!
hostname A1-K340-R1
!
logging rate-limit console 10 except errors
!
username dilerium privilege 15 password 7
1301051308090A2B
username dataservice privilege 15 password 7
06151F244F5A1B1851
ip subnet-zero
no ip domain-lookup
!
!
!
no ip dhcp-client network-discovery
!
interface Ethernet0
 ip address 10.0.250.7 255.255.255.224
 hold-queue 32 in
 hold-queue 100 out
 no shutdown
!
interface ATM0
 ip address 192.168.2.21 255.255.255.252
 no atm ilmi-keepalive
 pvc 0/67
  encapsulation aal5snap
!
 dsl equipment-type CO
 dsl operating-mode GSHDSL symmetric annex B
 dsl linerate AUTO
 no shutdown
!
```

```
!
!
banner motd C
_____________________________________________

                  Welcome
    This Router is for PRIVATE use ONLY
    BORDERLIGHT NETWORK
    Management by: Borderlight AB
    Switch: $(hostname), Line: $(line)
_____________________________________________ C
!
line con 0
exec-timeout 30 0
login local
stopbits 1
line vty 0 4
exec-timeout 30 0
```

4.4.1 Explanation:

no shut—For new routers, the only configuration that is necessary to activate the ADSL port (the ATM interface) is to perform a no shut on the ATM interface. If the ADSL trainup is successful, you see the ATM interface line and line protocol become active. If not, use the debug command to debug the trainup sequence, as explained throughout other Cisco documentation but not repeated here

hold-queue—Each network interface, including this ATM interface, has a hold-queue limit. This limit is the number of data packets that the interface can store in its hold queue before rejecting new packets. When the interface empties the hold queue by one or more packets, the interface can accept new packets again.

The command no hold-queue with the appropriate keyword restores an interface's default values. The keyword in specifies the input queue, and the keyword out specifies the output queue. The default input hold queue is 75 packets. The default output hold-queue limit is 100 packets. A queue size has no fixed upper limit. The input hold queue prevents a single interface from flooding the network server with too many input packets. Further input packets are discarded if the interface has too many input packets outstanding in the system.

This limit prevents a malfunctioning interface from consuming an excessive amount of memory. For slow links, use a small output hold-queue limit. This approach prevents storing packets at a rate that exceeds the link's transmission capability.

For fast links, use a large output hold-queue limit. A fast link might be busy for a short time (and thus require the hold queue), but it can empty the output hold queue quickly when capacity returns.

pvc 0/67—Begins to configure this PVC, as assigned by the DSL network provider, as virtual circuit 32 on virtual path 1 (or any other valid combination) on this interface or subinterface; this command opens PVC configuration mode.

Depending on the version of Cisco IOS Software, you might or might not see the command no **atm ilmi-keepalive** in the configuration, because this is now a default value. When you enable Integrated Local Management Interface (ILMI) keepalives on a dual ATM module, periodic ILMI keepalive messages are sent to the ATM switch on the active.

The ATM switch responds to the ILMI keepalives. If the ATM switch fails to respond to four consecutive keepalives, the dual switches from the active to the backup. The ILMI keepalives feature is useful only if the module is connected to two different ATM switches.

dsl equipment-type:
To configure the DSL ATM interface to function as CO equipment or CPE, issue the **dsl equipment-type** command in ATM interface mode. To restore the default equipment type, use the no form of this command.

dsl equipment-type {co | cpe}
--no dsl equipment-type

The following are the syntax descriptions for the above commands:

- **co** - Configures the DSL ATM interface to function as CO equipment.

- **cpe** - Configures the DSL ATM interface to function as CPE.

Defaults

The DSL ATM interface functions as CPE.

dsl linerate:

To specify a line rate for the DSL ATM interface, issue the **dsl linerate** command in ATM interface mode. To restore the default line rate, use the no form of this command.

dsl linerate {kbps | auto}
- **no dsl linerate**

The following are syntax description for the above commands:

- **kbps** - Specifies a line rate in kilobits per second for the DSL ATM interface. Allowable entries are 72, 136, 200, 264, 392, 520, 776, 1032, 1160, 1544, 2056, and 2312.

- **auto** - Configures the DSL ATM interface to automatically train for an optimal line rate by negotiating with the far-end DSL Access Multiplier (DSLAM) or WIC.

Defaults

The DSL ATM interface automatically synchronizes its line rate with the far-end DSLAM or WIC.

dsl operating-mode (g.shdsl):

To specify an operating mode of the DSL for an ATM interface, issue the **dsl operating-mode** ATM interface command. To restore the default operating mode, use the no form of this command.

dsl operating-mode gshdsl symmetric annex {A | B}
-no dsl operating-mode

- The following are syntax descriptions for the above commands.
- **gshdsl** - Configures the DSL ATM interface to operate in multi-rate high-speed mode per ITU G.991.2.

- **symmetric** - Configures the DSL ATM interface to operate in symmetrical mode per ITU G.991.2.

- **annex {A | B}** - Specifies the regional operating parameters. Enter A for North America and B for Europe. The default is A.

Defaults

The default operating mode is gshdsl symmetric annex A.

4.4.2 Verification

You should see the following going across the console session. You will need to issue the **term mon** command, if you are Telneted into the routers, to view the console messages.

```
00:51:25: %GSI-6-RESET: Interface ATM0/0, bringing
up the line. It may take several seconds 00:52:09:
%ATM-5-UPDOWN: Changing VC 0/35 VC-state to PVC ac-
tivated.
00:52:09: %ATM-5-UPDOWN: Changing VC 8/35 VC-state
to PVC activated.
00:52:10: %LINK-3-UPDOWN: Interface Virtual-
Access1, changed state to up
00:52:10: %DIALER-6-BIND: Interface Vi1 bound to
profile Di0
00:52:11: %LINK-3-UPDOWN: Interface ATM0/0, changed
state to up
00:52:12: %LINEPROTO-5-UPDOWN: Line protocol on In-
terface ATM0/0, changed state to up
00:52:12: %LINEPROTO-5-UPDOWN: Line protocol on In-
terface Virtual-Access1, changed state to up
```

This section provides information you can use to confirm your configuration is working properly.

Certain **show** commands are supported by the Output Interpreter Tool (registered customers only) , which allows you to view an analysis of **show** command output.

- **`show running-config`** - Verifies the current configuration, and views the status for all controllers.
- **`show controllers atm slot/port`** - Views ATM controller statistics.
- **`show atm vc`** - Verifies the Permanent Virtual Circuit (PVC) status.
- **`show dsl interface atm`** - Views the status of the G.SHDSL modem
- **show interface atm** - Views the status of the ATM interface.
- The following is example output from the **show atm vc** command. Make sure that the active PVCs are up.

```
gshdsl_co#show atm vc

VCD / Peak Avg/Min Burst
Interface Name VPI VCI Type Encaps SC Kbps Kbps
Cells Sts
0/0 1 0 35 PVC SNAP UBR 2304 UP
0/0 2 8 35 PVC MUX UBR 2304 UP
```

The following is example output from the **`show dsl interface atm`** command. If the line is down, the following statement appears: **`Line is not active. Some of the values may not be accurate.`** You can also verify whether the equipment type and operating mode configuration are correct for your application.

```
gshds_co#show dsl interface atm 0/0

Globespan G.SHDSL/SDSL Chipset Information
Equipment Type: Customer Premise
Operating Mode: G.SHDSL Annex A
Clock Rate Mode: Auto rate selection Mode
Reset Count: 1
Actual rate: 2312 Kbps
Modem Status: Data (0x1)
Received SNR: 39 dB
SNR Threshold: 23 dB
Loop Attenuation: -0.3400 dB
Transmit Power: 7.5 dBm
Receiver Gain: 4.3900 dB
Last Activation Status: No Failure (0x0)
```

```
CRC Errors: 33372
Chipset Version: 1
Firmware Version: R1.5
dsl4-2612a#show dsl interface atm 0/0
Globespan G.SHDSL/SDSL Chipset Information
Line is not active. Some of the values printed may
not be accurate.
Equipment Type: Customer Premise
Operating Mode: G.SHDSL Annex A
Clock Rate Mode: Auto rate selection Mode
Reset Count: 1
Actual rate: 2312 Kbps
Modem Status: Idle (0x0)
Received SNR: 38 dB
SNR Threshold: 23 dB
Loop Attenuation: -0.3400 dB
Transmit Power: 7.5 dBm
Receiver Gain: 4.3900 dB
Last Activation Status: No Failure (0x0)
CRC Errors: 33372
Chipset Version: 1
Firmware Version: R1.5
```

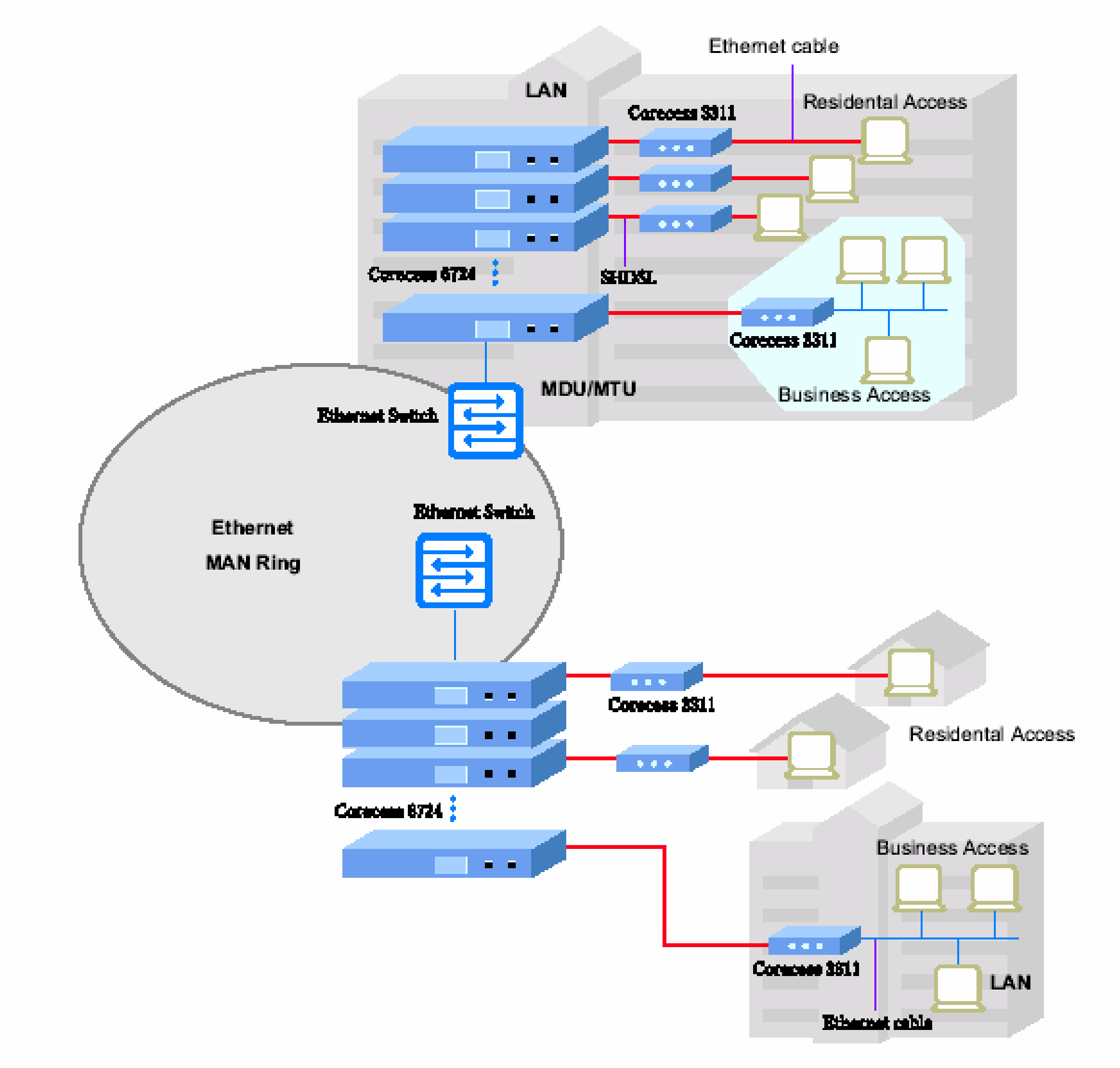
If you are unable to ping across the ATM circuit, verify that the ATM interface is UP/UP by issuing the **show interface** command for the ATM interface on both routers. Issue the **show interface atm** command to view the status of the ATM interface. Make sure that the ATM slot, port, and the line protocol are up, as shown in the following example.

```
gshdsl_cpe#show interfaces atm0

ATM0 is up, line protocol is up
Hardware is PQUICC_SAR (with Globespan G.SHDSL mod-
ule)
MTU 1500 bytes, sub MTU 1500, BW 2312 Kbit, DLY 80
usec,
reliability 255/255, txload 1/255, rxload 1/255
Encapsulation ATM, loopback not set
Encapsulation(s): AAL5, PVC mode
10 maximum active VCs, 2 current VCCs
VC idle disconnect time: 300 seconds
Last input never, output 00:00:08, output hang ne-
ver
Last clearing of "show interface" counters never
```

```
Input queue: 0/75/0/0 (size/max/drops/flushes); To-
tal output drops: 0
Queueing strategy: None
5 minute input rate 0 bits/sec, 0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
261 packets input, 11170 bytes, 0 no buffer
Received 0 broadcasts, 0 runts, 0 giants, 0 throt-
tles
0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ig-
nored, 0 abort
264 packets output, 11388 bytes, 0 underruns
0 output errors, 0 collisions, 2 interface resets

0 output buffer failures, 0 output buffers swapped
out
```

5 DSL architecture with Corecess

5.1 DSL End to End architecture with Corecess DSLAMs



As shown in the figure above, the dslams can be connected to a switch connected in a ring structure. The ring topology is for redundancy, to enable a back up link for the traffic if one link fails. The switches which connect

The switches are situated in the core points of the metropolitan area network, and the dslam attached to the core switch will act as the distribution point/ access points, where traffic is distributed to the end users.

The switches are governed by spanning tree protocol operating between the ports connecting the core switches in the ring topology. This will avoid multiple loops from occurring in the metro network. The spanning tree protocol will enable traffic transportation in one direction, even when the switches have two possible paths to send the traffic, due to the ring structure.If one of the links on a switch is disconnected, the other link attached to the switch is enabled to carry traffic by the spanning tree protocol.

Gshdsl enables symmetric data rates in both the down stream (from the service provider network to the end user) and upstream (from the end user device / network to the service providers network). This attribute has made gshdsl an attractive option for business neworks. Gshdsl enabled data rates from 2.32Mbps to 328kbps symmetric.

Vdsl enables asymmetric but very high speed down stream data rates for both small business and private use. Vdsl data rates are from 8Mbps upstream to 12Mbps downstream.

Corecess 6724 Gshdsl DSLAMs can function in two modes, in bridge mode and in Point to Point Protocol mode. When in the bridge mode the dslam operates like a wire connecting a local PC to the service providers network.

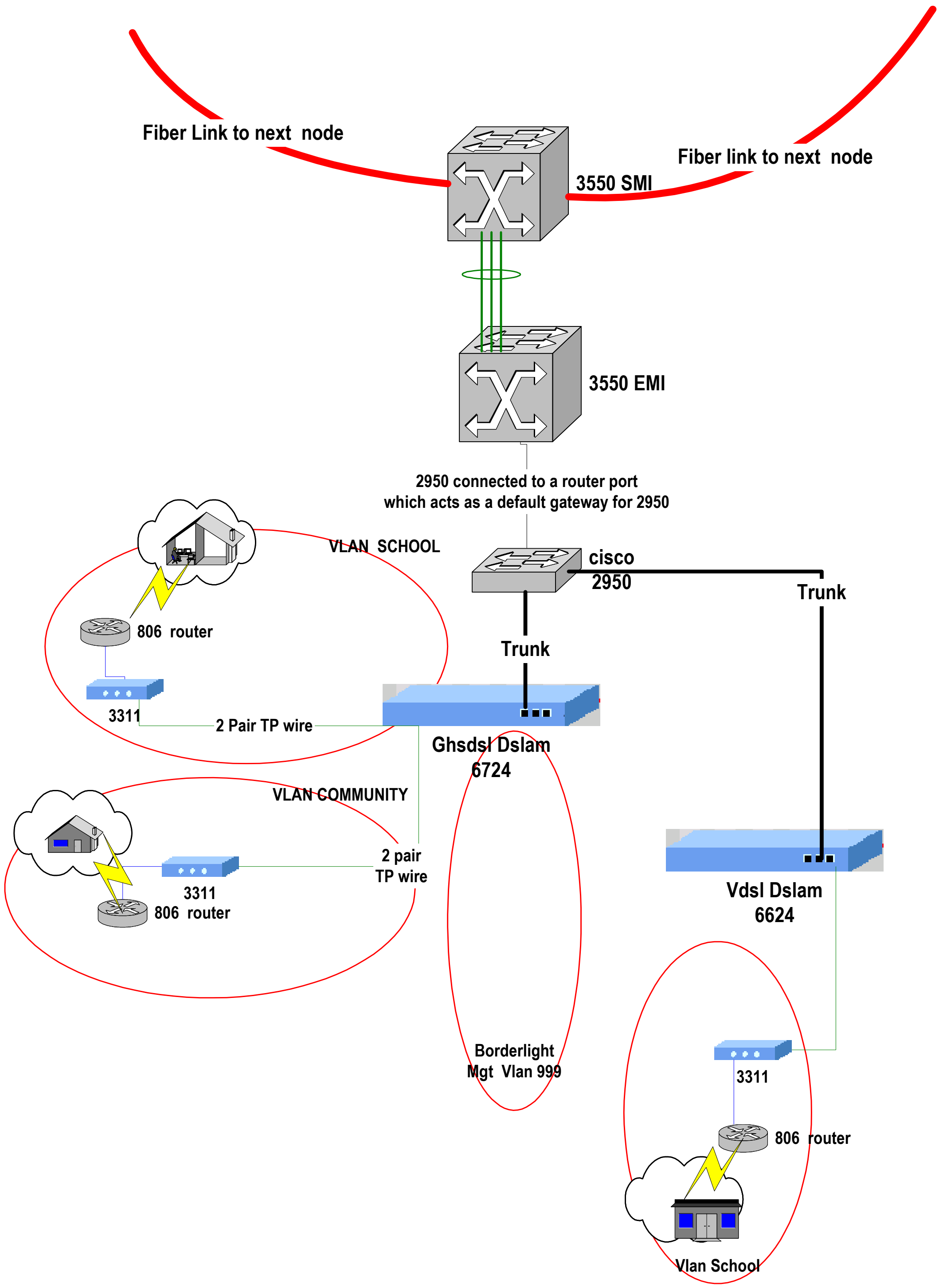
The bridge can function as a dhcp server or just plain bridge. To enable a dslam to function also as a dhcp server, the following information must be gathered.

1. Subnet number sand subnet masks to all its subnets it will be providing IP numbers to
2. Range of IP numbers it can assign in each subnet
3. Maximum IP number Leased time
4. IP address of the default gateway.
5. IP address of the DNS server.

When the corecess dslam is configured to operate in Bridge mode also as a dhcp server, it will start assigning IP addresses to all the subscribers dynamically without another separate dhcp server.
The corecess 6624 dslam have a few differences in terms of how it is configured, but the principle functionalities are the same.

I will illustrate the configuration in a 6724 gshdsl dslam based on Borderlights topological layout and network requirement.

5.2 Configuring 6724 Gshdsl dslam for synchronous connectivity



The DSLAM will be configured according to the above topology and network requirements. Here the dslam is configured in bridge mode and not configured to function also as a dhcp server.

```
CC6724> PriviMode
  Enter privileged command mode password : ********
  Privileged command mode turned on.
CC6724$ ppp all clear |<- clearing any previous ppp
configurations if any
CC6724$ ip |<- move to ip directory
CC6724 ip$ IFconfig flush |<- delete all interfaces
configured in ppp mode
CC6724 ip$ home
CC6724$ bridge Device add all |<- add all subports
and Ethernet ports to the bridge device.
CC6724$ ip IFconfig add bridge  168.192.142.2
168.192.142.1 255.255.192.0 |<- setting Ethernet
ports ip address default gateway and subnet mask.
CC6724$ snmp SysName gshdsl_1 |<-system name
Gshdsl_1$ SysTime set 2003 06 11 wed 10.00.01 |<-
system time for future log checks
```

Enabling shdsl parameters such as transmission speed and mode of transmission and data rates

```
Gshdsl_1$ shdsl |<- move to shdsl directory
Gshdsl_1 shdsl$ admin all enable |<- enable all
subports and Ethernet port
Gshdsl_1 shdsl$ annex all annexb |<- make transmis-
sion mode to be detected for all sub ports accoding
to European standard.
Default if annexa—for American standard, but an-
nexab would detect cpe transmission mode and assign
the appropriate mode for the port transmission whi-
le training the line.

Gshdsl_1 shdsl$ DataRateMode all adaptive
```

Data rates can be fixed rate or adaptive rate. In fixed rate the port will not negotiate a viable rate with the end device while training the line. In adaptive rate the port will negotiate the proper rate suitable for transmission over the line while training the line. This will start training at 2Mbps and negotiates with decrements of 64Kbps.

This will ensure transmission even with difficult distances.
But no further than 10Kfeet.

Defining VLANs.There are 3 vlans in the configurations below. A vlan is a broadcast domain defined by application, function or project team, regardless of the physical location of the end device.

Gshdsl_1 shdsl$ home write |<- get back to default prompt and save the current configuration
Gshdsl_1$ DefineVlan 999 management |<- vlan number and vlan name
Gshdsl_1$ dv 101 school
Gshdsl_1$ dv 100 community
A vlan is non existent until a port is assigned to it.

Gshdsl_1$ AddItemToVLan 1 2 3 4 5 999 management
Gshdsl_1$ aitv 6 7 8 9 10 11 12 13 14 15 101 school
Gshdsl_1$ aitv 16 17 18 19 20 21 22 23 24 100 community

32 vlans are possible to define on a dslam.The Ethernet port, which acts as a truck port carrying all vlans to the device connected belongs to all the vlans defined. This port is called the system port. This port is numbered port 25.
Before initial configuration all subports and system port belong to the default vlan VLAN_0.

When a port is assigned to a vlan other than the default vlan, that port is deleted from the default vlan vlan_0. when a port which belongs to a vlan other than the default vlan is assigned to a vlan other than the default vlan, then that port belongs to two vlans.
This is considered as overlapped vlans.

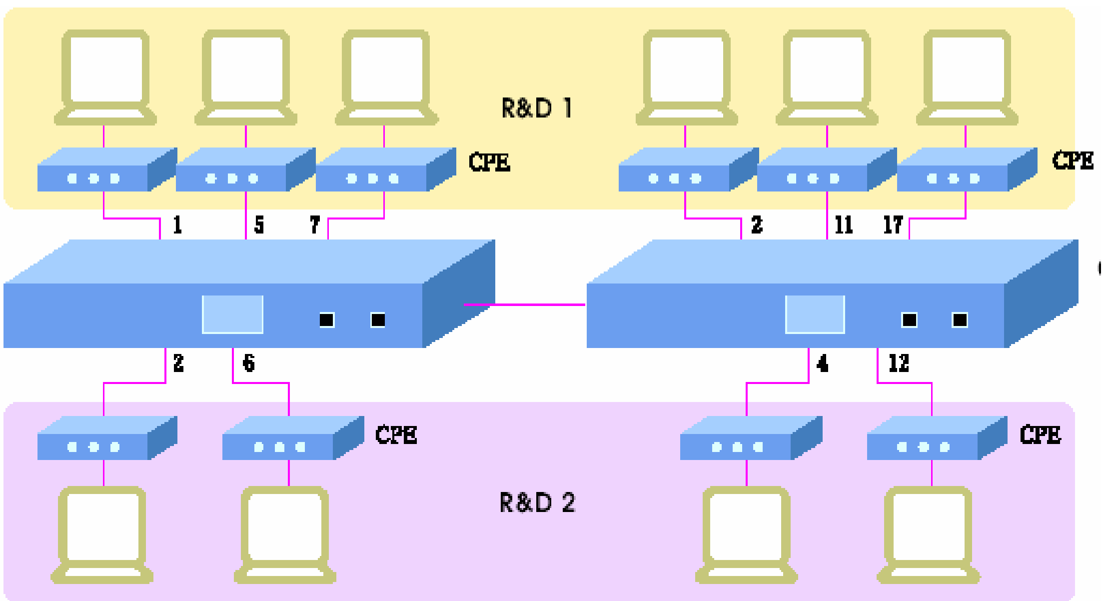
To enable telnet to the dslam the system port which is the Ethernet port (25) is given an IP address, subnet mask and a default gateway address.
The system port will be connected to a router or layer 3 switch to enable inter vlan routing.

Unlike in 6724, in 6624 the vdsl dslam every vlan can have an ip address and a default gateway of its owm and the system ip address given for management of the dslam through telnet is given to the default vlan, vlan_0.

When sharing a vlan between multiple switches, the vlan information must be carried over to the next switch. The transmitted frame should inform the consecutive switches which vlan it belongs to.

Since the Switches do not share vlan information between each other, the vlan the frame belongs to must be clear marked. The Tagged Vlan is a method of inserting information about VLan (tag) where the source node belongs to. The tag is an additional value to inform vlan information to the Ethernet frame.

To enable vlan tagging
Gshdsl_1$ tag on |<- enable vlan tagging for vlans spanning multiples switches.
Gshdsl_1$ Write |<- save configuration



The above picture illustrates vlans spanning multi-ple switches.

6 Flavors of DSL

There are various flavors of DSL technologies, all with their respective acronyms: High-bit-rate Digital Subscriber Line (HDSL), the second generation of HDSL (HDSL2), Single-pair High-bit-rate Digital Subscriber Line (S-HDSL), Symmetric Digital Subscriber Line (SDSL), Asymmetric Digital Subscriber Line (ADSL), Rate Adaptive Digital Subscriber Line (RADSL) and Very High-bit-rate Digital Subscriber Line (VDSL). These terms refer to the way transmission bandwidth is configured and used to support the customer's bandwidth needs.

Digital Subscriber Line is fundamentally another name for an ISDN-BRI channel operating at the Basic Rate Interface with two 64 Kbps circuit switched channels and one 16 Kbps packet switching and signaling channel. This circuit can carry both voice and data in both directions at the same time. However, DSL has come to refer to those various arrangements in which advanced modulating techniques are imposed onto the local channel in order to derive higher throughput in one or both directions.

The basic acronyms for all DSL arrangements came from Bellcore, so we must blame them for the basic confusion between a line and its modems. In general we say that DSL signifies a modem, or a modem pair, and not a line at all. Yes, a modem pair applied to a line creates a digital subscriber line, but when a telephone company buys DSL, or ADSL, or HDSL, it buys modems, quite apart from the lines, which they already own. So, DSL is a modem, not a line. This confusion becomes quite important to avoid when we talk about prices. A "DSL" is one modem; a line requires two.

DSL itself, apart from its later siblings, is the modem used for Basic Rate ISDN. A DSL transmits duplex data, i.e., data in both directions simultaneously, at 160 kbps over copper lines up to 18,000 feet of 24 ga wire. The multiplexing and demultiplexing of this data stream into two B channels (64 kbps each), a D channel (16 kbps), and some overhead takes place in attached terminal equipment. By modern standards DSL does not press any transmission thresholds, but its standard implementation (ANSI T1.601 or ITU I.431) employs echo cancellation to separate the transmit signal from the received signal at both ends, a novelty at the time DSL first found its way into the network.

Most of the DSL modem standards treat the DSL modem as a ‘bit pump’ whose primary task is to transport data quickly and faithfully between end point transceivers, over a specified environment which includes defined loop-sets and noise models. These loop-sets and noise models are designed to be representative of the environment the modem will experience in real access networks. The impairments specified in the DSL modem standards govern the signal-to-noise (SNR) ratio and hence range and achievable bit rate. Generally speaking DSL modems are designed to achieve Bit Error Rates (BER) of less than 1 errored bit in 107, over the test environments specified in the respective standards or reports.

The access network is a hostile environment and most DSL modem physical layer standards will include some or all of the following key requirements in order to provide reliable transmission and vendor interoperability.

- Test loops – makeup and topology (to ensure adequate penetration).
- Cross talk or steady state noise margin (to allow for interactions from other DSL in a multi-pair cable).
- Data rates (both line and payload).
- Impulsive or transient noise margin (to allow for noise spikes e.g. ringing).
- Transmitter power spectral density limits (to ensure spectral compatibility and minimize unwanted RF emissions).
- Return loss (to ensure good line matching and signal power transfer).
- Line interface balance (to prevent EMC problems).
- Framing and data scrambling (to prevent cyclo-stationary effects e.g. line spectra).
- Latency (to minimize delay e.g. for voice traffic).
- Jitter and wander (to minimize data loss).
- Start up protocols (handshaking).
- Warm/cold start limits (time taken to synchronize and achieve reliable bit transport – to minimize circuit unavailability).
- Line coding (to achieve efficiency in terms of bits/s/Hz)
- Duplexing (e.g. time, frequency, echo cancellation).
- Forward error correction (to self-correct physical layer transmission errors and not burden higher layer protocols with data re-transmission.)
- Embedded operations and maintenance (for the transfer of service related information e.g. QoS).

Few of the hostile conditions that plagued the transport of information over copper wires when using the higher frequencies without disturbing the lower POTS spectrum were:

1. ***Attenuation*** - The dissipation of the power of a transmitted signal as it travels over the copper wire line. In-home wiring also contributes to attenuation.

2. ***Bridged taps*** - These are unterminated extensions of the loop that cause additional loop loss with loss peaks surrounding the frequency of the quarter wavelength of the extension length.

3. ***Crosstalk*** - The interference between two wires in the same bundle, caused by the electrical energy carried by each.

6.1 Attenuation and resulting distance limitations

One might compare the transmission of an electric signal to driving a car. The faster you go, the more energy you burn over a given distance and the sooner you have to refuel. With electrical signals transmitted over a copper wire line, the use of higher frequencies to support higher-speed services also results in shorter loop reach. This is because high-frequency signals transmitted over metallic loops attenuate energy faster than the lower-frequency signals.

One way to minimize attenuation is to use lower-resistance wire. Thick wires have less resistance than thin wires, which in turn means less signal attenuation and, thus, the signal can travel a longer distance. Of course, thicker-gauge wire means more copper, which translates into higher per-foot plant costs. Therefore, telephone companies have designed their cable plant using the thinnest gauge wire that could support the required services.

In the U.S., wire thickness is represented by the denominator composed of the fraction of an inch in wire size, assuming a numerator of 1. Therefore, a wire that is 1/24 inch in diameter is referred to as 24 AWG (American Wire Gauge). Wire gauges of 24, and more often 26, are present in most North American cable plants. The design rules used by nearly all telephone companies provided for a change in wire gauge with a thinner gauge used near the entrance of a central office to minimize physical space requirements and changing to thicker gauges over long loops to maximize loop reach. In most markets outside of North America, wire gauges are referred to by their diameter in millimeters. For example, 0.4 mm, which is comparable to 26 gauge, and 0.5 mm, which is comparable to 24 gauge, are the most common; although in many developing countries, heavy gauges of 0.6 mm to 0.9 mm can be found in newly urbanized areas. This variation in wire gauge adds to the challenge of determining a particular DSL system's performance over a particular loop.

6.2 Advanced modulation methods to minimize attenuation

In the early 1980's, equipment vendors were working aggressively to develop Basic Rate ISDN, which would provide up to two 64 Kbps B-channels, plus a 16 Kbps D-channel used for signaling and packet data. The information payload, plus other overhead associated with implementation, resulted in 160 Kbps in total transmitted information. A key requirement of ISDN was that it had to reach customers over the existing non-loaded copper wire loops, equating to 18,000 feet.

However, an AMI implementation of Basic Rate ISDN would require use of the lower 160,000 Hz, which resulted in too much signal attenuation and would fall short of the required 18,000 feet loop reach on 26-gauge wire. By 1988, advancements in signal processing and line coding doubled the effectiveness of legacy AMI code by sending two bits of information with each cycle of an analog waveform or baud.

The line code was called 2 Binary, 1 Quaternary (2B1Q). A 2B1Q implementation of Basic Rate ISDN uses frequencies ranging from 0 to approximately 80,000 Hz, which has less attenuation and results in the desired 18,000-foot loop reach.

6.3 Bridged Taps

Bridged taps are unterminated extensions of the loop that cause additional loop loss with loss peaks surrounding the frequency of the quarter wavelength of the extension length.

Since wavelength and frequency have an inverse relationship, short bridged taps have the greatest impact on wideband services, while long bridged taps have a greater impact on narrowband services.

Most loops contain at least one bridged tap, and the effect of multiple taps is cumulative. Premises wiring contains additional bridged taps. The additional loss created is greatest on short bridged taps; consequently, technologies that operate at lower frequencies are less impacted.

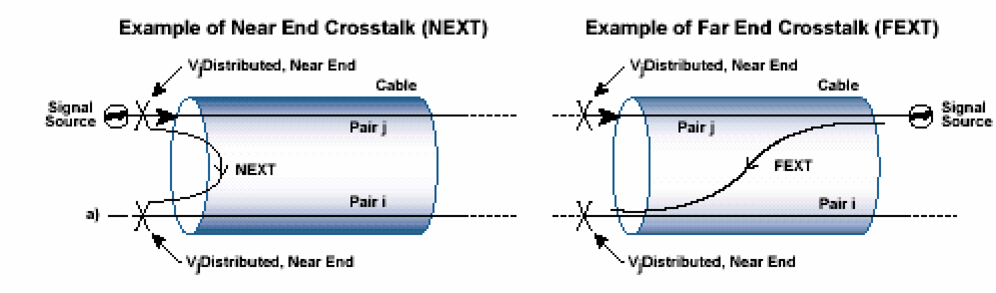
6.4 The effects of cross talk

The electrical energy transmitted across the copper wire line as a modulated signal also radiates energy onto adjacent copper wire loops that are located in the same cable bundle. This cross coupling of electromagnetic energy is called crosstalk.

In the telephone network, multiple insulated copper pairs are bundled together into a cable called a cable binder. Adjacent systems within a cable binder that transmit or receive information in the same range of frequencies can create significant crosstalk interference.

This is because crosstalk-induced signals combine with the signals that were originally intended for transmission over the copper wire loop. The result is a waveform shaped differently than the one originally transmitted.

Crosstalk can be categorized in one of two forms. Near end crosstalk, commonly referred to as NEXT, is the most significant because the high-energy signal from an adjacent system can induce relatively significant crosstalk into the primary signal. The other form is far end crosstalk, or FEXT, which is typically less of an issue because the far end interfering signal is attenuated as it traverses the loop.



NEXT/FEXT Conceptual Model
Figure 6-1

Crosstalk is a dominant factor in the performance of many systems. As a result, DSL system performance is often stated relative to the presence of other systems which may introduce crosstalk.

For example, the loop reach of a DSL system may be stated as being in the presence of 49 ISDN disturbers or 24 HDSL disturbers. As you can imagine, it is rather unlikely that you will deploy a DSL service in a 50-pair cable that happens to have 49 (two-wire) ISDN circuits or 24 (four-wire) HDSL circuits concurrently running in the same bundle.

Therefore, these performance parameters typically represent a conservative performance outlook.

Transmitting and receiving information using the same frequency spectrum creates interference within the single loop system itself. This interference differs from crosstalk because the offending transmit waveform is known to the receiver and can effectively be subtracted from the attenuated receive signals. Eliminating the effects of the transmitter is referred to as echo cancellation.

6.4.1 Minimizing Crosstalk

If the effects of the attenuation and crosstalk are not too significant, the DSL systems can accurately reconstruct the signal back into a digital format. However, when the effect of these phenomena becomes too significant, the signals are misinterpreted at the far end and bit errors occur.

Some DSL systems use different frequency spectra for the transmit and receive signals. This frequency-separated implementation is referred to as Frequency Division Multiplexing (FDM). The advantage of FDM-based systems over echo-canceled systems is that NEXT is eliminated. This is because the system is not receiving in the same range of frequencies in which the adjacent system is transmitting.

FEXT is present, and the FEXT signal is substantially attenuated and less of an interferer because the origin of the FEXT signal is at the distant end of the loop. Therefore, FDM-based systems often provide better performance than echo-canceled systems, in terms of crosstalk from similar adjacent systems.

One interesting phenomenon that should be considered is that echo-canceled systems of a like type introduce what is calledself NEXT. Self NEXT introduces significant interference to other liketype echo-canceled systems in the same cable binder. As a result, the deployment of multiple like-type echo-canceled systems will degrade the performance of all other like-type systems within the cable binder. For example, a single CAP or 2B1Q-based T1 HDSL system may achieve the targeted 12 kft (kilofeet) loop reach. However, as additional CAP or 2B1Q-based systems are added to the cable bundle, the loop reach of the first system and the subsequent systems may be reduced to 9 kft or less. This same phenomenon is true of nearly all echo-canceled systems such as 2B1Q in general, echo-canceled CAP HDSL and SDSL, and echo-canceled DMT ADSL systems, which are discussed in subsequent sections. Therefore, when selecting a DSL technology, service providers should examine the system performance in the presence of self NEXT, which is certain to exist as more services are deployed.

xDSL is drawing significant attention from implementers and service providers because it promises to deliver high-bandwidth data rates to dispersed locations with relatively small changes to the existing telco infrastructure. xDSL services are dedicated, point-to-point, public network access over twisted-pair copper wire on the local loop ("last mile") between a network service provider (NSP's) central office and the customer site, or on local loops created either intra-building or intra-campus.

The engineering compromise of FDM systems is that the separated upstream and downstream signals occupy a greater range of frequencies than echo-canceled systems which overlap the transmit and receive signals resulting in less reach. In some cases, attenuation becomes the most significant factor in performance.

In other cases, crosstalk is the most significant factor in performance. Therefore, the optimal implementation varies as a function of the environment. In deployments where crosstalking systems are expected to be limited and NEXT is moderate to low, an echo-canceled system may perform better. In other cases where deployments of crosstalking systems are expected to be significant and NEXT is likely to be more dominant, an FDM system may perform better.

About the only sure way to manage the issues of crosstalk is to first research the services that are deployed within a given cable bundle and avoid those services that will provide substantial crosstalk. One example of this is the traditional T1 or E1 services.

The spectral placement of T1 AMI and similarly the E1 HDB3-based services provides extensive crosstalk to almost all DSL-based services. As a result, most service providers follow design rules that do not allow the use of T1 or E1 services in the same cable bundles with DSL-based services. You should expect reductions in loop reach in scenarios where T1 or E1 is provisioned in the same cable bundle as DSL-based services.

6.5 Modem Technology

MODEM, an acronym which stands for Modulation / DEModulation . A modem enables two computers too communicate by using the public switched telephone network. The network can only carry signals in the sound frequency range, so modems needed to translate the computers digital information into high pitched sound which can be transported over the phone lines.

When the sound arrives at their destination, they are demodulated – turned back into digital information for the receiving computer.

All modems use some form of compression and error correction. Compression algorithms enable through put to be enhanced by 2 to 4 times over normal transmission. Error correction examines incoming data for integrity and requests retransmission of a packet when it detects a problem.

Voice modems have been able to transmit from 1.2Kbps to 28.8Kbps, and currently with extensive work on V.34 coding voice modem transmission has gone up to 33.6 Kbps.

10 bits per Hertz of bandwidth, a startling figure that approaches Shannons theoretical limits given by the equation

$$C = Bw * \log_2(1+S/N)$$

This simply states that the channel capacity is equal to the bandwidth into log base 2 of 1 plus the signal to noise ratio in that bandwidth.

We have these modems because of almost sublime advances in algorithms, digital signal processing, and semiconductor technology. Voice grade modems operate at the subscriber premises end of voice grade lines and transmit signals through the core switching network without alteration; the network treats them exactly like voice signals.

This has been their singular power that, despite rather slow speeds compared to terminals today, they can be connected immediately anywhere a telephone line exists, and there are nearly 600 million such locations.

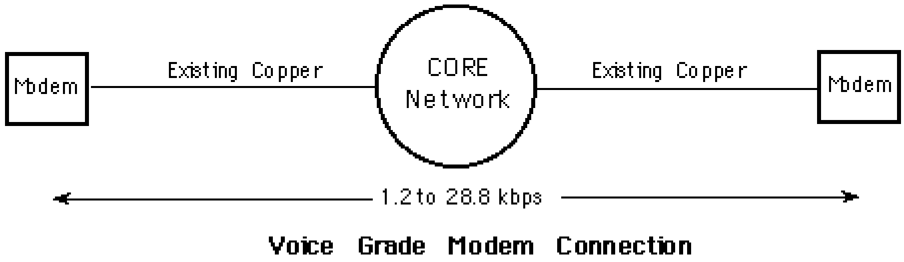


Figure 6-2

Bandwidth limitations of voice band lines do not come from the subscriber line, however they come from the core network. Filters at the edge of the core network limit voice grade bandwidth to 3.3 kHz. Without filters, copper access lines can pass frequencies into MHz regions, albeit with substantial attenuation. Indeed, attenuation, which increases with line length and frequency, dominates the constraints on data rate over twisted pair wire.Thus to tap into this high end of the line bandwidth, the loading coils and the repeaters must be removed.

ISDN, HDSL, ADSL, VDSL and SDSL are all DSL modem technologies designed to operate on telephone wires intended originally for voice-band communication (300Hz to 3.4kHz). As a prerequisite to successful operation, all DSL systems require the removal of any loading coils. These were often inserted in some access networks, at regular intervals,

To improve the voice-band transmission characteristics. Advances in DSP technology combined with innovation in algorithms and coding methods have allowed access to previously untapped information capacity. Bandwidth utilization has increased by two orders of magnitude over the last ten years or so; from under 100kHz for narrow-band ISDN to over 10MHz for VDSL.

Over the years customers watched modem vendors evolve their products on a standard basis. This technique, although some what time consuming, was very important and led to significant feature enhancements.

Initially several modulation schemes were used, by the time V.34 modem came out all the major modulation schemes were combined in that standard giving the customer one modem that could be used in many applications. As the modem market matured customers became less concerned with internals of the standard and more concerned with features, size and flexibility.

As a result of the progress in analog modem technology, and with the advent of mass market consumer-level PCs, there are over 500 million modems in the world today.

The xDSL modem market will follow similar market patterns.

6.6 T1 or E1

In the early sixties engineers at Bell Labs created a voice multiplexing system that first digitized a voice signal into a 64 kbps data stream (representing 8000 voltage samples a second with each sample expressed in 8 bits) and then organized twenty four of them into a framed data stream, with some conventions for figuring out which 8 bit slot went where at the receiving end.

The resulting frame was 193 bits long, and created an equivalent data rate of 1.544 Mbps. The structured signal was called DS1, but it has acquired an almost colloquial synonym -- T1 -- which also describes the raw data rate, regardless of framing or intended use. AT&T deployed DS1 in the interoffice plant starting in the late sixties (almost all of which has since been replaced by fiber), and by the mid-seventies was using DS1 in the feeder segment of the outside loop plant.

In Europe, and at CCITT (now ITU), the collection of world PTTs other than ATT modified Bell Labs original approach, as they were habitual to do, and defined E1, a multiplexing system for 30 voice channels running at 2.048 Mbps. In Europe E1 is the only designation, and stands for both the formatted version and the raw data rate.

Until recently, T1 and E1 circuits were implemented over copper wire by using crude transceivers with a self-clocking Alternate Mark Inversion (AMI) protocol. AMI requires repeaters 3000 feet from the central office and every 6000 feet thereafter, and takes 1.5 MHz of bandwidth, with a signal peak at 750 kHz (U.S. systems). To a transmission purist, this is profligate and ugly, but it has worked for many years and hundreds of thousands of lines (T1 and E1) exist in the world today.

Telephone companies originally used T1/E1 circuits for transmission between offices in the core switching network. Over time they tariffed T1/E1 services and offered them for private networks, connecting PBXs and T1 multiplexers together over the Wide Area Network (WAN).

Today T1/E1 circuits can be used for many other applications, such as connecting Internet routers together, bringing traffic from a cellular antenna site to a central office, or connecting multimedia servers into a central office. An increasingly important application is in the so-called feeder plant, the section of a telephone network radiating from a central office to remote access nodes that in turn service premises over individual copper lines.

T1/E1 circuits feed Digital Loop Carrier (DLC) systems that concentrate 24 or 30 voice lines over two twisted pair lines from a central office, thereby saving copper lines and reducing the distance between an access point and the final subscriber.

Note, however, that T1/E1 is not a very suitable service for connecting to individual residences. First of all, AMI is so demanding of bandwidth, and corrupts cable spectrum so much, that telephone companies cannot put more than one circuit in a single 50 pair cable, and must put none in any adjacent cables. Offering such a system to residences would be equivalent to pulling new wire to most of them. Secondly, until recently no application going to the home demanded such a data rate. Thirdly, even now, as data rate requirements accelerate with the hope of movies and high speed data for everyone, the demands are highly asymmetric -- bundles downstream to the subscriber, and very little upstream in return -- and many situations will require rates above T1 or E1.

In general, high speed data rate services to the home will be carried by ADSL or VDSL (or similar types of modems over CATV lines).

6.7 Asymmetric data transmission

'Asymmetry allows to take advantage of the environment'

Maximizing loop reach with various line codes resulted in extensive study of the characteristics of the loop plant itself. This study revealed that we could transmit a signal a greater distance from the CO to a remote home or office than could be achieved in the opposite direction. This as due to the effects of crosstalk, which are more dominant on the telephone company side of the copper wire loops than on the remote subscriber side.

This phenomenon is due to the fact that more copper wires – each of which introduces a crosstalk component – are combined in large bundles as they get closer to entering the CO.

Conversely, as we traverse the loop from the central office out to the end service user, the loops tend to branch off for connection, resulting in fewer copper wire loops. Therefore, less aggregated crosstalk is introduced by the transmitters at the far end wire bundles.

Another way to take advantage of the characteristics of the telephone plant is by ensuring (in FDM systems) that the lower frequencies are used to transmit toward the CO.

Since lower frequencies are attenuated less than high frequencies, this arrangement ensures that the received signal is as high as possible when it reaches the noisy CO environment (where crosstalk is worse).

In summary, you can more reliably transmit a higher-speed signal from the CO to the remote location than can be transmitted from the remote location to the CO. Devices that were designed to support this concept of a higher-speed service from the CO to the service user and a lower-speed service from the service user to the CO are called Asymmetric Digital Subscriber Line, or ADSL, devices.

Thus all asymmetric digital data transmission techniques entered the world!

Reversing the direction of an ADSL system to provide the higherspeed channel into the network, with the lower-speed channel to the service user, results in substantially reduced loop reach. In addition, if this configuration is implemented in the cable binder with ADSL services configured in the opposite direction, the opposing systems will provide substantial self NEXT, and one or both systems may become inoperable. If such a configuration is allowed by the ILEC, the opposing services must be provisioned over different cable binders.

7 ADSL (Asymmetric Digital Subscriber Line)

ADSL technology is asymmetric. It allows more bandwidth downstream—from an NSP's central office to the customer site—than upstream from the subscriber to the central office. This asymmetry, combined with always-on access (which eliminates call setup), is best suited for Client Server applications.

Thus it's quite appropriate for applications like Internet/intranet surfing, video-on-demand, and remote LAN access, home shopping, Multimedia and PC services require more downstream bandwidth than upstream, which mostly includes clicking on a link or opening a webpage. This has been the most attractive feature for residential users.

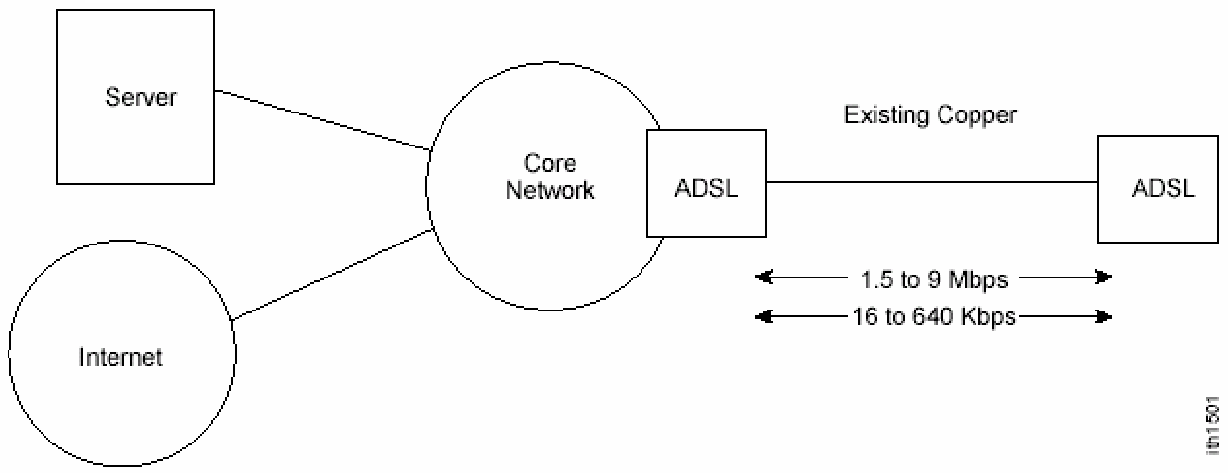
The asymmetric nature of ADSL has less to do with transmission technology than with the cable plant itself. Twisted pair telephone wires are bundled together in large cables. Fifty pair to a cable is a typical configuration towards the subscriber, but cables coming out of a central office may have hundreds or even thousands of pairs bundled together. An individual line from a CO to a subscriber is spliced together from many cable sections as they fan out from the central office (Bellcore claims that the average U.S. subscriber line has twenty-two splices).

Alexander Bell invented twisted pair wiring to minimize the interference of signals from one cable to another caused by radiation or capacitive coupling, but the process is not perfect. Signals do couple, and couple more so as frequencies and the length of line increase. It turns out that if you try to send symmetric signals in many pairs within a cable, you significantly limit the data rate and length of line you can attain.

Happily, the preponderance of target applications for digital subscriber services are asymmetric. Video on demand, home shopping, Internet access, remote LAN access, multimedia access, specialized PC services all feature high data rate demands downstream, to the subscriber, but relatively low data rates demands upstream. MPEG movies with simulated VCR controls, for example, require 1.5 or 3.0 Mbps downstream, but can work just fine with no more than 64 kbps (or 16 kbps) upstream. Even though the protocols governing the Internet or LAN access require higher upstream rates in most cases it can get by with 10 : 1 downstream to up stream bandwidth.

ADSL transmits more than 6 Mbps to a subscriber, and as much as 640 kbps more in both directions (shown in Figure 7-1). Such rates expand existing access capacity by a factor of 50 or more without new cabling. ADSL can literally transform the existing public information network from one limited to voice, text, and low-resolution graphics to a powerful, ubiquitous system capable of bringing multimedia, including full motion video, to every home this century.

Figure 7-1 The components of a ADSL network include a telco and a CPE.



ADSL Connection

7.1 ADSL Capabilities

An ADSL circuit connects an ADSL modem on each end of a twisted-pair telephone line, creating three information channels—a high-speed downstream channel, a medium-speed duplex channel, and a basic telephone service channel. The basic telephone service channel is split off from the digital modem by filters, thus guaranteeing uninterrupted basic telephone service, even if ADSL fails.

The high-speed channel ranges from 1.5 to 6.1 Mbps, and duplex rates range from 16 to 640 kbps. Each channel can be sub multiplexed to form multiple lower-rate channels.

ADSL modems provide data rates consistent with North American T1 1.544 Mbps and European E1 2.048 Mbps digital hierarchies (see Figure 15-2) and can be purchased with various speed ranges and capabilities. The minimum configuration provides 1.5 or 2.0 Mbps downstream and a 16 kbps duplex channel; others provide rates of 6.1 Mbps and 64 kbps duplex. Products with downstream rates up to 8 Mbps and duplex rates up to 640 kbps are available today ADSL modems accommodate Asynchronous Transfer Mode (ATM) transport with variable rates and compensation for ATM overhead, as well as IP protocols.

Downstream data rates depend on a number of factors, including the length of the copper line, its wire gauge, presence of bridged taps, and cross-coupled interference. Line attenuation increases with line length and frequency and decreases as wire diameter increases. Ignoring bridged taps. ADSL performs as shown in Table 7-1.

Although the measure varies from Telco to Telco, these capabilities can cover up to 95% of a loop plant, depending on the desired data rate. Customers beyond these distances can be reached with fiber based digital loop carrier (DLC) systems. As these DLC systems become commercially available, telephone companies can offer virtually ubiquitous access in a relatively short time.

Many applications envisioned for ADSL involve digital compressed video. As a real-time signal, digital video cannot use link- or network-level error control procedures commonly found in data communications systems. ADSL modems therefore incorporate forward error correction that dramatically reduces errors caused by impulse noise. Error correction on a symbol-by-symbol basis also reduces errors caused by continuous noise coupled into a line.

ADSL has highly asymmetric data rates and is rather different to ISDN-BA/HDSL insofar as it supports coexistence of narrow-band POTS on the same wire-pair via a service splitter (see Figure 7-2).

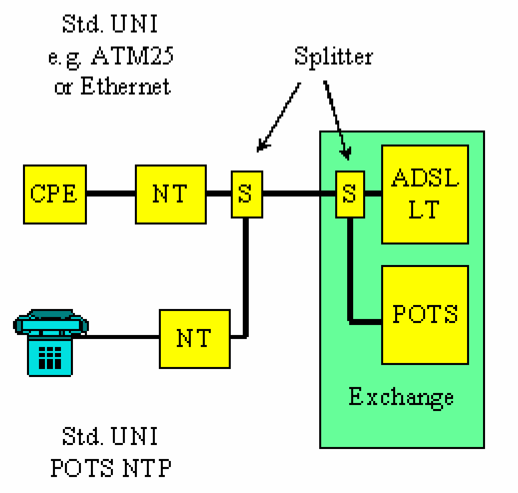


Figure 7-2

Figure 7-3 **This chart shows the speeds for downstream bearer and duplex bearer channels.**

Downstream Bearer Channels	
n x 1.536 Mbps	1.536 Mbps
	3.072 Mbps
	4.608 Mbps
	6.144 Mbps
n x 2.048 Mbps	2.048 Mbps
	4.096 Mbps
Duplex Bearer Channels	
C Channel	16 Kbps
	64 Kbps
Optional Channels	160 Kbps
	384 Kbps
	544 Kbps
	576 Kbps

24110

Table 7-1 **Claimed ADSL Physical-Media Performance**

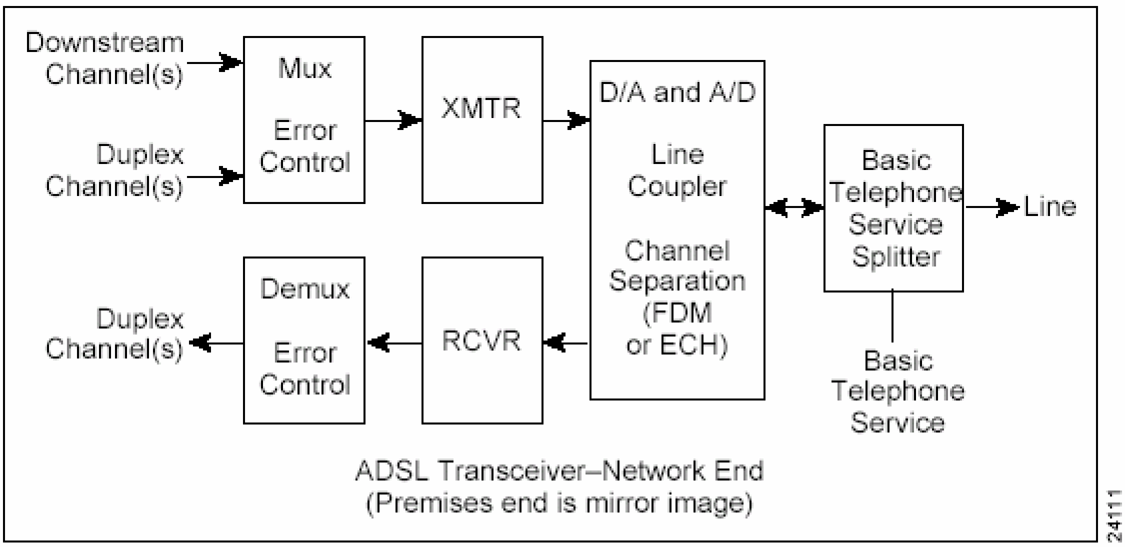
Data rate (Mbps)	Wire gauge (AWG)	Distance (feet)	Wire size (mm)	Distance (kilometers)
1.5 or 2	24	18,000	0.5	5.5
1.5 or 2	26	15,000	0.4	4.6
6.1	24	12,000	0.5	3.7
6.1	26	9,000	0.4	2.7

7.2 ADSL Technology Overview

ADSL depends on advanced digital signal processing and creative algorithms to squeeze so much information through twisted-pair telephone lines. In addition, many advances have been required in transformers, analog filters, and analog/digital (A/D) converters.

Long telephone lines may attenuate signals at 1 MHz (the outer edge of the band used by ADSL) by as much as 90 dB, forcing analog sections of ADSL modems to work very hard to realize large dynamic ranges, separate channels, and maintain low noise figures. Figure 7-4 displays the ADSL transceiver-network end.

Figure 7-3 **This diagram provides an overview of the devices that make up the ADSL transceiver–network end of the topology.**

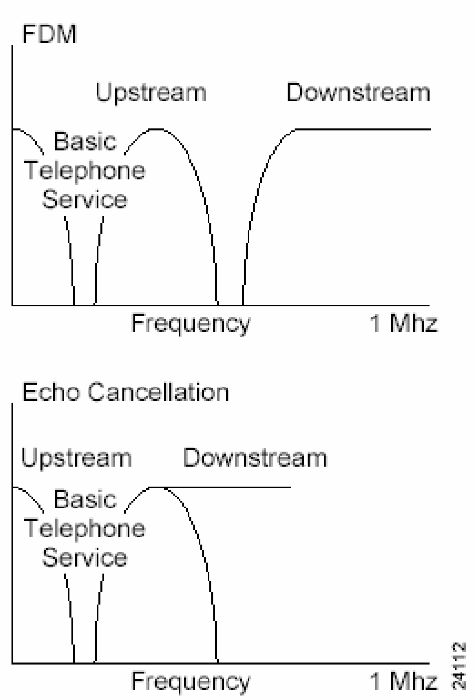


To create multiple channels, ADSL modems divide the available bandwidth of a telephone line in one of two ways—frequency-division multiplexing (FDM) or echo cancellation—as shown in Figure 7-5. FDM assigns one band for upstream data and another band for downstream data.

The downstream path is then divided by time-division multiplexing into one or more high-speed channels and one or more low-speed channels. The upstream path is also multiplexed into corresponding low-speed channels.

Echo cancellation assigns the upstream band to overlap the downstream, and separates the two by means of local echo cancellation, a technique well known in V.32 and V.34 modems. With either technique, ADSL splits off a 4 kHz region for basic telephone service at the DC end of the band.

Figure 7-5 **ADSL uses FDM and echo cancellation to divide the available bandwidth for services.**



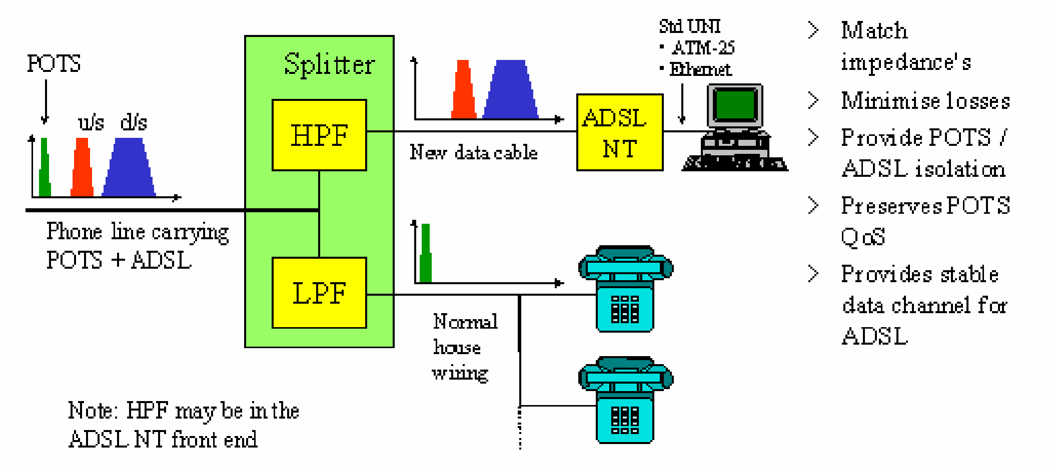


Figure 7-6

Very good quality transmission was required (BER much less than 1 in 109) because of the need to transport highly encoded, low redundancy, MPEG encoded video streams, where single errors produce very noticeable effects on picture quality.

This necessitated the use of data interleaving and Forward Error Correction (FEC) techniques, which were never considered for ISDN-BA or HDSL.

The price paid for these features was an increase in latency; and this is why early ADSL systems had up to 20ms of delay compared to ISDN-BA or HDSL which were limited to no more than 1.25ms.

ADSL has highly asymmetric data rates and is rather different to ISDN-BA/HDSL insofar as it supports coexistence of narrow-band POTS on the same wire-pair via a service splitter (see Figure 7-6).

ADSL uses Frequency Division Duplexing (FDD) in which a band of tones is allocated to upstream transmission (Customer to Exchange direction) and another band is allocated to downstream (Exchange to Customer). It pushes the usable access bandwidth up to around 1MHz.

Some variants of ADSL use echo cancellation techniques to make even better use of available bandwidth by overlapping some of the downstream band with upstream transmission. Figure 7 shows the use of FDD to separate upstream and downstream and the function of the master service splitter.

Downstream and upstream bit-rates are flexible and performance is very dependent on the loop length and noise conditions. ADSL is primarily FEXT limited, whereas ISDN-BA and HDSL are normally NEXT limited. It is this feature of FEXT limitation, which enables bit-rates in excess of 2Mbit/s downstream to be delivered to a large percentage of access network loops.

The upstream bandwidth is by its very nature much smaller than the downstream, and ADSL used in network trials around the world is generally achieving around 2Mbit/s downstream with a few hundred Kbps upstream.

Provision is now made for ATM cell transport and therefore the ADSL transceiver may be thought of as both a bit- and ATM cell pump with multi-service transport capability.

Several other factors might disqualify you from receiving ADSL:

- **Bridge taps** - These are extensions, between you and the central office, that service other customers.
- **Fiber-optic cables** - ADSL signals can't pass through the conversion from analog to digital to analog that occurs if a portion of your telephone circuit comes through fiber-optic cables.
- **Distance** - Even if you know where your central office is (don't be surprised if you don't -- the telephone companies don't advertise their locations), looking at a map is no indication of the distance a signal must travel between your house and the office. The wire may follow a very convoluted path between the two points.

Fiber-optic cables, one of the major disrupting factors of ADSL is actually what enables VDSL technology. In the next section, you'll find out why.

8 VDSL (Very high data rate DSL)

Telecom deregulation has sparked the emergence of the ever-growing competitive local exchange carrier (CLEC) industry segment, delivering a host of long-distance, cellular, high speed internet services.

As the internet gains more users, the content becomes more graphical, and the delivery of services becomes more ubiquitous, demand for faster access and more bandwidth is certain.

Those service providers who capitalize on this new environment of offering a full suit of narrow band and broadband services to deliver voice, data, and video will succeed in the new millennium.

While ADSL delivers high speed internet access over the existing narrow band network, it falls far short of being able to deliver full services that include video.

VDSL began life being called VADSL, because at least in its first manifestations, VDSL will be asymmetric transceivers at data rates higher than ADSL but over shorter lines and simpler implementation requirements than ADSL. But VADSL was renamed by the ANSI T1E1.4 working group.

The principle reason why T1E1.4 decided in VDSL over VADSL was that, unlike ADSL, VDSL is both symmetric and asymmetric. VDSL is ten times faster than ADSL and is over 30 times faster than HDSL. The trade off for increased speed is loop length: VDSL has shorter reach in the loop. While no general standards exist yet for VDSL, discussion has centered around the following downstream speeds:

12.96 Mbps (1/4 STS-1) 4,500 feet of wire

25.82 Mbps (1/2 STS-1) 3,000 feet of wire

51.84 Mbps (STS-1) 1,000 feet of wire

Upstream rates fall within a suggested range from 1.6 Mbps to 2.3 Mbps. The table below provides a comparison on the various DSL technologies available today.

Table 8-1 xDSL types

DSL type	Symmetric/ Asymmetric	Loop range in Km	Downstream (Mbps)	Upstream (Mbps)
IDSL	Symmetric	5.48	0.128	0.128
SDSL	Symmetric	3.048	1.544	1.544
HDSL (2 pairs)	Symmetric	3.657	1.544	1.544
ADSL G.lite	Asymmetric	5.48	1.5	0.256
ADSL	Asymmetric	3.657	6	0.640
VDSL	Asymmetric	0.914	26	3
	Asymmetric	0.305	52	6
	Symmetric	0.914	13	13
	Symmetric	0.305	26	26

In many ways VDSL is simpler than ADSL. Shorter lines impose far fewer transmission constraints, so the basic transceiver technology is much less complex, even though it is ten times faster. VDSL only targets ATM network architectures, obviating channelization and packet handling requirements imposed on ADSL.

VDSL admits passive network terminations, enabling more than one VDSL modem to be connected to the same line at customer premises, in much the same way as extension phones connect to home wiring for POTS.

Like other DSL technologies, VDSL uses the high frequency spectrum available over standard copper above the frequencies used for the lifeline plain old telephone services (POTS) and integrated Service Digital Network (ISDN) services. This baseband for lifeline POTS and ISDN service is preserved by using passive filters commonly known as splitters. This is loosely referred to as data- and Video-over-Voice technology.

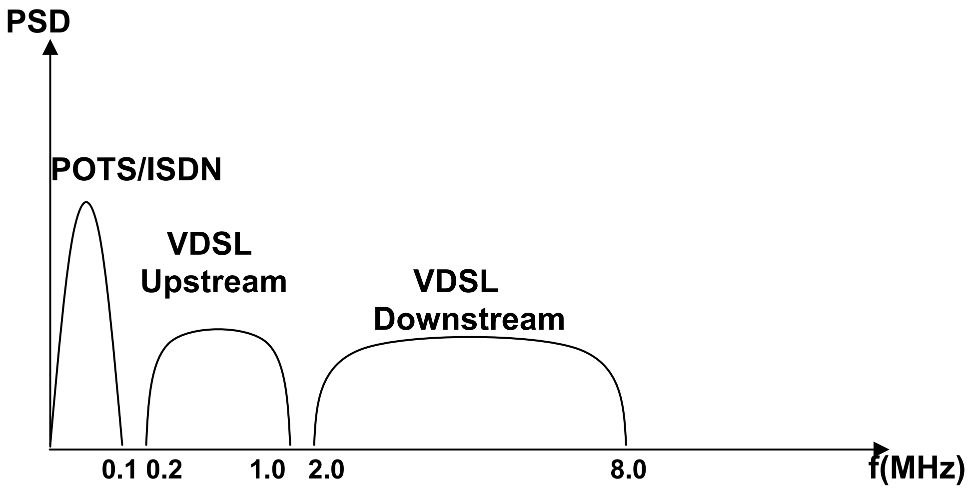
However, the picture clouds under closer inspection. VDSL must still provide error correction, the most demanding of the non-transceiver functions asked of ADSL. As public switched network ATM has not begun deployment yet, and will take decades to become ubiquitous, VDSL will likely be asked to transmit conventional circuit and packet switched traffic. (Indeed, a recent telephone company RFQ describes a VDSL-type transceiver with three circuit-switched video channels and a single ATM channel.)

Passive network terminations have a host of problems, some technical, some regulatory, that will surely lead to a version of VDSL that looks identical to ADSL (with inherent active termination) except its capability for higher data rates over greater spectrum allocation.

The VDSL spectrum is specified to range from 200 kHz to 30MHz. actual spectral allocation varies based on line rates and whether or not asymmetric or symmetric rates are being used.

The figure below illustrates an example of spectral allocation for asymmetric VDSL running at 25.92 Mbps downstream and 3.24 Mbps upstream.

Figure 8-1 Single-carrier VDSL Asymmetric Spectral Allocation



8.1 Asymmetric VDSL

VDSL has been designed to deliver a host of asymmetric broadband services, including digital broadcast TV, Video on Demand (VoD), high speed internet access, distance learning and telemedicine to name a few.

Delivery of these services requires the downstream channel to have a higher bandwidth than the upstream channel and is thus asymmetric. Foe example, HDTV (High-Definition TV) requires 18Mbps for down-stream video content. Upstream, however, it only requires the trans-mission of signaling information (i.e. channel changing or program selection), which is in the order of Kbps.

Downstream rates are derived from submultiples of the synchronous optical network (SONET) and synchronous digital hierarchy (SDH) canonical speed of 155.52 Mbps, namely 51.84Mbps, 25.92 Mbps, 12.96 Mbps.

8.2 Symmetric VDSL

VDSL has also been designed to provide symmetric services for small and medium business customers, the corporate enterprise, high speed data application, video teleconferencing and tele- consulting applications and etc.
At rates from 6.48 Mbps to 25.92 Mbps, it should be noted that VDSL provides symmetric services between the standard T1 (1.536 Mbps) and T3 (44.376 Mbps) rates, bridging the gap over single twisted-pair copper.
Although ANSI has not specified the distance and rates for long-range symmetric services,
6 Mbps to 1.5 Mbps over loops up from 914 m to 3048 m is likely to be supported.

8.3 FULL-SERVICE Broadband Network

There are three basic types or classification by which most communications can be categorized: Voice, Data and Video.

Today, service providers (both Telcos and Cable companies) deliver only one or two out of the three. The telcos who will survive the new communication environment- and especially those that will dominate- will be the ones who deliver all three services over a single unified network.

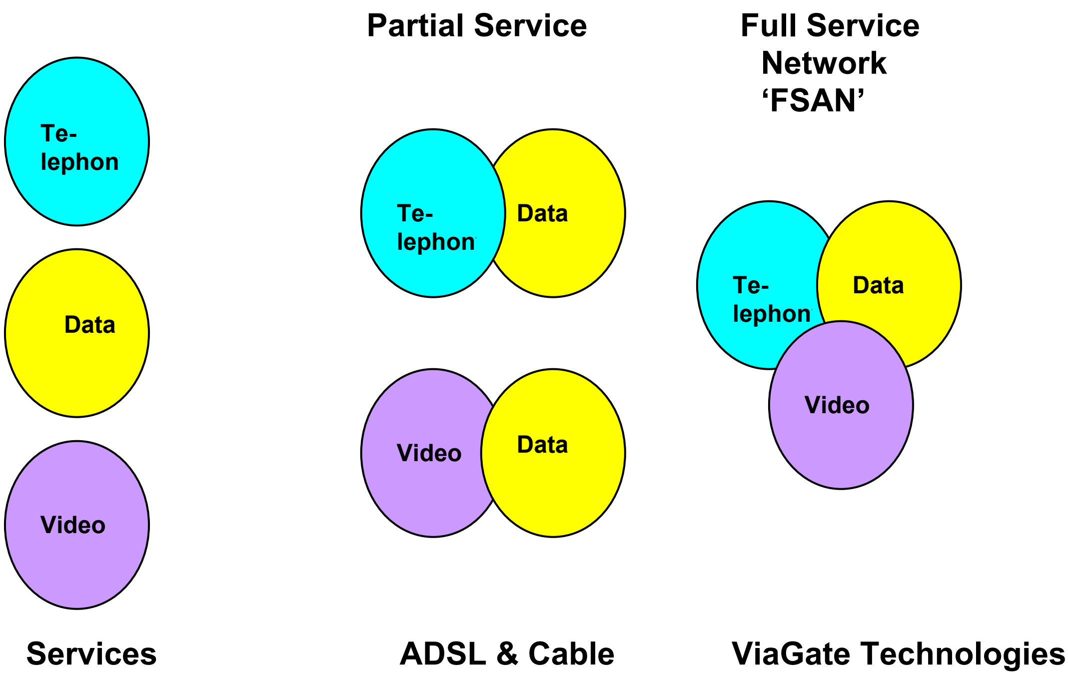
The basic architecture for this full service network that will deliver both narrow band and broadband services is a fiber backbone coupled with copper plant for the last mile.

This architecture has been specified and is currently being built by the world’s top sixteen telecommunication companies called the Full Service Access Network Consortium (FSAN).

FSAN is actively pursuing the standardization and deployment of this narrow band and broadband full-service access networks. FSAN is a consortium restricted to the 16 largest Telco operators in the world.

FSAN consensus specifies ATM as the primary transport technology, utilizing fiber in the core network and VDSL over copper in the last-mile access network. The architectures specified include Fiber-to-the-cabinet (FTTCab) and Fiber-to-the-Building (FTTB).

Figure 8-2 Full-Service Network



Very high-speed DSL is a natural evolution of ADSL to higher bit-rates and the use of even more bandwidth. This can be contemplated because the effective loop length is shortened due to progress of fiber into the backbone of existing access networks in an FSAN (Full Service Access Network) architecture known as Fiber to the Cabinet (FTTCab) as shown in Figure 8 and the VDSL concept is shown in Figure 8-3.

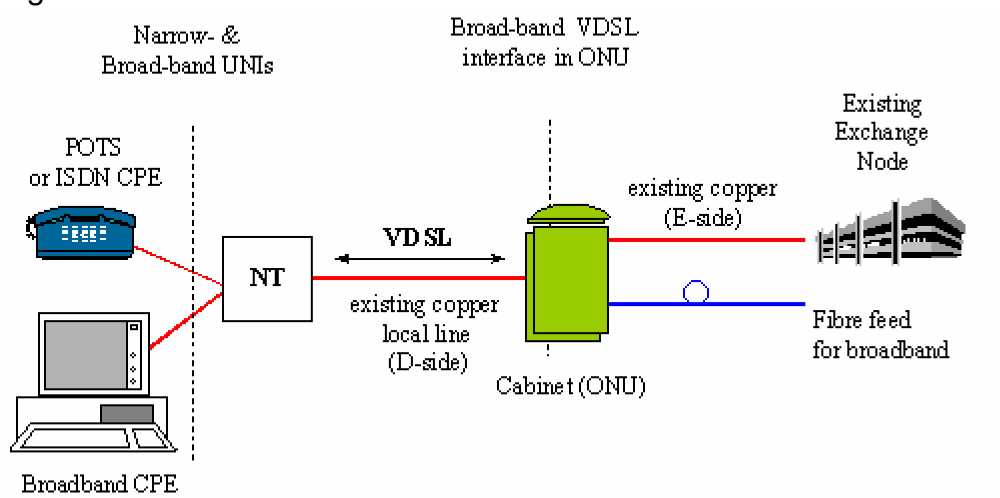


Figure 8-3

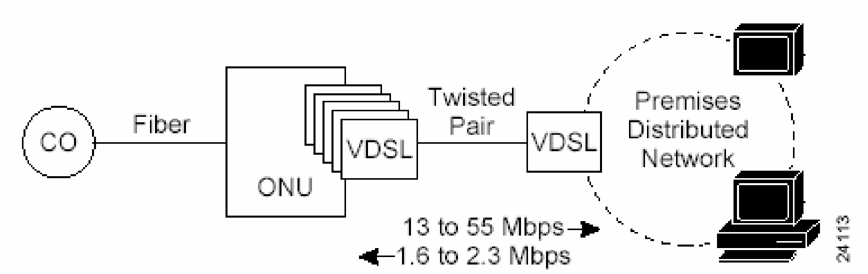
It is becoming increasingly clear that telephone companies around the world are making decisions to include existing twisted-pair loops in their next-generation broadband access networks. Hybrid fiber coax (HFC), a shared-access medium well suited to analog and digital broadcast, comes up somewhat short when used to carry voice telephony, interactive video, and high-speed data communications at the same time.

Fiber all the way to the home (FTTH) is still prohibitively expensive in a marketplace soon to be driven by competition rather than cost. An attractive alternative, soon to be commercially practical, is a combination of fiber cables feeding neighborhood optical network units (ONUs) and last-leg-premises connections by existing or new copper.

This topology, which is often called fiber to the neighborhood (FTTN), encompasses fiber to the curb (FTTC) with short drops and fiber to the basement (FTTB), serving tall buildings with vertical drops. One of the enabling technologies for FTTN is VDSL. In simple terms, VDSL transmits high-speed data over short reaches of twisted-pair copper telephone lines, with a range of speeds depending on actual line length.

The maximum downstream rate under consideration is between 51 and 55 Mbps over lines up to 1000 feet (300 m) in length. Downstream speeds as low as 13 Mbps over lengths beyond 4000 feet (1500 m) are also common. Upstream rates in early models will be asymmetric, just like ADSL, at speeds from 1.6 to 2.3 Mbps. Both data channels will be separated in frequency from bands used for basic telephone service and Integrated Services Digital Network (ISDN), enabling service providers to overlay VDSL on existing services. At present the two high-speed channels are also separated in frequency. As needs arise for higher-speed upstream channels or symmetric rates, VDSL systems may need to use echo cancellation.

Figure 8-4 **This diagram provides an overview of the devices in a VDSL network.**



8.4 VDSL Projected Capabilities

Although VDSL has not achieved ADSL's degree of definition, it has advanced far enough that we can discuss realizable goals, beginning with data rate and range. Downstream rates derive from submultiples of the SONET (Synchronous Optical Network) and SDH (Synchronous Digital Hierarchy) canonical speed of 155.52 Mbps, namely 51.84 Mbps, 25.92 Mbps, and 12.96 Mbps. Each rate has a corresponding target range:

Target Range (Mbps)	Distance (meters)
12.96–13.8	1500
25.92–27.6	1000
51.84–55.2	300

Upstream rates under discussion fall into three general ranges:

- 1.6–2.3 Mbps.
- 19.2 Mbps
- Equal to downstream

Early versions of VDSL will almost certainly incorporate the slower asymmetric rate. Higher upstream and symmetric configurations may only be possible for very short lines. Like ADSL, VDSL must transmit compressed video, a real-time signal unsuited to error retransmission schemes used in data communications.

To achieve error rates compatible with those of compressed video, VDSL will have to incorporate forward error correction (FEC) with sufficient interleaving to correct all errors created by impulsive noise events of some specified duration. Interleaving introduces delay, on the order of 40 times the maximum length correctable impulse.

Data in the downstream direction will be broadcast to every CPE on the premises or be transmitted to a logically separated hub that distributes data to addressed CPE based on cell or time-division multiplexing (TDM) within the data stream itself.

Upstream multiplexing is more difficult. Systems using a passive network termination (NT) must insert data onto a shared medium, either by a form of TDM access (TDMA) or a form of frequency-division multiplexing (FDM).

TDMA may use a species of token control called cell grants passed in the downstream direction from the ONU modem, or contention, or both (contention for unrecognized devices, cell grants for recognized devices).

FDM gives each CPE its own channel, obviating a Media Access Control (MAC) protocol, but either limiting data rates available to any one CPE or requiring dynamic allocation of bandwidth and inverse multiplexing at each CPE.

Systems using active NTs transfer the upstream collection problem to a logically separated hub that would use (typically) Ethernet or ATM protocols for upstream multiplexing.

Migration and inventory considerations dictate VDSL units that can operate at various (preferably all) speeds with automatic recognition of a newly connected device to a line or a change in speed.

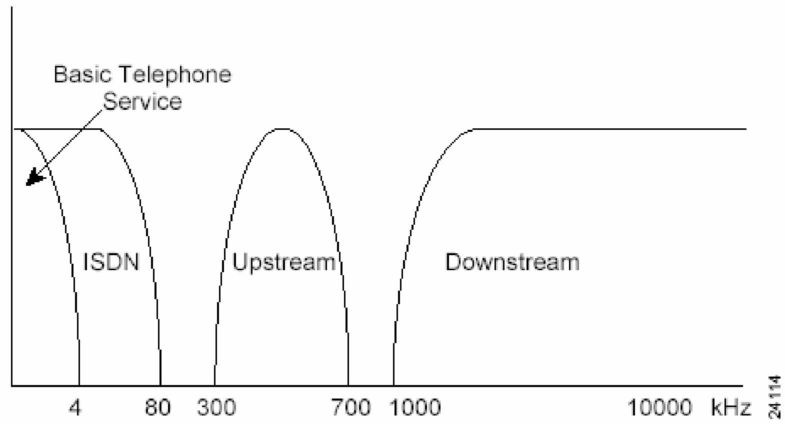
Passive network interfaces need to have hot insertion, where a new VDSL premises unit can be put on the line without interfering with the operation of other modems.

8.5 Channel Separation

Early versions of VDSL will use frequency division multiplexing to separate downstream from upstream channels and both of them from basic telephone service and ISDN (shown in Figure 8-5). Echo cancellation may be required for later-generation systems featuring symmetric data rates.

A rather substantial distance, in frequency, will be maintained between the lowest data channel and basic telephone service to enable very simple and cost-effective basic telephone service splitters. Normal practice would locate the downstream channel above the upstream channel. However, the DAVIC specification reverses this order to enable premises distribution of VDSL signals over coaxial cable systems.

Figure 8-5 Early versions of VDSL will use FDM to separate downstream from upstream channels and both of them from basic telephone service and ISDN, as this example shows.



8.6 Forward Error Control

FEC will no doubt use a form of Reed Soloman coding and optional interleaving to correct bursts of errors caused by impulse noise. The structure will be very similar to ADSL, as defined in T1.413. An outstanding question is whether FEC overhead (in the range of 8%) will be taken from the payload capacity or added as an out-of-band signal. The former reduces payload capacity but maintains nominal reach, whereas the latter retains the nominal payload but suffers a small reduction in reach. ADSL puts FEC overhead out of band.

8.7 Upstream Multiplexing

If the premises VDSL unit comprises the network termination (an active NT), then the means of multiplexing upstream cells or data channels from more than one CPE into a single upstream becomes the responsibility of the premises network. The VDSL unit simply presents raw data streams in both directions. As illustrated in Figure 8-6, one type of premises network involves a star connecting each CPE to a switching or multiplexing hub; such a hub could be integral to the premises VDSL unit.

In a passive NT configuration, each CPE has an associated VDSL unit. (A passive NT does not conceptually preclude multiple CPE per VDSL, but then the question of active versus passive NT becomes a matter of ownership, not a matter of wiring topology and multiplexing strategies).

Now the upstream channels for each CPE must share a common wire. Although a collision-detection system could be used, the desire for guaranteed bandwidth indicates one of two solutions.

The first invokes a cell-grant protocol in which downstream frames generated at the ONU or farther up the network contain a few bits that grant access to specific CPE during a specified period subsequent to receiving a frame.

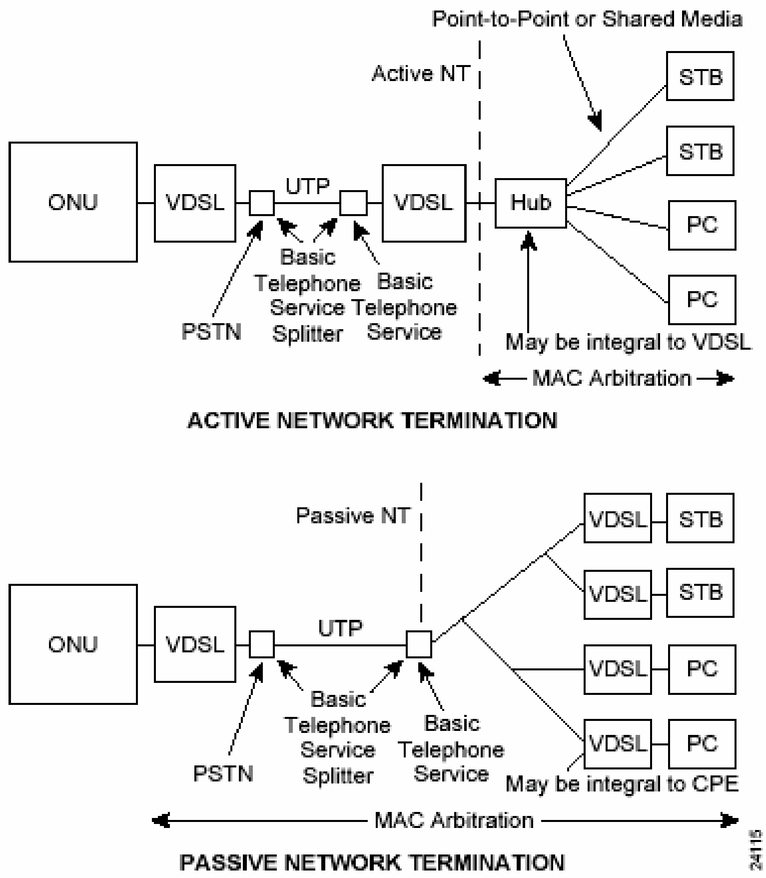
A granted CPE can send one upstream cell during this period. The transmitter in the CPE must turn on, send a preamble to condition the ONU receiver, send the cell, and then turn itself off.

The protocol must insert enough silence to let line ringing clear. One construction of this protocol uses 77 octet intervals to transmit a single 53-octet cell.

The second method divides the upstream channel into frequency bands and assigns one band to each CPE. This method has the advantage of avoiding any MAC with its associated overhead (although a multiplexer must be built into the ONU), but either restricts the data rate available to any one CPE or imposes a dynamic inverse multiplexing scheme that lets one CPE send more than its share for a period.

The latter would look a great deal like a MAC protocol, but without the loss of bandwidth associated with carrier detect and clear for each cell.

Figure 8-6 **This figure shows examples of termination methods in passive and active networks.**



8.8 VDSL Issues

VDSL is still in the definition stage; some preliminary products exist, but not enough is known yet about telephone line characteristics, radio frequency interface emissions and susceptibility, upstream multiplexing protocols, and information requirements to frame a set of definitive, standardizable properties.

One large unknown is the maximum distance that VDSL can reliably realize for a given data rate. This is unknown because real line characteristics at the frequencies required for VDSL are speculative, and items such as short bridged taps or unterminated extension lines in homes, which have no effect on telephony, ISDN, or ADSL, may have very detrimental affects on VDSL in certain configurations.

Furthermore, VDSL invades the frequency ranges of amateur radio, and every above-ground telephone wire is an antenna that both radiates and attracts energy in amateur radio bands.

Balancing low signal levels to prevent emissions that interfere with amateur radio with higher signals needed to combat interference by amateur radio could be the dominant factor in determining line reach.

A second dimension of VDSL that is far from clear is the services environment. It can be assumed that VDSL will carry information in ATM cell format for video and asymmetric data communications, although optimum downstream and upstream data rates have not been made certain.

What is more difficult to assess is the need for VDSL to carry information in non-ATM formats (such as conventional Plesiochronous Digital Hierarchy [PDH] structures) and the need for symmetric channels at broadband rates (above T1/E1).

VDSL will not be completely independent of upper-layer protocols, particularly in the upstream direction, where multiplexing data from more than one CPE may require knowledge of link-layer formats (that is, ATM or not).

A third difficult subject is premises distribution and the interface between the telephone network and CPE. Cost considerations favor a passive network interface with premises VDSL installed in CPE and upstream multiplexing handled similarly to LAN buses.

System management, reliability, regulatory constraints, and migration favor an active network termination, just like ADSL and ISDN that can operate like a hub, with point-to-point or shared-media distribution to multiple CPE on-premises wiring that is independent and physically isolated from network wiring.

However, costs cannot be ignored. Small ONUs must spread common equipment costs, such as fiber links, interfaces, and equipment cabinets, over a small number of subscribers compared to HFC(Hybrid Fiber Coax).

VDSL therefore has a much lower cost target than ADSL because VDSL may connect directly from a wiring center or cable modems, which also have much lower common equipment costs per user.

Furthermore, VDSL for passive NTs may (only *may*) be more expensive than VDSL for active NTs, but the elimination of any other premises network electronics may make it the most cost-effective solution, and highly desired, despite the obvious benefits of an active NT.

8.9 Standards Status

At present five standards organizations/forums have begun work on VDSL:

• *T1E1.4*—The U.S. ANSI standards group T1E1.4 has just begun a project for VDSL, making a first attack on system requirements that will evolve into a system and protocol definition.

• *ETSI*—The ETSI has a VDSL standards project, under the title High-Speed Metallic Access Systems, and has compiled a list of objective, problems, and requirements. Among its preliminary findings are the need for an active NT and payloads in multiples of SDH virtual container VC-12, or 2.3 Mbps. ETSI works very closely with T1E1.4 and the ADSL Forum, with significant overlapping attendees.

• *DAVIC*—DAVIC has taken the earliest position on VDSL. Its first specification due to be finalized will define a line code for downstream data, another for upstream data, and a MAC for upstream multiplexing based on TDMA over shared wiring. DAVIC is only specifying VDSL for a single downstream rate of 51.84 Mbps and a single upstream rate of 1.6 Mbps over 300 m or less of copper. The proposal assumes, and is driven to a large extent by, a passive NT, and further assumes premises distribution from the NT over new coaxial cable or new copper wiring.

• *The ATMForum*—The ATMForum has defined a 51.84 Mbps interface for private network UNIs and a corresponding transmission technology. It has also taken up the question of CPE distribution and delivery of ATM all the way to premises over the various access technologies described above.

• *The ADSL Forum*—The ADSL Forum has just begun consideration of VDSL. In keeping with its charter, the forum will address network, protocol, and architectural aspects of VDSL for all prospective applications, leaving line code and transceiver protocols to T1E1.4 and ETSI and higher-layer protocols to organizations such as the ATM Forum and DAVIC.

The key to VDSL is that the telephone companies are replacing many of their main feeds with fiber-optic cable. In fact, many phone companies are planning **Fiber to the Curb** (FTTC), which means that they will replace all existing copper lines right up to the point where your phone line branches off at your house. At the least, most companies expect to implement **Fiber to the Neighborhood (FTTN)**. Instead of installing fiber-optic cable along each street, FTTN has fiber going to the main junction box for a particular neighborhood.

By placing a VDSL transceiver in your home and a **VDSL gateway** in the junction box, the distance limitation is neatly overcome. The gateway takes care of the analog-digital-analog conversion problem that disables ADSL over fiber-optic lines. It converts the data received from the transceiver into pulses of light that can be transmitted over the fiber-optic system to the central office, where the data is routed to the appropriate network to reach its final destination. When data is sent back to your computer, the VDSL gateway converts the signal from the fiber-optic cable and sends it to the transceiver. All of this happens millions of times each second!

There are two competing consortiums that are pushing to standardize VDSL. The problem is that their proposed standards use carrier technologies that are incompatible with one another. The VDSL Alliance, a partnership between Alcatel, Texas Instruments and others, supports VDSL using a carrier system called **Discrete MultiTone** (DMT). According to equipment manufacturers, most of the ADSL equipment installed today uses DMT.

The other VDSL group is called the VDSL Coalition. Led by Lucent and Broadcom, the Coalition proposes a carrier system that uses a pair of technologies called **Quadrature Amplitude Modulation** (QAM) and **Carrierless Amplitude Phase** (CAP).

CAP operates by dividing the signals on the telephone line into three distinct bands: Voice , Upstream, and Down stream frequencies. These three channels widely separated, minimizes the possibility of interference between the channels on one line, or between the signals on different lines.

QAM is a modulation technique that effectively triples or quadruples the information sent over a line, depending on the version used. It accomplishes this by modulating (varying the shape of the carrier wave) and phase shifting (varying the angle of the carrier wave). An unmodulated signal provides for only two states, 1 or 0, which means that it can send a single bit of information per cycle. By sending a second wave that is shifted 90 degrees out of phase with the first one, and then modulating each wave so that there are two points per wave, you get eight states. This allows you to send 3 bits per cycle instead of just 1.

Why 3 bits? Remember that you are sending binary information. Two states equal a single bit ($2^1 = 2$). Four states are equivalent 2 bits ($2^2 = 4$). Eight states equal 3 bits ($2^3 = 8$).

By adding four more waves, shifted 15 degrees out of phase, you get 16 states and can send 4 bits per cycle ($2^4 = 16$). Adding another bit increases the number of phase shifts geometrically. To go beyond 4 bits per cycle becomes increasingly difficult because the number of necessary states doubles for each bit: $2^5 = 32$, $2^6 = 64$ and so on. There is a possibility that VDSL will encompass both standards, with providers selecting which technology they will implement across their system.

In addition to the emergence of the DSL technology and a new class of Telco, CATV companies are pursuing the telephony market by installing equipment to provide two-way communications over their existing cable installation. They are successfully rolling out internet services with cable modems hybrid fiber/coax (HFC) and are now developing new technology to add voice to their existing video services.

Even though the cable industry appears to do well at providing broadcast video and internet access, the key to success will be the integration of voice and telephony services and broadband video (i.e. High-Definition Television [HDTV]), into their networks. Therefore, the cable companies will be limited in their ability to roll out full-service networks carrying video, data and voice.

The most promising technology capable of delivering full service is Very High data-rate DSL (VDSL). VDSL technology provides the Telco with the ability to create the type of business that is critical for success in the new millennium.

8.10 VDSL Based service sets

The original charter for ADSL was to deliver a full suit of broadband services to the residential consumer, so why the need for VDSL? The reality is that ADSL is Internet-Only technology, limited in its ability to deliver a full complement of broadband services. VDSL, on the other hand, is well suited to deliver these services today and tomorrow.

Table 8-2 VDSL Applications

Full Service, One network	True Multimedia	High-speed Internet Access
Video on Demand	Broadcast Digital TV	Distance Learning
Telemedicine	Interactive Video	Video Conferencing
HDTV	Electronic Commerce	Electronic Publishing
Intranet and Telecom-muting	Video games	Karaoke on Demand

Table 8-3 Application requirements ADSL vs. VDSL

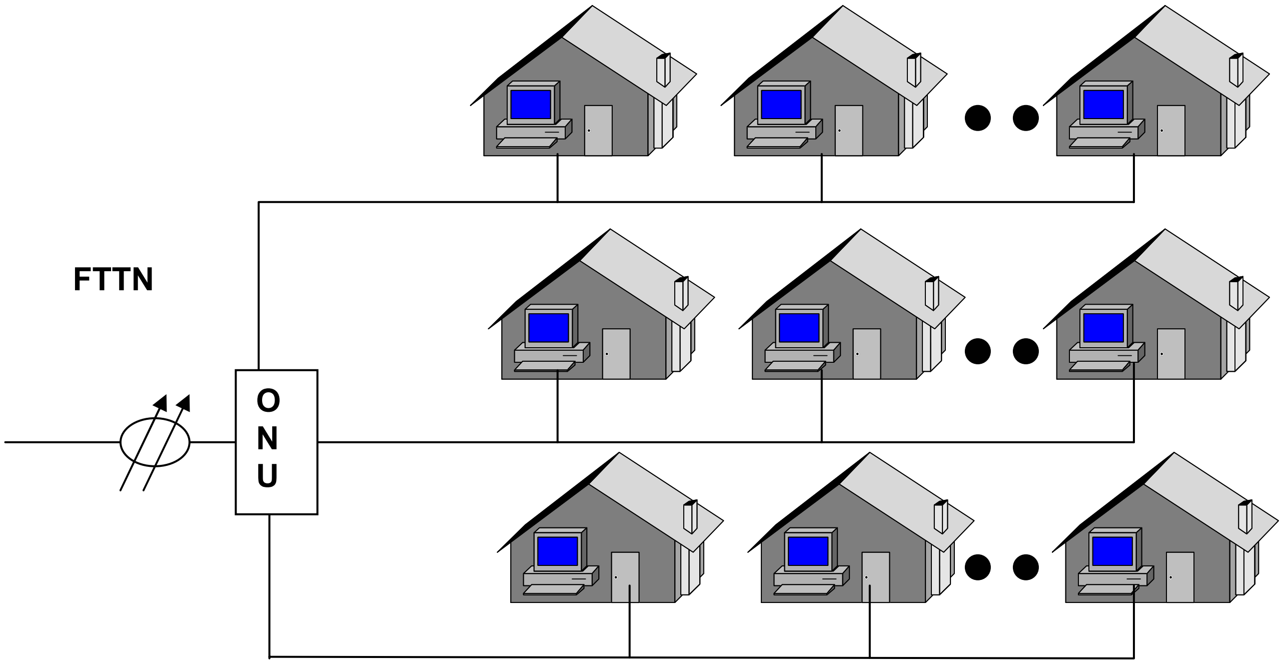
Application	Downstream	Upstream	ADSL	VDSL
Internet hosting	400 kbps-1.5 Mbps	128 kbps-640 kbps	Yes	Yes
Web hosting	400 kbps-1.5 Mbps	400 kbps-1.5 Mbps	Today only	Yes
Video conferen-cing	384 kbps-1.5Mbps	384 kbps-1.5 Mbps	Today only	Yes
Video on De-mand	6.0 Mbps-18.0 Mbps	64 kbps - 128 kbps	Today only	Yes
Interactive Video	1.5 Mbps – 6.0 Mbps	128 kbps–1.5Mbps	Today only	Yes
Telemedicine	6 Mbps	384 kbps-1.5 Mbps	Today only	Yes
Distance learning	384 kbps-1.5 Mbps	384 kbps–1.5Mbps	Today only	Yes
Multiple digital TV	6 Mbps – 24 Mbps	64kbps- 640 kbps	Today only	Yes
Telecommuting	1.5Mbps – 3Mbps	1.5Mbps-3 Mbps	No	Yes
Multiple VoD	18 Mbps	64kbps- 640 kbps	No	Yes
High definition TV	18Mbps	64 kbps	No	Yes
Note: Based on ITU standard 6 Mbps, 640 kbps				

As a result of the above full service capabilities VDSL is expected to overtake ADSL in the DSL market in a few years.

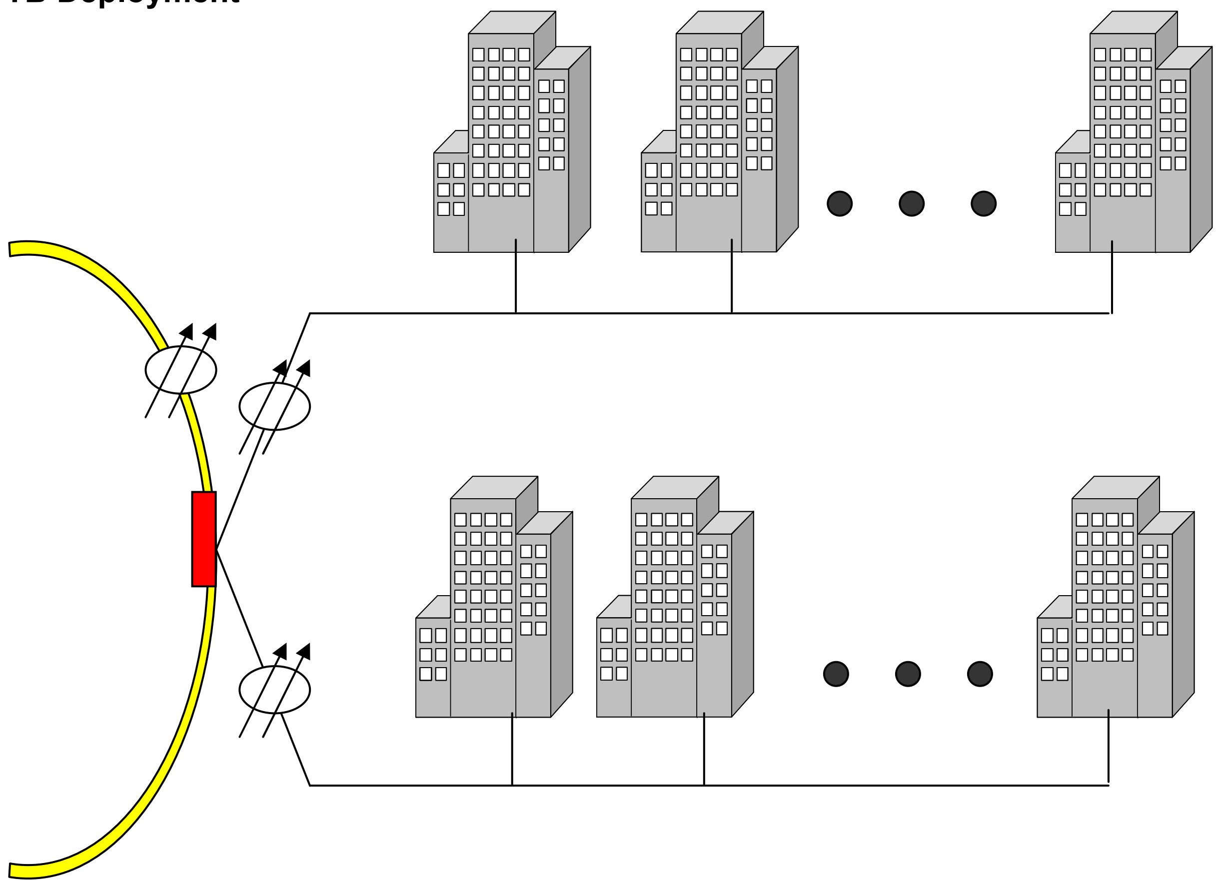
Deployment Scenarios

FTTN and FTTCab Deployment

FTTN



FTTB Deployment



9 HDSL (High-bit-rate Digital Subscriber Line)

High-bit-rate Digital Subscriber Line (HDSL) derives its name from the high bandwidth that is transmitted in both directions over two copper loops. HDSL has proven to be a reliable and cost effective means for providing repeater-less T1 and E1 services over two twisted pair loops.

This proven technology has already resulted in the deployment of over 1.5 million HDSL equipped circuits throughout the local access infrastructure. HDSL transceivers can reliably transmit a 2.048 Mbps data signal over two non-loaded, 24 gauge (0.5mm), unconditioned twisted wire pair loops at a distance of up to 13 kft (4.2 km) without the need for repeaters.

Eliminating the need for repeater equipment and removal of bridged taps significantly simplifies the labor and engineering effort to provision the service.

This attribute eliminates the need to identify, modify, and verify a controlled environment, with power, secured access, and other factors needed to support repeater equipment. It also reduces the time, cost, and effort of isolating faults and taking corrective action when a failure does occur.

Studies by some service providers have indicated that trouble shooting and replacing defective repeater equipment often costs significantly more than the cost of the equipment itself. These attributes translate into increased network up time and reduced engineering time; making possible T1 provisioning in a matter of days, as opposed to weeks. Faster service provisioning and greater up leads to increased customer satisfaction and increased service revenues.

To provision a 12 kft (3.6 km) local loop with traditional T1 transmission equipment requires two transceivers and two repeaters. To provision the same loop with HDSL requires only two HDSL transceivers, one at each end of a line.

High bit-rate DSL modem standards evolved from earlier work on ISDN-BA. The HDSL concept was originally developed in North America when DSL engineers tried to increase the clock rates of ISDN to see how far and fast a high bit-rate system could go, given that Digital Signal Processing (DSP) technology was also rapidly advancing at the same time.

Research work led to the discovery that even simple 4-level PAM could be made to work at rates up to 800kbit/s whilst achieving good coverage (known as the Carrier Serving Area in North America).

Echo cancellation techniques were again used to enable 784kbit/s duplex over a single wire-pair fulfilling the requirement of reach and adequate Signal-to-Noise margin for good Quality of Service. HDSL is a bi-directional symmetric transmission system (see Figure below) that allows the transport of signals with a bit-rate of 1.544Mbit/s or 2.048Mbit/s on multiple access network wire-pairs.

Two different options for the line code are recommended; the Pulse Amplitude Modulation 2B1Q and the Carrierless Amplitude/Phase modulation (CAP). CAP is applicable for 2.048Mbit/s, while for 2B1Q two different frames are defined.

2B1Q
2B1Q represents a straightforward signal type that has two bits per baud arranged as one qua- ternary or
Four-level pulse amplitude modulated scheme. It essentially transmits data at twice the fre- quency of the signal.

CAP
Carrierless Amplitude/Phase modulation (CAP) is a proprietary digital modulation technique 2. is relatively low in cost and is based on a mature technology. One twisted copper wire pair sup ports POTS in the 0-4 kHz bandwidth. CAP-based DSL technology uses frequencies sufficient above the POTS “voice band” to provide bandwidth for low-speed upstream and high-speed

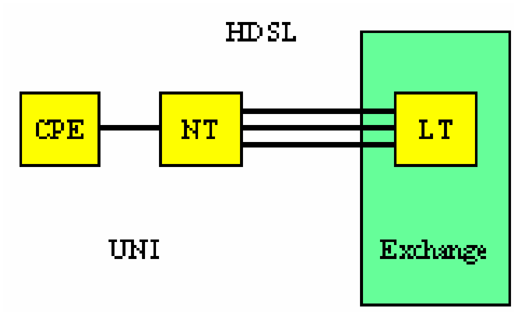


Figure 9-1

The 2B1Q standard for 2.048Mbit/s caters for both duplex transmission on a single pair and parallel transmission on two or three pairs. This allows for the distribution of the data to several pairs and for the reduction of the symbol rate in order to increase the line length or transmission reach. CAP is defined for one or two pairs only and the 1.544Mbit/s 2B1Q for two pairs only.

HDSL is simply a better way of transmitting T1 or E1 over twisted pair copper lines. It uses less bandwidth and requires no repeaters. Using more advanced modulation techniques, HDSL transmits 1.544 Mbps or 2.048 Mbps in bandwidths ranging from 80 kHz to 240 kHz, depending upon the specific technique, rather than the greedy 1.5 MHz absorbed by AMI.

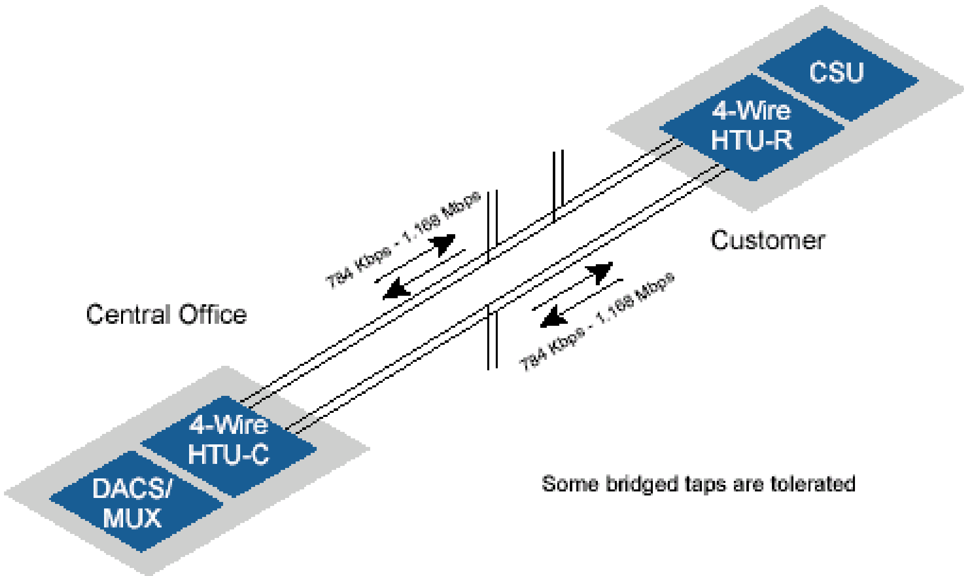
HDSL provides such rates over lines up to 12,000 feet in length (3.6 km on 24 gauge), the so-called Carrier Serving Area (CSA), but does so by using two lines for T1 and three lines for E1, each operating at half or third speed.

Most HDSL will go into the feeder plant, which connect subscribers after a fashion, but hardly in the sense of an individual using a phone service.

Typical applications include PBX network connections, cellular antenna stations, digital loop carrier systems, interexchange POPs, Internet servers, and private data networks. As HDSL is the most mature of DSL technologies with rates above a megabit, it will be used for early-adopter premises applications for Internet and remote LAN access, but will likely give way to ADSL and SDSL in the near future.

In the early 1990's, some vendors encouraged the use of 2B1Q at higher speeds as an alternate way to provision T1 and E1 services, without repeaters. The technique consisted of splitting the ,544,000-bit-per-second service into two pairs (four wires), which each ran at 784,000 bits per second. By splitting the service across two lines and increasing the bits per baud, the per-line speed and resulting need for frequency spectrum could be reduced to allow longer loop reach. This technique was referred to as High-bit-rate Digital Subscriber Line, or HDSL. The result was that an HDSL-based DS-1 service could be implemented over Carrier Serving Area (CSA) specified loops of up to 12,000 feet long (assuming 24 gauge; or 9,000 feet with 26-gauge wire), with no repeaters.

The early 2B1Q-based E1 HDSL initiatives split the 2.048 Mbpsservice across three wire pairs (a total of six wires) in an effort to achieve the targeted loop reach. As the technology matured and performance improved, E1 HDSL implementations migrated to a two-pair (four-wire) implementation, each operating at 1.168 Mbps, which was similar to the T1 implementations.

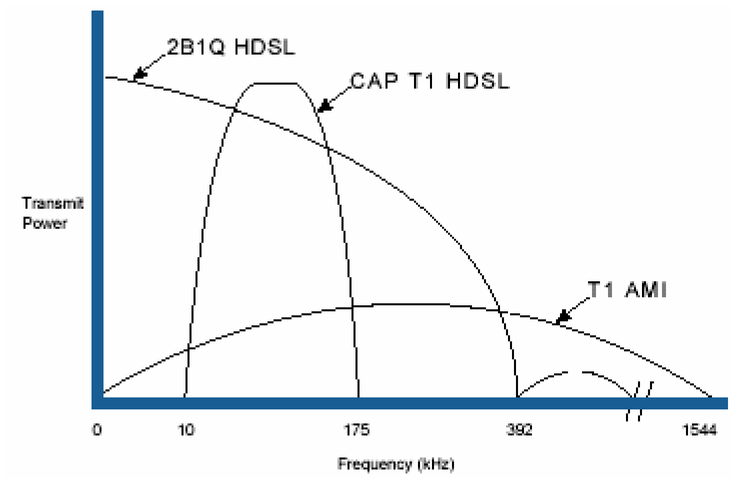


Repeaterless T1/E1 Replacement Model. HTU-C is the HDSL Termination Unit/Central Office and HTU-R is the HDSL Termination Unit on the Remote user end
Figure 9-2

In parallel with the 2B1Q initiative, Paradyne (at the time a subsidiary of AT&T) began development of a similar HDSL transceiver using a line code called Carrierless Amplitude and Phase (CAP) modulation. Like 2B1Q, CAP was an advanced line-coding technique allowing multiple bits of information to be represented by a single frequency cycle or baud. However, CAP could be designed to transmit multiple bits ranging from two to nine bits per baud. This enabled CAP-based transceivers to transmit the same amount of information using a lower range of the frequency spectrum than 2B1Q, equating to less signal attenuation and greater loop reach.

As a result of 2B1Q's proven market acceptance with ISDN and CAP's performance benefits, both line codes were endorsed with technical reports by both the American National Standards Institute (ANSI) and European Telecommunications Standardization Institute (ETSI) standards committees for HDSL.

There are some instances where vendors have developed HDSL products using line codes other than 2B1Q or CAP. However, these examples are isolated, and alternative line codes are not recognized by the standards organizations.



Comparison of HDSL and T1 AMI Frequency Spectra
Figure 9-3

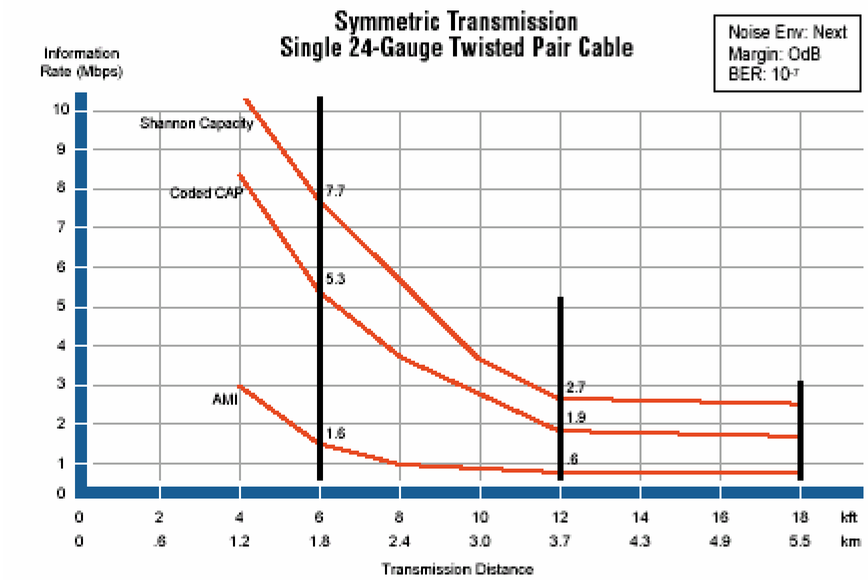
Figure 9-3 illustrates the range of frequencies used by a conventional T1 AMI encoded transmission versus that used by a T1 HDSL transmission technology.

While the diagram is not to scale, the data illustrates that T1 AMI uses nearly four times the spectrum of 2B1Q and nearly nine times that of CAP.

The higher-frequency signals associated with the AMI implementation get weak sooner than the HDSL transmissions. As a result, the CAP and similarly 2B1Q HDSL systems have substantially longer loop reach than AMI or HDB3-based T1 or E1 systems, respectively.

Figure 9-4 provides a theoretical comparison of the supported line speed versus loop reach for AMI, Coded CAP and the Shannon Capacity.

The comparisons assume certain industry defined test conditions and, under these conditions, the Shannon Capacity plots represent the theoretical maximum loop reach for a given line speed.



Line Speed and Loop Reach Comparison
Figure 9-4

9.1 FCC and Spectrum Management

In an effort to spur competition after the implementation of the Telecom Reform Act of1996, the FCC held a roundtable on Spectrum Management in October 1998 to obtain industry input into the development of rules that would allow different carriers to share the same cables with competing products.

As an outcome of the roundtable, ANSI Committee T1E1.4 was asked to develop a standard on Spectrum Management.

T1E1.4 was selected because of its technical expertise in developing loop access technology standards. Progress has been slow, primarily due to the difficulty in reaching a workable balance between CLEC and ILEC deployment concerns.

However, approval is expected in the February 2001 time frame, with expectations that the FCC will adopt key aspects of the standard in a future order. The industry will use this standard as a basis for technology deployment and loop reach rules.

9.2 Spectrum Management Standard

The objectives of the standard are to enable innovation and competition among service providers and also among vendors that provide products while protecting existing services.

This is accomplished by use of transmit power, frequency and loop reach restrictions. Nine spectrum management classes were developed covering frequency spectrums of various widths and associated loop reach restrictions.

Wider spectrums permit higher data rates, but also have greater restrictions on loop reach.

10 SDSL (Symmetric Digital Subscriber Rate)

'SDSL Offers HDSL Speeds on a Single Pair'

SDSL was originally developed by Conexant Semiconductors (previously Rockwell). Conexant used the single-rate European SDSL standard TR-90 and implemented "Autobaud" to auto negotiate the line rate. Because no standard exists for this technology, interoperability is not possible between vendors who use different silicon on either end of the loop.

Without a standard, this technology will be short lived. G.shdsl does everything SDSL does plus provides a path for multi-vendor interoperability, standards-based auto-negotiation of service type and data rate, and achieves 30 to 50 percent better reach at all data rates.

Transceiver systems of SDSL can now achieve an entire T1 or E1 line speed on a single loop at distances approaching, and in some scenarios exceeding, the conventional two-loop HDSL systems. This single-pair implementation of T1 or E1 HDSL is referred to as Symmetric Digital Subscriber Line (SDSL).

Due to the lack of a formal naming convention in the industry, the term SDSL has become more generic over time and is also used to refer to symmetric service at a variety of rates over a single loop.

In principle, the tradeoff between four-wire HDSL and two-wire SDSL systems is loop reach. By splitting the information across two loops, HDSL systems can operate in lower frequencies than SDSL, resulting in a slight loop reach advantage for HDSL.

However, in most markets, T1 SDSL's single-pair loop reach of approximately 11,000 feet (3.4 km) compared to T1 HDSL's dual-pair 12,000 feet (3.6 km), assuming 24 AWG, is close enough to be negligible. In these markets, SDSL's ability to support a full T1 or E1 service using one-wire pair rather than two is a distinct advantage.

On its face SDSL is simply a single line version of HDSL, transmitting T1 or E1 signals over a single twisted pair, and (in most cases) operating over POTS, so a single line can support POTS and T1/E1 simultaneously.

However, SDSL has the important advantage compared to HDSL that it suits the market for individual subscriber premises which are often equipped with only a single telephone line.

SDSL will be desired for any application needing symmetric access (such as servers and power remote LAN users), and it therefore complements ADSL. It should be noted, however, that SDSL will not reach much beyond 10,000 feet, a distance over which ADSL achieves rates above 6 Mbps.

10.1 Applications suited for SDSL

Potential uses for this technology include fractional T1 with a particular advantage in 768 Kbps systems, Work-at-home LAN Access, Distance Learning, Internet Access, and Campus or Large Facility LAN to LAN connectivity. Since S-HDSL/SDSL can be implemented with and without POTS and at multiple data rates, it can have different capacity and reach limitations.

This also allows for easy, cost-effective implementation of such services as remote cell site support of PCs, remote LAN access, distance education and training, digital imaging, or any other service, which requires a larger amount of bandwidth both ways.

10.2 Market status of SDSL

SDSL is very much in the requirements capture phase. It is likely to be symmetric and based on older HDSL technology, but using more advanced techniques to enable greater transmission flexibility over a single wire-pair.SDSL has application suitable for both business and residential sectors, and could therefore have potentially very high volumes.

Since S-HDSL/SDSL operates on a single copper pair as opposed to the traditional two-pair HDSL described above, and it also provides symmetric data rates beyond the frequency spectra of the normal POTS and ISDN, it allows easy implementation of applications that require symmetric data rates on a single local loop while maintaining the existing telephone service on the same loop.

Because only one pair is needed in this arrangement, the capacity of the entire local loop infrastructure is greatly magnified. With this capability, local providers can extract the maximum value from their existing plant, or deploy new capacities both more quickly and at a lower capital expenditure. This allows for rapid and cost effective deployment of intermediate data rate services.

It is worth noting that some existing narrow-band switch suppliers are viewing this technology as a way of increasing the life of their products. SDSL could be used as an embedded line card upgrade to enable 2 x B channels of switched traffic to continue to be put through the switch plane.

Any access transport capacity left could then be groomed away from the switch plane into an emerging connectionless broadband IP or ATM based broadband core network. Additionally, SDSL capability sits nicely within digital subscriber line access multiplexer (DSLAM) architectures as a complementary access technology to HDSL, ADSL and VDSL

10.3 New Generations of Symmetric Services

Refinement and development of new line codes for symmetric DSL services has continued even as HDSL and SDSL have been deployed rapidly and in mass. Particularly, there are two emerging standards for symmetric DSL which are beginning to enter the market:

10.3.1 HDSL2

A single-pair, ANSI standard-based replacement for HDSL. HDSL2 offers the same 1.544 Mbps bandwidth as traditional four-wire HDSL solutions, with the advantage of requiring only a single copper pair, plus the additional advantage of being a standards-based solution with multi-vendor interoperability. HDSL2 is expected to be applicable in North America only, which is why some vendors are opting to build to the emerging universal G.shdsl specification.

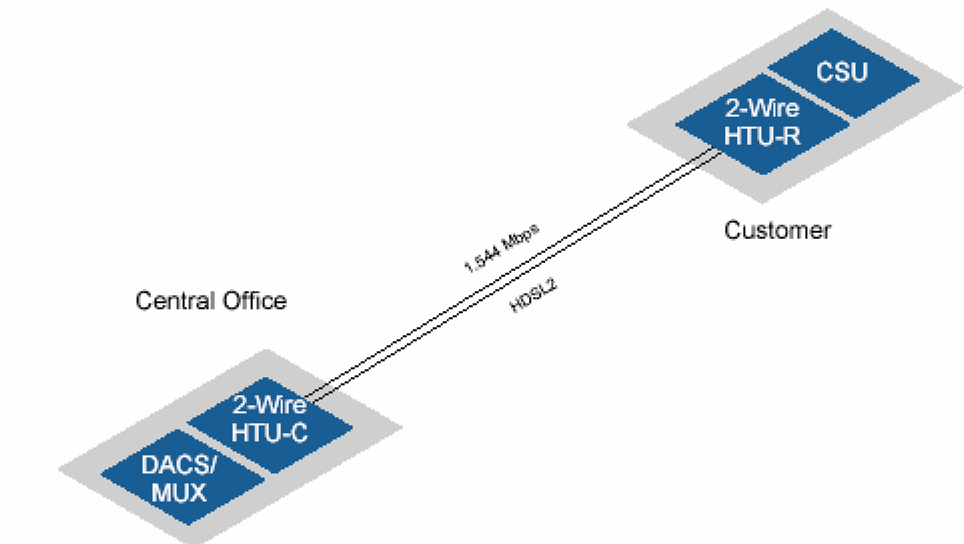
HDSL2 is a recently introduced technology which offers the same capacity over a single pair copper loop as does SDSL, but it is standardized by the telecommunication community.

HDSL2 is considered to be the next generation of HDSL. HDSL2 was designed to accomplish three primary goals.

1. It's Full T1 rates (1.544 Mb/s) on a single pair of copper with the same spectral compatibility as traditional HDSL

2. Vendor interoperability, meaning that service providers are no longer tied to proprietary solutions (both provider line end and remote end transceiver units can be mixed and matched among vendors).

3. It must extend to full CSA reach which is 12,000 feet (3.6 km).



T1 Replacement Model Using HDSL2
Figure 10-1

HDSL2 can be thought of as offering everything traditional HDSL offers, but it can be done on a single pair of copper. The fact that HDSL2 is a standardized technology over a single-pair makes it a unique solution and a viable replacement for SDSL.

It is important to remember that all HDSL2 products are intended to be interoperable. But in order to be an interoperable product, among many criterion defined by the HDSL2 standard, all products must use the HDSL2 OPTIS (**Overlapped Phase Trellis-coded Interlocked Spectrum**) line code which was invented by PairGain Technologies (one of the many contributors to the ANSI standards committee).

Vendors that adhere to the standard by using OPTIS will all be interoperable.

Unfortunately there are currently some vendors claiming to have HDSL2, but they are not using OPTIS or an OPTIS chip-set. This is a false claim and unfortunately their products will not be interoperable as they are not compliant with the HDSL2 standard.

HDSL2 is a technology that offers great benefits to all service providers because it allows them to deliver twice the bandwidth on the same number of pairs that they currently use to deliver traditional HDSL.

In some cases it will allow providers an opportunity to drop a noisy pair while still providing service to the same number of customers. Also, with HDSL2 being an interoperable solution, it opens up the marketplace on favorable grounds to service providers.

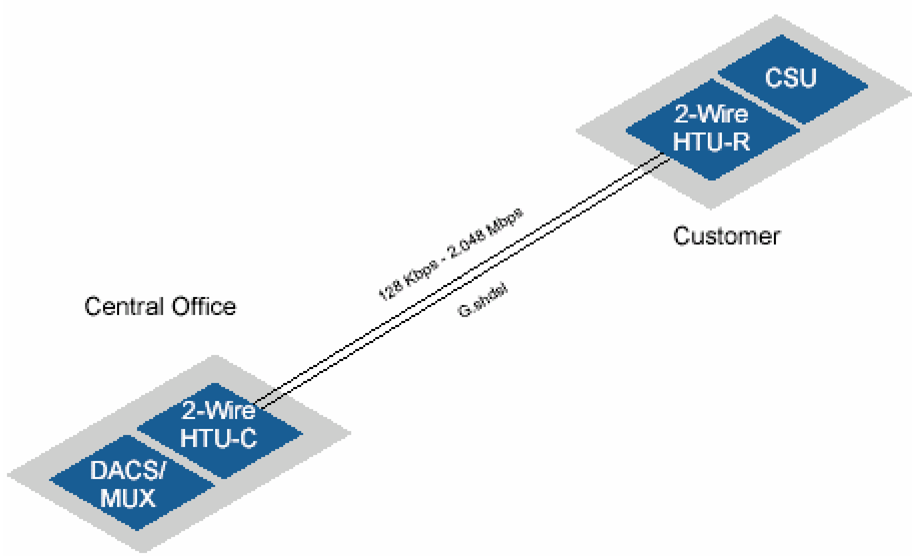
No longer are they tied to a proprietary solution. An interoperable product means that not only can RBOCS (Regional Bell Operating Companies) and CLECS (Competitive Local Exchange Carrier) buy from multiple vendors, but their vendors will be competing for business with a near- commodity product.

This means that the service providers will see better pricing, enhanced features and outstanding customer service, as the suppliers strive to differentiate themselves.

10.3.2 G.shdsl

A new standards-based replacement for SDSL. This multi-rate replacement for proprietary SDSL offers symmetric bandwidths of between 192 Kbps to 2.3 Mbps, with a 30 percent longer loop reach than SDSL and improved spectral compatibility with other DSL variants within the network.

G.shdsl is expected to be applicable worldwide.



T1/E1 Replacement Model using G.shdsl
Figure 10-2

G.SHDSL is designed for businesses that require high-speed data transfer in both directions. Primarily driven by Competitive Local Exchange Carriers (CLECs), the SDSL systems have been derived from high bit rate DSL (HDSL).

Developed in the early 1990s, HDSL uses two binary one quaternary (2B1Q) modulation and two twisted pair cables to deliver T1 service at 1.544 Mbps. Most Symmetrical Digital Subscriber Line (SDSL) systems have been proprietary and based on 2B1Q modulation over a single twisted pair.

While some CLECs are building a subscriber base using SDSL technology, spectral compatibility concerns and a lack of standards have caused many incumbent local exchange carriers (ILECs) to hesitate in deploying SDSL services.

The asymmetric upstream and downstream data rates of ADSL are fine for Internet surfing, yet insufficient for applications that require large file transfers in both directions.

Although it is possible to deploy ADSL in a symmetric fashion, the technology has never been optimized for symmetric operation. Under best-case conditions, a user might only achieve a 784 kbps symmetric service.

G.SHDSL has been designed specifically for symmetric data transfers, allowing upstream and downstream data transfers in excess of 2 Mbps over a single pair of copper wires.

G.SHDSL delivers a 10-7 bit error rate (BER) to a specified distance under worst-case noise conditions. The subscriber can count on a guaranteed bandwidth and a certain quality of service for important transactions.

G.SHDSL allows business users to have multiple phone connections combined with a fax and broadband data channel. With G.SHDSL, multiple voice and video channels can be embedded in the data payload.

The difference resides in the transmission latency. ADSL uses Reed-Solomon (RS) Forward Error Correction (FEC) coding, resulting in a relatively large transmission latency of 20 ms, this latency makes it difficult to transport time sensitive voice and real time video within the ADSL payload.

Although the ADSL FEC can be turned off to bring transmission latency to acceptable levels, this action ultimately reduces the performance margin and BER of the line.

By comparison, the latency of G.SHDSL is less than 1.2 ms, which is suitable for digital voice transport and real time video conferencing. Since the various services are handled in the digital domain, bandwidth can be dynamically allocated between voice, video, and data.

By supporting a variety of line rates and payload configurations, G.SHDSL allows different service applications to be tailored for medium sized businesses, small businesses, telecommuters, and home offices.

10.3.3 Terminology:

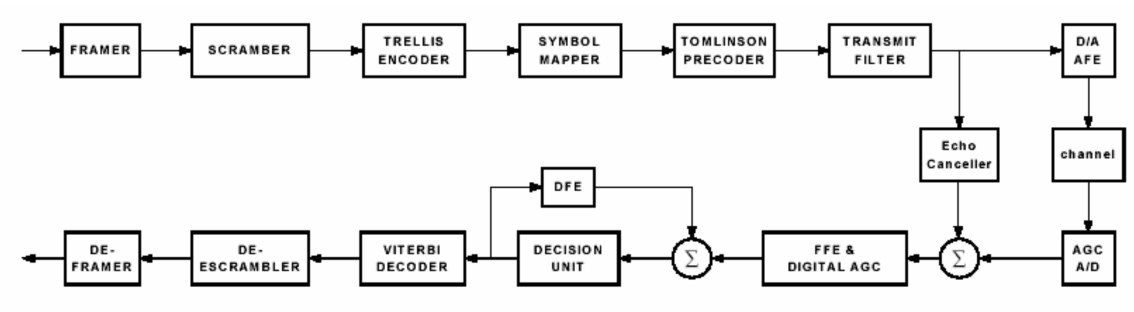
- G.SHDSL is primarily developed for the access network. Feeder cables are generally arranged in large binder groups and normally extend along major corridors from the telephone company Central Office (CO) to distribution frames. At the distribution frame, the cables then branch out into the access network, which extends to individual subscribers. Often, large bundles of feeder cables are deployed directly into large corporations and industrial centers. Feeder lines are also used for internetworking wireless base stations, or connecting an ISP to the CO.

- In North America, 80 percent of feeder network loops reside within 10,500 feet of the central office, and generally have a mix of T1 and HDSL services within the cable binder groups. In contrast, the access network generally has shorter loops (under 6,000 feet) with the cables carried in smaller binder groups. Also, there is a lower incidence of T1 and E1 service, which can often be dominant sources of noise.

- Table 1 compares the various symmetric DSL technologies. Performance varies with noise conditions and line characteristics. G.SHDSL solution generally provides longer reach than its 2B1Q predecessor. For instance, at 1.544 Mbps, G.SHDSL can reach over 8 kft on 26 AWG cable under self near end crosstalk (self-NEXT) conditions. By comparison, single pair HDSL merely reaches 5.8 kft under similar conditions.

Comparison of SDSL Technologies
Table 10-1

	ITU G.991.1 (G.HDSL)		ANSI T1.418 (HDSL2) (under G.991.2 Annex A)	G.991.2 (G.SHDSL)		
	2 pair HDSL	1 pair HDSL		Annex A	Annex B	Annex B Option
Data Rate (Mbps)	1.544 2.048 2.304	0.784 1.168 1.544 2.048 2.304	1.544s	0.192 – 2.304	0.192s - 2.304	2.048 and 2.304
Encoding	2B1Q	2B1Q	Trellis coded PAM 16	Trellis coded PAM 16	Trellis coded PAM 16	Trellis coded PAM 16
Transmit Power (dBm)	13.5	13.5	16.5	13.5 (basic) 16.5 (optional PSD)	13.5 (basic) 14.5 (2.048, 2.304 Mbps)	16.5 up 16.5 down (optional 2,048 kbps PSD) 15.25 up 14.5 down (optional 2,304-kbps PSD)
PAR	2.5	2.5	3.8	3.0 (basic) 3.8 (optional PSD)	3.0 (basic) 3.5 (2.048, 2.304 Mbps PSD)	3.5 (optional PSD)



G.SHDSL Transceiver Block Diagram
Figure 10-3

10.3.4 Features:

- At the 2.048 Mbps data rate and under worst-case conditions, G.SHDSL can reach 2.4 km and still provide 6 dB of margin and a 10-7 BER.

- The transceiver consists of the scrambler, 16 level symbol mapper, transmit pre-coder, and transmit filter

- Another G.SHDSL function for the access network is warm start

- G.SHDSL has provisions for mapping ATM cells into the DSL channel.

10.3.5 Line probing and warm start

- During pre-activation, a broadband line probe is used to characterize the line attenuation and signal-to-noise ratio (SNR). When activating, the modems first use G.994.1 signaling to determine the rate, power, pulse duration, and PSD of the line probe. Next, the line-probe sequence begins. The modem at the remote end will first send out a series of pulses. The duration of the line probe pulses can range from 0.5 to 3.1 sec. On completion of remote end signaling, the CO side sends and completes its probe sequence. The modems return to the G.994.1 signaling and trade attenuation as well as SNR details.

- Based on this information, the modems then determine full activation line rate and power levels, and proceed to full activation. In all, the pre-activation and probe sequence may add 10 to 20 sec to the activation time. Depending on the data rate, another 15 to 30 sec may be needed to train the equalization and echo cancellers and fully activate the modems at each end of the line. While use of the handshake and line probe is optional, most manufacturers will use this capability to implement power back off and achieve interoperability.

- Another G.SHDSL function for the access network is warm start. Operators and users alike prefer that modems go into low power mode when not in use. Modems require 15 to 30 sec to fully train the equalizers and echo cancellers. However, in a warm start application, the modem will save the equalizer coefficients prior to going into an idle state. In this case, the modem can undergo a fast retrain upon receiving a wake up signal locally or from the other end of the line. The stored DSP coefficients are reloaded and the modem's clock recovery mechanism will then resynchronize with the incoming signal. The warm start has a reactivation requirement of less than 500 ms.

- VOCAL Technologies, Ltd. holds patents on line probing for DSL systems.

10.3.6 ATM functionality

- G.SHDSL has provisions for mapping ATM cells into the DSL channel. A Transmission Convergence (TC) function performs the functions of Header Error Checking (HEC), rate decoupling, and cell delineation. Essentially, the TC function maps the asynchronous cell traffic to and from the synchronous DSL channel. Cells are mapped byte wise into a clear G.SHDSL payload. If there are gaps in the transmission and cells are not coming from the ATM layer, the TC function will insert IDLE cells into the G.SHDSL transmit path. The TC also performs the function of cell delineation, allowing ATM traffic to be handed to the higher layer through a cell base handshake. The cell delineation is based on the HEC algorithm. The HEC is also used to filter corrupted cells rather than pass them up to the higher layer. Packet transport is also possible with G.SHDSL.

- G.SHDSL provides the possibility for combining synchronous narrowband DS0 channels with a broadband data channel. This capability allows for multiple voice lines, either ISDN or traditional POTS, to be combined with a data service. Depending on the application, the bandwidth for voice channels may be set up dynamically in the event of a call. The bandwidth can then be returned to the data channel once the call session is over.

10.3.7 G.shdsl Technology Advantages

10.3.7.1 Multi-rate and Extended Reach

Figure 10-4 below demonstrates G.shdsl's rate-adaptive capability. The G.hs (handshake) protocol negotiates the highest achievable data rate given the loop conditions.

Figure 1 also illustrates G.shdsl's superior rate and reach performance characteristics compared to other available technologies. G.shdsl's ability to extend service reach by 30 percent increases the total addressable DSL market.

10.3.7.2 Multi-service

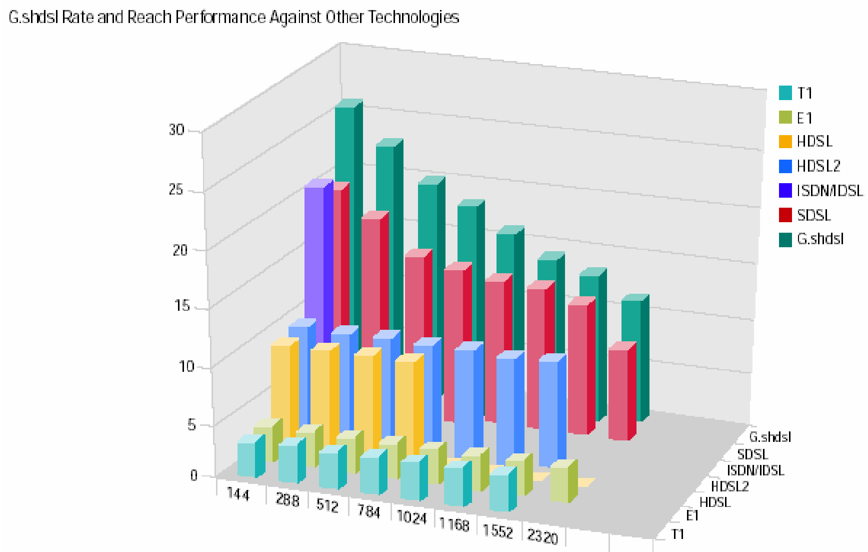
Using the G.hs (handshake) protocol during pre-activation, the service type is negotiated during start-up (training). T1, E1, ISDN, ATM, or IP framing can be negotiated during training. With this protocol, the most efficient framing type can be negotiated to avoid unnecessary over-head and latency on the DSL link.

Protocol stacks for framing types are illustrated in Figures 2-4. This is extremely important because on slower links, some services such as VoIP and VoATM do not work as well.

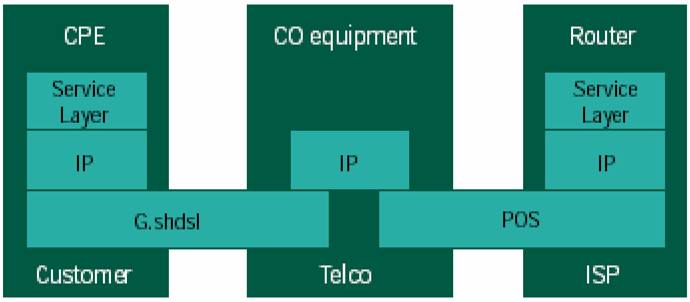
Therefore, it is important to enable transport of native time-division multiplexing (TDM) if toll-quality voice is to be transported over the DSL link. For networks that use IP in the core, G.hs can negotiate IP framing all the way to the edge, eliminating the overhead associated with ATM cell headers when the primary traffic type is IP.

10.3.7.3 Low Cost

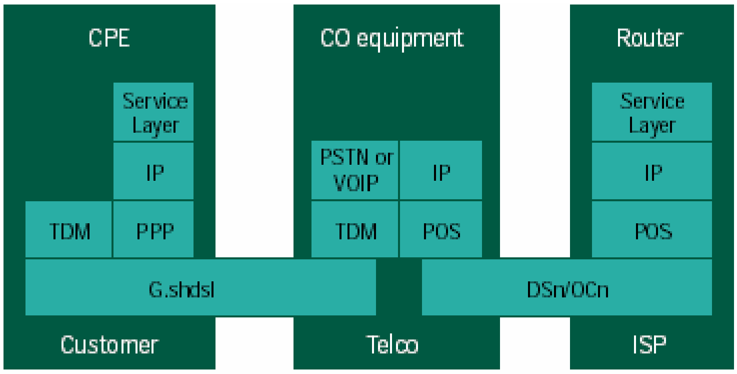
The G.shdsl standard has attracted the attention of many vendors and enabled price competition in markets that have traditionally been mo-nopolized by single vendors. Several vendors are currently shipping G.shdsl-capable components. The TC-PAM line code, which is the foundation for G.shdsl, allows for easy interoperation due to the low complexity level of the transceivers.



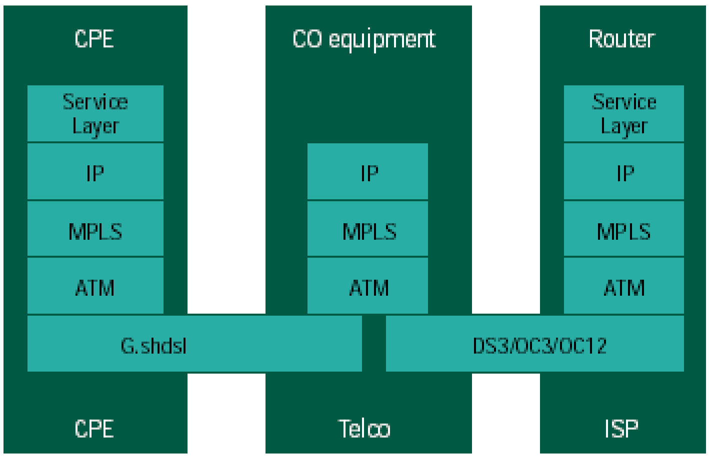
G.SHDSL rate and reach performance with other Technologies
Figure 10-4



Cisco IP Solution
Figure 10-5



Cisco IP + TDM Solution
Figure 10-6



Cisco IP + ATM Solution
Figure 10-7

10.3.7.4 Repeatable and DLC Ready

G.shdsl TC-PAM line code is capable of increasing reach by 30 percent. Table 1 provides a feature/performance comparison between G.shdsl and some of the popular access technologies deployed today.

	G.SHDSL	SDSL	HDSL2	HDSL		E1	ISDL/ISDN
Standard	**Yes**	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**No**
ATM Farming	**Yes**	**No**	**No**	**No**	**No**	**No**	**No**
T1 Framing	**Yes**	**No**	**Yes**	**Yes**	**Yes**	**No**	**No**
E1 Framing	**Yes**	**No**	**No**	**No**	**No**	**Yes**	**No**
Super Reach	**Yes**	**No**	**No**	**No**	**No**	**No**	**No**
High Density	**Yes**	**Yes**	**No**	**No**	**No**	**No**	**Yes**
Rate Adaptive	**Yes**	**No**	**No**	**No**	**No**	**No**	**No**
Repeaters	**Yes**	**No**	**No**	**Yes**	**Yes**	**No**	**Yes**

Feature performance comparison between G.shdsl and other technologies
Table 10-2

10.3.7.5 Low Power

Because of the low-complexity TC-PAM line code, silicon vendors have been able to provide a sub-watt chipset that matches the densities achieved by technologies such as SDSL and IDSL. With this technology, up to 1000 ports per 7-foot rack can be deployed while still meeting stringent NEBS requirements.

10.3.7.6 Spectral Compatibility

Spectral Compatibility is an important topic that is being addressed by both European and North American standards bodies. The current Draft Spectral Management Standard defines seven spectral classes that are used to police binder groups and guarantee maintained spectral compatibility of multiple binder groups. Cisco solutions meet the guidelines of spectral compatibility as defined in the "Draft Spectral Management Standard."

11 ISDN (Integrated Service Digital Network)

With millions of lines deployed worldwide, ISDN is the second most common method of Internet access next to voice band modems. ISDN can provide up to 144 kbps of bandwidth to the home user.

The bandwidth can be used for voice or data depending on the application requirements. ISDN is repeatable and can support customers served by digital loop carrier (DLC) systems. G.shdsl can interoperate with U-Brite and ISDN repeaters.

11.1 IDSL (ISDN over Digital Subscriber Line)

IDSL is very similar to ISDN, except that there is no channelization (for example the 2B + 1D channels are bonded together to provide a single 144-kbps pipe). Typically, Frame Relay runs on the local loop and FRF.8 is performed in the DSLAM to convert the Frame Relay traffic to ATM. When FRF.8 is performed, quality-of-service (QoS) is not guaranteed, therefore loosing the ability to transport VoDSL. Cisco G.shdsl solution utilizes ATM framing guaranteeing QoS to the customer premise which is served by DLC systems.

12 Cable Modem vs. DSL

‘The GOOD, the BAD and the UGLY!’

Cable modems are another new dedicated Internet connection technology delivered by the cable companies. While ostensibly faster than DSL, cable modems have several inherent limitations that you should consider when choosing between the two types of service.

12.1 Cable modem

1. In order to have cable modem service you have to order cable television service as well. While you also need phone service for DSL, almost everyone already has phone service but many people do not have cable television service. For those who don’t already have cable service this is an added expense. Plus, cable modem service, as opposed to DSL, is not widely available.

2. The speed of cable modem service can vary widely. The cable modem service is organized as a local area network (LAN). This means that hundreds, and perhaps thousands, of persons share a single fiber cable connection. So during hours of peak usage the bandwidth available to each user can drop dramatically to the point where the connection is even slower than your older dial-up modem connection.

3. Because cable modem is set up as a Local Area Network (LAN) for the neighborhood, the connection is not as secure as DSL. The "neighborhood" may extend to thousands of homes in a particular area. It is possible that a neighbor could view the entire contents of your hard drive if either you or the cable company hasn’t taken steps to prevent such an invasion. With DSL, your connection is not shared with anyone else in the neighborhood.

4. Because you share the cable mode bandwidth with all others in your neighborhood, the cable modem companies will not allow you to use more than one computer on a single cable modem hookup. In fact, some cable companies will disconnect your service if they discover that you have a set up LAN on the cable modem connection. Most DSL companies on the other hand do not object to setting up a LAN at your home or business that uses the DSL connection.

12.2 DSL

12.2.1 Is the connection always fast?

For DSL, the answer is yes. With a 1.5 Mbps DSL connection, downloading a 100-megabyte file takes only 66 seconds. For cable modem, the answer is maybe because it depends on how many users are sharing your connection.

12.2.2 Is the service secure?

For DSL, the answer for the most part is yes. Your DSL connection isn’t shared across the entire neighborhood like the cable modem connection. The DSL goes directly from your computer to the telephone company to our high speed Internet backbone connections. Thus your neighbors can't simply browse your hard drive since DSL isn't designed around a LAN. Of course, with any connection to the Internet it is important to protect your machine from intrusion with the appropriate software or hardware.

12.2.3 Do you need to order another phone connection?

For DSL, the answer is no. With DSL, you can be on the phone talking at the same time you are surfing the Internet and you don’t need to order another phone line. For cable modem, the answer is yes because you must have cable television service to get cable modem service.

12.2.4 Can you use more than one PC on the connection?

For DSL, the answer is yes. Multiple computers on the same DSL connection won't hog the bandwidth of others in your neighborhood. Cable modem companies might disconnect your service if you set up multiple computers on their connection.

13 Internet-Ready Buildings (IRBs)

Internet-ready buildings is defined as making a Multi Dwelling Unit (MDU) ready for high speed broadband services using internet protocol (IP) with the entire required infrastructure, network, operation, and service functions included.

13.1 Overview

After the deregulation of Telecom in 1996, the Incumbent and Competitive Local Exchange providers got the same opportunity as the government owned Telco’s to provide telecommunication services to the public.

This reform act allowed the penetration of different business opportunities in the residential and commercial environment through access network, with copper, coax, fiber or wireless infrastructure, and resulted in an untapped business market for service providers.

It didn’t take long for service providers to realize the revenue potential in offering internet and other broadband services to a multi tenant unit (MTU) where probable customers were in 100s and possibly thousands. In relation to the last mile an IRB resides at the last drop of the subscriber network.

Traditional internet access methods can create problems for building proprietors because tenants want different ISPs, each of which requires their own access to the buildings telephone closet. Additionally, each tenant may want different ISPs to provide different services. Therefore, traditional access methods using typical wiring configurations can be taxing for the building proprietor.

Figure 13-1 shows the wiring configuration that is typical in many buildings today and that, as may be seen, is overly complicated. Furthermore, building owners or proprietors currently do not share in any of the revenue being derived from their tenants for the internet services the ISPs are delivering.

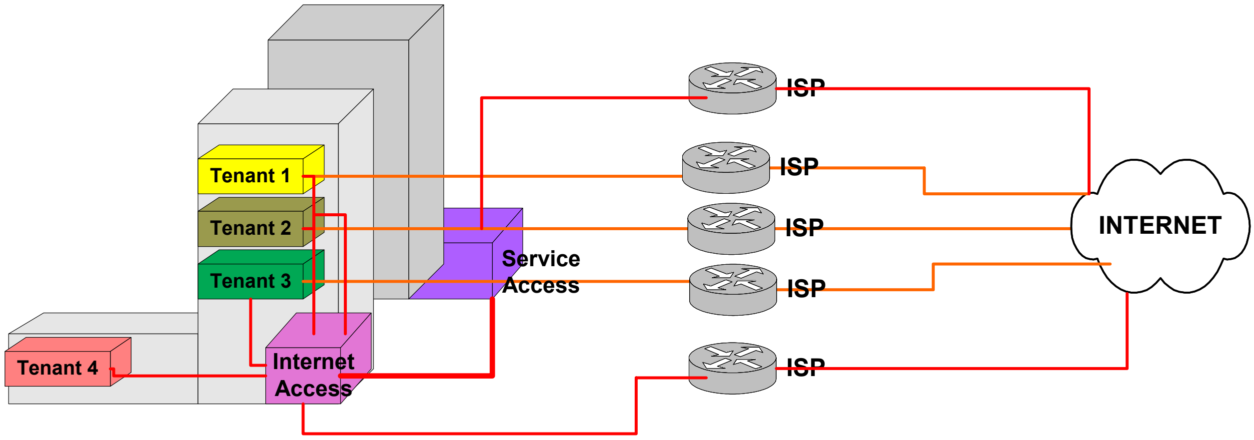


figure 13-1

In this new era of networking DSL is strengthening its hold as a leading deployment method for access the local loop in support of both internet and intranet connectivity.

DSL offers the speeds that business customers are looking for (up to 2.3 Mbps symmetric speeds for SDSL) at prices that is more affordable for even a small business. The opportunity for services providers offering DSL services is extremely large.

CLECs proved DSLs effectiveness by rolling out services nation wide. An area growing in popularity as a solution to bypass the local loop by both the CLECs and the ISPs is providing DSL that supports premises-based deployment within a MTU.

Figure 13-2 demonstrates how a typical building with tenants who utilize DSL technology that is supplied by a CLEC from a local CO would look.

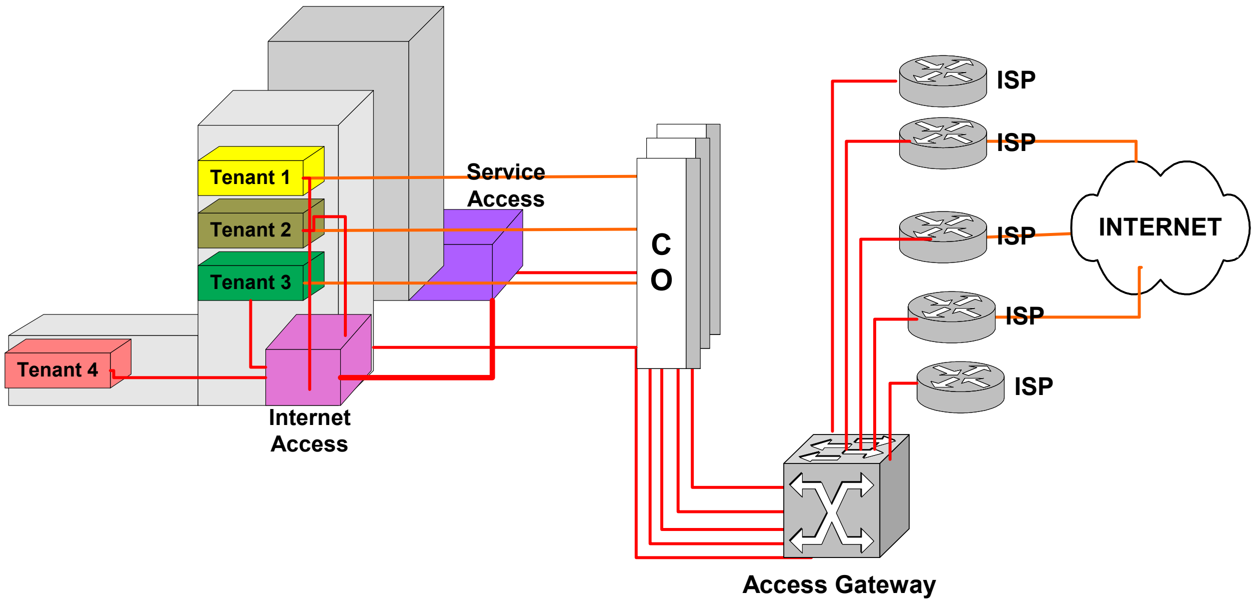


Figure 13-2

In this environment DSL can be used to support private leased lines for each business to connect to the internet without ever having to leaving the building. A DSL access router (DSLAR) can be used to connect the business tenants to the internet. In practice, the DSLAR method is more cost effective and efficient.

Another important advantage associated with brining DSL inside the building or a campus environment is that it may become a revenue sharing opportunity for the building proprietor.

Bringing in an access network through wired or wireless connection to utilize the already existing telephone copper wire infrastructure as the distribution network cut down the cost of deployment to a fraction of the anticipated value.

Any remaining overhead costs and costs for the service divided amongst the hundreds and thousands of occupants lowered the buying cost to a remarkably attractive number. This was a valuable factor for residential users.

13.2 Implementation Overview

Multiple DSL lines can be supported within the building and terminated to a device in the basement. This solution can be compared to having the local phone company run separate dedicated access lines to each individual business in the building so that internet access can be supported.

Using the existing wiring compared to having new lines installed represents a major savings. Furthermore, a building proprietor could directly charge an ISP $5 per line, as opposed to the phone company charging the ISPs anywhere from $300 to @1,200 per dedicated line. Savings are passed on to the internet users.

Thus, the business tenants save money, and the building proprietor makes money. However charges are based on the bandwidth purchased by the customer.

For the next step of implementation, a device referred to as a customer premise equipment (CPE) is installed at the business office location. The CPE connects the business LAN to the copper wire.

The copper wire connects the CPE to the DSLAR normally installed in the location where all of the copper wires terminate from all of the offices served in the building (typically in the building basement). The next step is to connect all the DSL users to the ISP.

To connect an ISP, a dedicated line is installed between the building and the ISP. Note that only one line is used to connect all of the businesses in the building to the ISP, as opposed to multiple lines to every business. The leased line technology terminates at the DSLAR to complete the network topology.

13.3 Competition

The world community is facing a future in which commercial and residential data connection (i.e. the internet) will be a utility like water, electricity and gas at present. This would require re-networking the multi tenant environment, creating an IRB.

The deregulation phenomenon taking place in the world will allow different business entities to penetrate the residential and commercial environment through the access network either with copper wire, coax, and fiber or wireless infrastructures. This will highly motivated by the business opportunity seized by supplying on-demand services.

The major players' in this arena will be Incumbent Local Exchange Carriers (ILECs), Inter Exchange Carries (IECs), Post Telephone and Telegraph administrations (PTTs), Internet Service Providers (ISPs), Competitive Local Exchange Carriers (CLECs), Cable TV (CATV) operators, Very Small Aperture Terminal (VSAT) operators, etc.

Manufacturers and standards bodies initiated many activities related to the copper wire and digital subscriber line (xDSL) technologies. The Institute of Electrical Electronic Engineering (IEEE) as well as Multimedia Cable Network Systems Ltd. (MCNS) are amongst the leaders. MCNS is working on Hybrid Fiber/Coax (HFC) cable issues.

The Full Service Access Network (FSAN) initiative is working on the fiber to the home (FTTH), using asynchronous transmission mode (ATM) technology over fiber, with copper- using VDSL at the last drop. On the other side of the wireline solution, wireless manufactures are working on new, high capacity solutions, including Direct Broadcast Satellite (DBS) and Local Multipoint Distribution System (LMDS), which were licensed for a new spectrum by the Federal Communication Commission (FCC) and are going to boom in the coming years.

13.4 Deployment Provisions

Prior to implementing a DSL solution, certain factors influence the businesses' access to the internet. Deployment depends on the following factors.

i. The use the customer makes of the internet

ii. The applications required of the business or the supporting ISP

iii. Whether or not email is required.

iv. If the email server resides at the customers location or if the ISP maintains the mail accounts.

v. Whether a Web server to promote information about the business is required.

vi. Whether the web server resides at the customer's location or the ISP maintains it.

These factors have direct impact on the amount of bandwidth the customer requires to use the internet over DSL effectively, as well as what type of bandwidth is required to connect the building to the ISP.

13.5 The Last-Mile Picture

Giving a closer look at the last mile of a common service network, the service itself is a starting point and may be broadcast video, Internet data, etc that is transported t the last mile through the core network.

This core transport may be a metropolitan, national, or international backbone carried over different kinds of network technologies. The last mile or the subscriber network starts at the Central Office (CO) in the telephone-company case or at the head end in the cable Multiple System Operator (MSO) case.

In the satellite case, the ground dishes pointed to the satellite may be considered the beginning of the last mile. For terrestrial wireless, such as LMDS, the last mile starts at the feeding point to the base station. To generalize the last-mile architecture, it must be divided into primary and secondary access networks.

The primary access network starts at the CO or the Head End (in Cable systems) and runs to the neighborhood or building. According modern architectures such as HFC in cable or Fiber-In-The-Loop (FITL), a fiber runs across the primary access network, feeding a remote node such as Digital Loop Carrier (DLC) in a street cabinet or an Optical Network Unit (ONU) in the cable. In the case of full-copper last mile, the remote node might be the street Intermediate Distribution frame (IDF). The secondary access network is where the distribution takes place.

Distribution takes place in the coax wiring in the case of cable and in the copper wire in the case of telephone systems. The last drop is beyond the point of demarcation that brings the service wire into the customer premises.

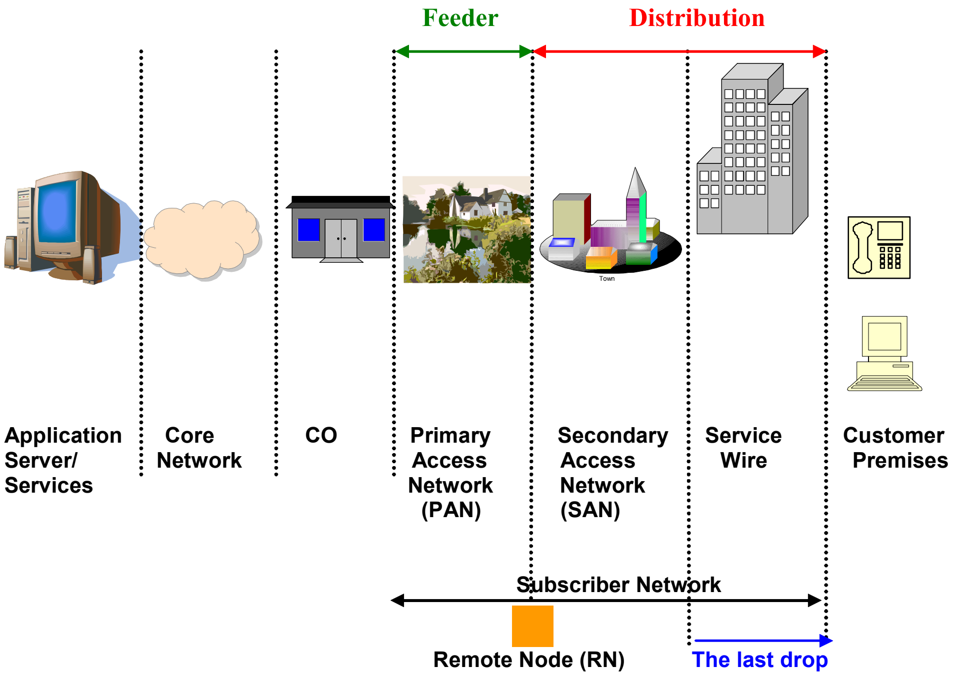


Figure 13-3

The IRB resides at the last drop, starting at the point of demarcation and terminating at the customer premises. Getting access to the IRB requires a fat uplink pipe from the core network through the secondary access networks. In many cases a single feeder from the core network to the last drop may be used.

13.6 Implementing an In-Building DSL solution

There are two main categories for implementers of an in-building solution: the building proprietor and the service provider. The building proprietor may operate in to ways:

i. Rent the copper lines to the service provider

ii. Implement the network and the leased internet access from the service provider

The service provider may also operate according to one of two possible ways.

i. Leased the in-building copper wiring from the building proprietor and provide internet access for the buildings

ii. Provide a means by which the building proprietor can lease access to the internet.

13.7 Building proprietors

13.7.1 Copper Landlords

As service providing landlords, building proprietors have a business relationship with ISPs that is similar to the landlord-tenant relationship. In essence, proprietors lease property.

They may either approach an ISP with the suggestion to lease copper wire within their facilities or, given the competition for the service subscribers, may be approached by an ISP.

In either event, building proprietors charge a certain amount of money for leasing ISPs the copper pairs within their facilities. The price of the lease can be determined on a per-line basis or calculated as a whole for the entire building.

Two other issues to consider are location and power. The ISP will require a location within the building to house the DSLAR, and the ISP will also require power to support the equipment. Other charges may be incurred for electricity usage. Furthermore, the ISP will require 34-hour access to the equipment for maintenance and for adding users.

13.7.2 Service providing Landlords

As service providing landlords, building proprietors act as corporate information systems experts. They lease internet access from a local ISP and provide connectivity to the internet for the businesses within their own facilities.

They also install and maintain the equipment necessary to this supported function. This scenario is not complex as it sounds; indeed, the objective is to keep simple for both the ISPs and the building proprietors.

First, the proprietors must promote Internet access to the customers within the facility. Relevant factors to consider include the following:

- How much the capital equipment expenditure will cost
- The number of offices to support
- The amount of money the local ISP will charge for the dedicated access into the Internet
- The cost of the actual dedicated line from either the ISP or the Local telephone company
- How much the proprietor will charge customers for the service

Once the issues of the internet access promotion are addressed, proprietors must begin building the infrastructure necessary to support provisioning of Internet service. The following steps are necessary for an in-building solution.

i. Create a relationship with a local ISP in preparation for accessing the internet

ii. Learn the layout of the copper wiring within the facility to know where the endpoints are.

iii. Find a location for the DSLAR. This must be at a location where power can be supplied, and must be near the main wiring closet.

iv. Provide cabling and required components to connect the in-building wiring to the DSLAR.

v. At the customer premises location, verify that a dedicated pair of wires runs from the office location to the horizontal wiring cross-connect on the floor of the business and then down to the main wiring center location. This will complete the cable installation required to support DSL.

vi. Provision a leased line via the local telephone company between the building being networked and the ISP’s location. The amount of bandwidth required to support this application depends on the number of customers who require support, the bandwidth usage, and a reasonable over subscription rate. An ISP can assist in calculating these figures.

13.8 Service Providers

The most critical factor in support of an in-building solution is to promote the opportunity within the building effectively. In this respect, building proprietors gain customers just as they would by gaining tenants.

The only difference is that building proprietors can offer high-speed line rates at significant discounts, as the access line charge can be included in the total cost of doing business with the service providers.

13.9 Turnkey solution

If the ISPs are familiar with leasing dry copper pairs from the telephone company to provide DSL service to customers, then implementing a DSL solution with direct connection and control of both ends of the copper wire (one end from the DSLAM equipment at the basement which the ISP have access to and the other end installed at the customer side within the building) is no different, but in the later the ISP has an agreement not with the Telephone company but the building proprietor for providing the services necessary.

Here they must create a relationship with the building proprietor and work out the details described under the section ‘Copper Landlords’.

13.10 MDU/MTU Market segmentation

The market of multi tenant buildings is divided into three major segments:

- The largest segment is the residential MTUs and includes consumer multi dwelling units from the size of skyscrapers to garden-style complexes. Here the residential market requirements are well defined for Internet services.

- The second largest market is for commercial MTUs which include Business MTUs consisting of sky scrapers down to commercial campuses to strip malls. The fiber infrastructure reaches the building basement or the street cabinet. One interesting segment of this market is the executive suites, a fast growing and dynamic area. The MTU market is very versatile from a service providers perspective.

- The third is the hospitality segment. This market includes hotels, dormitories, and hospitals. Currently, in hotels, internet service is mainly a demand of business travelers and is quickly becoming a necessity for middle to high value hotels.

Other niche segments can be found, including commercial and educational applications in schools, clubs and marinas.

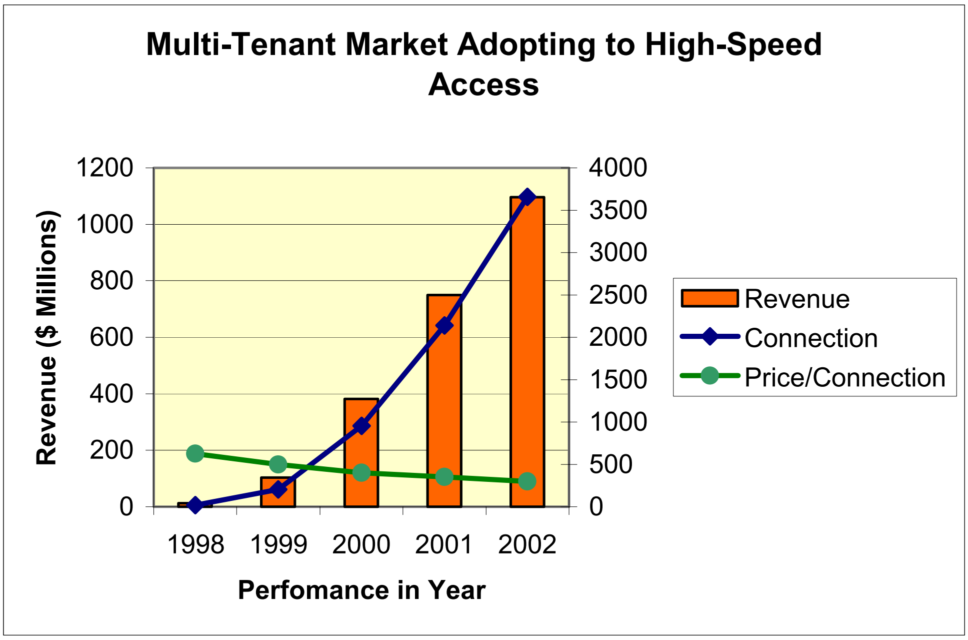
13.11 MTU Market Opportunity

There are a number of powerful reasons why an ISP or CLEC would be interested in offering DSL services to the MTU market. First the MTU market opportunity is projected to reach over $1 billion with more than 3.5 million connections by 2003. The table 13-1 published by the International Engineering Consortium lays proof for the claim.

These numbers are very appealing for ISPs, CLECs, and Value Added Resellers (VARs) who are in excellent position to capitalize on this market because they have the experience and technological know how to make an effective service offering.

Another attractive reason for ISPs to jump into an MTU application is that, once they have presence in a building that is approved by the building owner, they may capture the business of the other clients in the building.

This gives them an opportunity to sell their services to all the tenants in the building with endorsement from the building management, than seeking out individual businesses as is customary for them otherwise. This is a major sales potential for the ISPs.



	1998	1999	2000	2001	2002
Revenue	$12	$103	$382	$749	$1096
Price/Connection	$625	$500	$400	$350	$300
Connection	20	205	955	2139	3655

Table 13-1

In the case of ISP provisioning the service, a leased line must be first provisioned to the building proprietor in the same manner that the ISP provisions a line to a corporate customer.

The business tenant will have its own IP network, as will the building proprietor. In most cases, due to the internal expertise of the ISP, it will be the ISP who provisions the DSL service to the customer. It is important, however, that the ISP and the building proprietor both benefit from bringing DSL into the building.

In essence, an Internet Ready Buildings not only increases the value of a building, but also brings in an additional revenue opportunity to the building owners by allowing the ISPs to bring in their services to the building. For the ISPs, it is a cost effective and efficient reach to multiple customer venues in one implementation.

Nevertheless it is still argued that if Internet is a Utility commodity like water and electricity, when water and electricity companies are not charged to bring in the utility into the building, why must the ISPs be charged for bringing in the Internet?

13.12 IRB Implementation Networks Examples

13.12.1 Access to wireless operator

For wireless CLECs, LMDS is one of the leading technologies, enabling quick market penetration, since there is none or else little infrastructure to be laid up to the distribution network.

CLECs initial target market is the corporate sectors, which may require symmetrical characteristics of traffic. However, CLECs can use their LMDS to provide high speed internet services to residential building and complexes as well.

See figure 13-4**,** The standard telephone connectivity is illustrated here. The POTs connection from the customer premise to connection box in the basement is taken in a bundle to the telecom house owned by the Telco (or telephone operators).

This Telecom house acts as a remote node to the central office distributing telephone connectivity to the neighborhood. This is commonly called the local loop. The Telco house collects the neighborhood local loops and sends it in a bundle to the central office or the telecommunication company.

Every building's telephone wires run down to the basement of the building were they are patched via a connection box to the remote telecom house connection box.

Through an installed antenna and terminal at the building top, they may connect the IRB network via a dedicated link (single fiber or a CAT 5/ CAT 6 cable) to the Telco room in the building basement.

This enables a high resolution service from a single connection at the point of demarcation using the existing legacy copper wire with DSL transport techniques for implementing the IRB provides CLECs with a wireless copper architecture that represents a win-win solution.

This configuration converts the building into a business unit, thus making it broadband ready for service. This type of architecture is an excellent business case for cellular operators who are looking to extend their business activities.

Using the cellular base stations as an infrastructure for deploying the LMDS service drastically reduces the required investments.

Here by connecting the copper wires through a splitter, and separating the voice calls from the data, will enable the voice calls to be transported through the POTS and the data traffic to be connected to the internet service provider's core network via the LMDS.

The Digital Subscriber Line Access Multiplexer multiplexes the individual data lines into a single channel to the router. The router then routes the data traffic within the access network infrastructure via the LMDS to the internet or their relevant destination. See figure 13-5.

For wireless VSAT operators, the story is the same. However, the traffic is not symmetrical, and an additional uplink connection does not necessarily exist. In the latter case, a wireline uplink mechanism is needed, making this application more cumbersome to deploy.

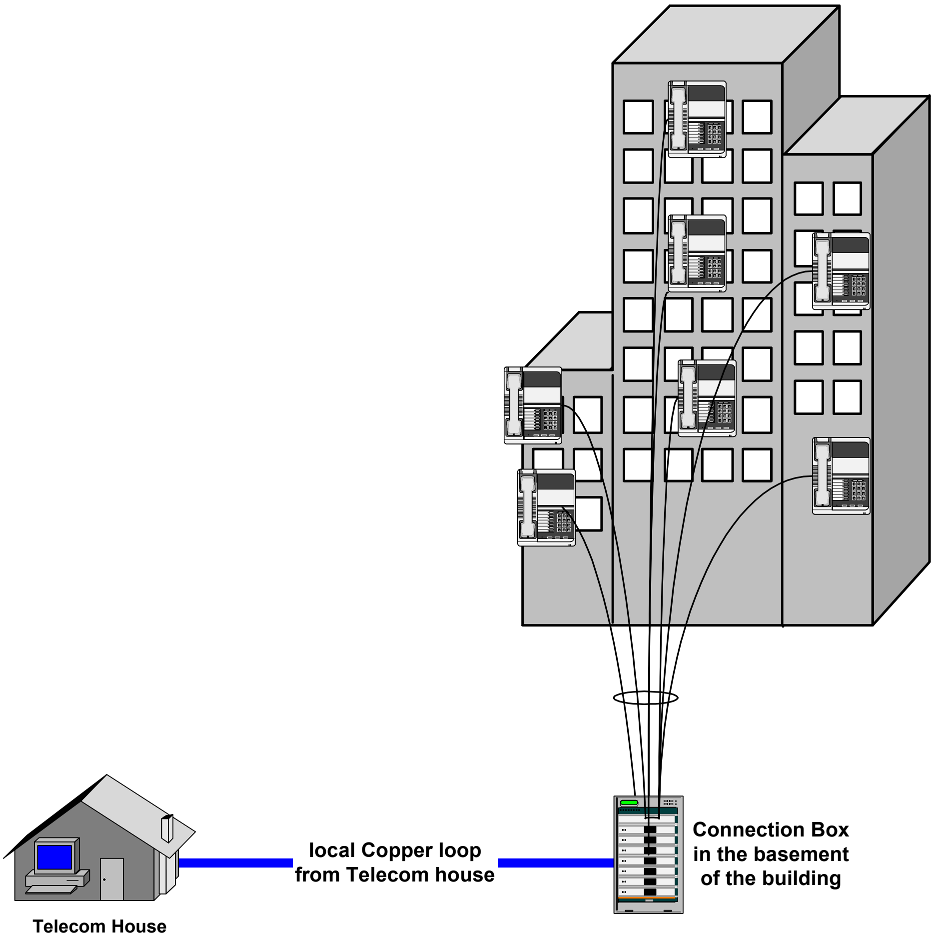

local Copper loop
from Telecom house
Connection Box
in the basement
of the building
Telecom House

Figure 13-4

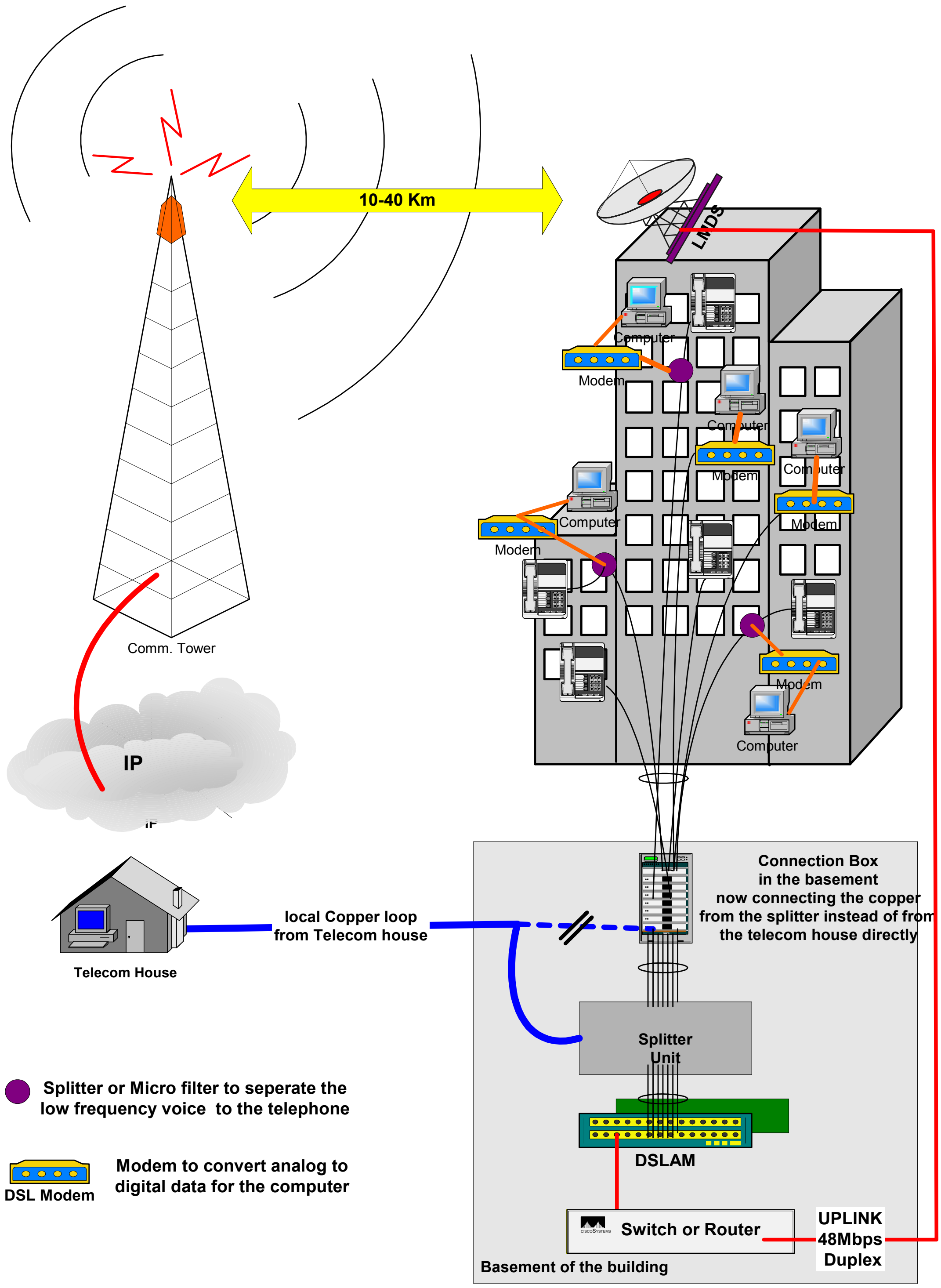

10-40 Km
LMDS
Computer
Modem
Comm. Tower
IP
Telecom House
local Copper loop
from Telecom house
Connection Box
in the basement
now connecting the copper
from the splitter instead of from
the telecom house directly
Splitter
Unit
DSLAM
Switch or Router
UPLINK
48Mbps
Duplex
Basement of the building
Splitter or Micro filter to seperate the
low frequency voice to the telephone
DSL Modem
Modem to convert analog to
digital data for the computer

Figure 13-5

13.12.2 Access to Wireline operators

For ILECs, PTTs and CLECs, asymmetrical digital subscriber line (ADSL) services in mass numbers to the MDU’s (where the digital subscriber line access multiplexer [DSLAM] is located in the CO) seems impractical and overly expensive from a technological point of view.

Instead of having the DSLAM in the CO, it would be more technically practical to have the DSLAM in basement of the building and extending the service to the buildings point of demarcation from one central remote node. This is far more robust and economical.

This implmentation is accomplished by leasing out and installing one or more xDSL lines as uplink to the IRB from within the copper bundle connecting the CO of the ISP to the IRB.

Here a few high quality copper pairs which don’t carry POTs services can be selected to feed the IRB via a DSLAM placed at the basement of the IRB and the rest of the ports available in the DSLAM can be used to provide data service to the customer of the IRB.

As the bundle from the CO or the telecom house usually has more than enough extra copper pairs leasing out a few would be economical and would not affect the existing telephone infrastructure. Nevertheless, the xDSL connection can be installed over four wires rather than the usual two, thus improving transport capabilities and also coverage area.

In the case of higher-bandwidth requirement, an additional xDSL connection can be installed. Again, feeding an IRB enables a point-multipoint service, creating a central pipe that serves many customers. When the IRB is implemented through the legacy copper wires, the building is broadband-ready for business.

An ISP or CLEC can adopt this application by leasing the unbundled copper from the local telephone company at the CO. Working with IRBs reduces the overall cost, as only a few copper wires are required for leasing; distribution is done at the IRB.

In the classical ADSL solution, leased copper is needed per customer. Moreover, with the IRB, the single pipe with the service is multiplied now by the number of subscribers, which brings it to an economical solution.

The configuration steps:

1. A DSLAM is placed at the basement of the IRB, and a few copper pairs arriving to the building are used as uplink to the IRB, which is sent to the CO or the Telecom house to be sent to the CO.

2. The rest of the ports of the DSLAM are used for distribution of data service to the customers in the building.

See figure 13-6

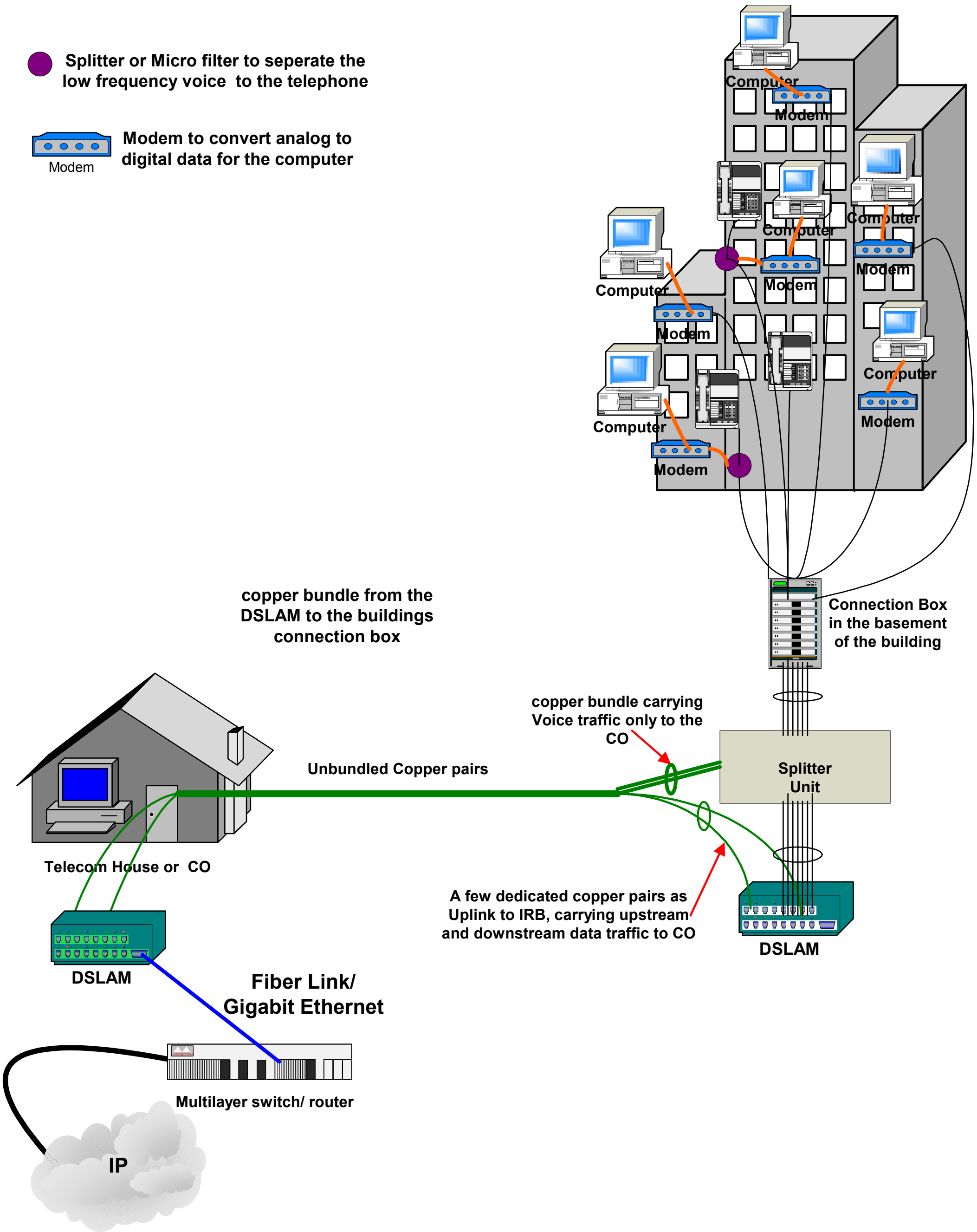


Figure 13-6

This design, though seems economically alluring, it is not one of the most technically sound ones. As you can see a few xDSL links carrying 2Mbps links which sum to a total uplink of N * 2Mbps will be catering for M number of customers each getting 2Mbps each, This will reduce to a very serious bottle neck in the uplink, eventually causing the whole network to slow down.

Here N is the number of copper pairs not carrying voice traffic leased out from the unbundled copper link from the CO or the Telecom house, and M is the number of customers serviced.

If M= N the problem is tolerable, but if M >> N the problem will be devastatingly severe. Therefore this design is considered to be immature, and not commonly deployed.

13.12.3 Access to Fiber In The Loop (FITL)

For ILECs, PTTs, and IXCs, Fiber in the loop is the most advanced architecture for neighborhood services. Fiber can reach the curb, the street cabinet, or the building basement.

Here the IRB is connected with a high capacity uplink capable of providing very high speed services reaching the subscribers in the IRB.

The simplest case to bring in very high capacity data service is to bring in the fiber into the buildings Telco room in the basement. This can be done in 2 possible manners.

Figure 13-7- Here a high capacity fiber core network connects the individual IRBs to the Internet and other broadband application serviced by the relevant service providers. The building groups are serviced by a fiber core. A high speed multi layer switch belonging to the core feeds fibers to the basement of the building where the DSLAM can distribute the data traffic over the existing copper infrastructure.

The DSLAM in this case is placed in the basement or Telco room of every building and the multilayer switch may be placed in a street cabinet or a Telecom house in the neighborhood of the buildings.

The multi layer switch and the fiber uplink feed to the individual buildings constitute the access network, and the DSLAM and the copper links to the customer premises constitute the distribution network.

Figure 13-8 - Here the IRB is supplied with capacity for individual residents or customers with more than normal ADSL or SDSL capacity using Cat 5 or Cat 6 cables all the way up to the customers.
The access network to the IRB consists of a fiber feed acting as the uplink to the IRB which connects a router or multi layer switch in the basement or the Telco room of the building.

The distribution network consists of LAN cables extending up to the individual customers delivering capacity in the range of symmetrical 10 Mbps to 100 Mbps.

Both of the above networks eliminate the uplink bottle necks faced in figure 13-6, which is an attractive attribute of these designs. Though these designs may be a bit costlier than the design implementation in figure 13-6, it is a technically effective, robust and provides greater capacity than the former.

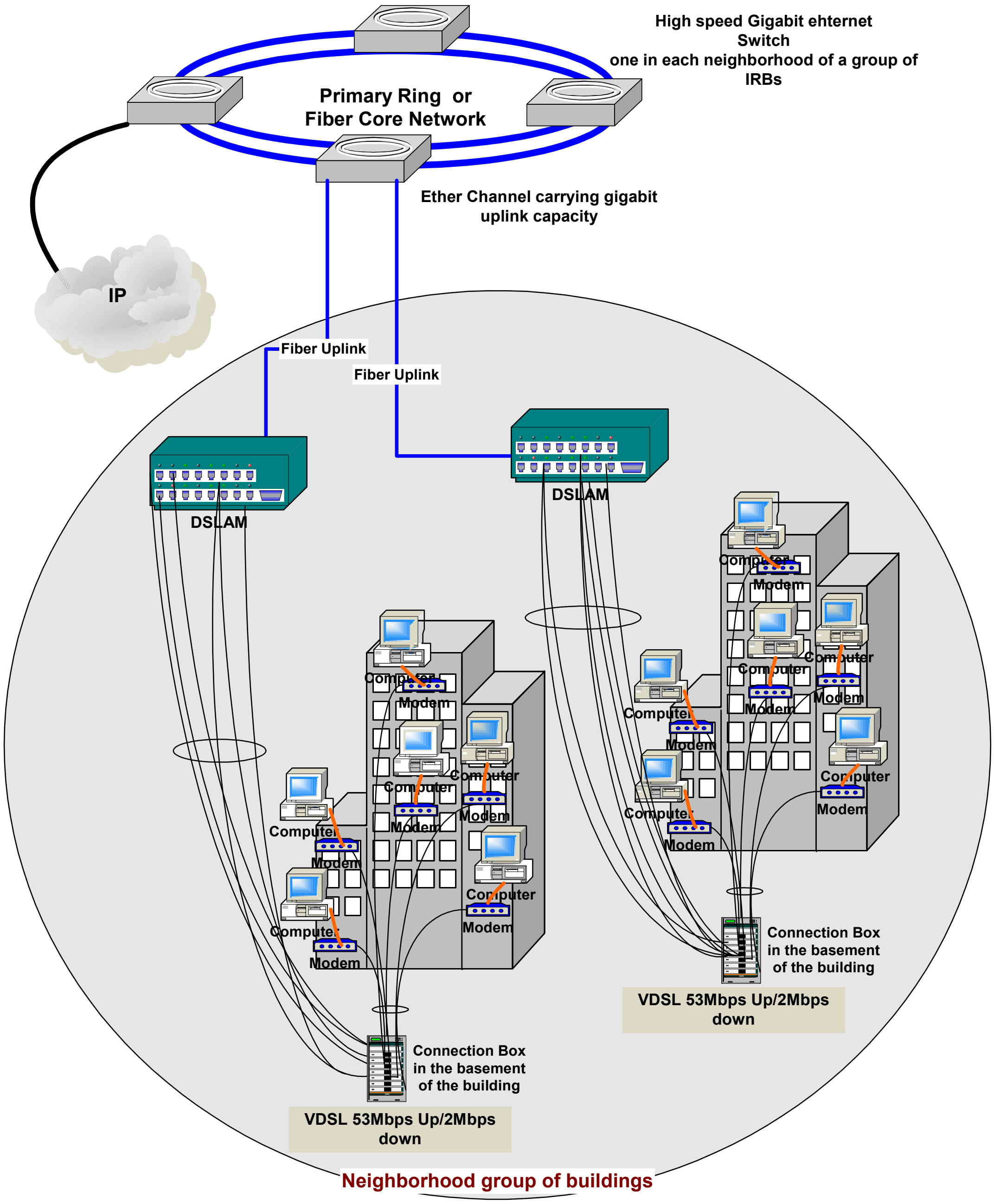


Figure 13-7

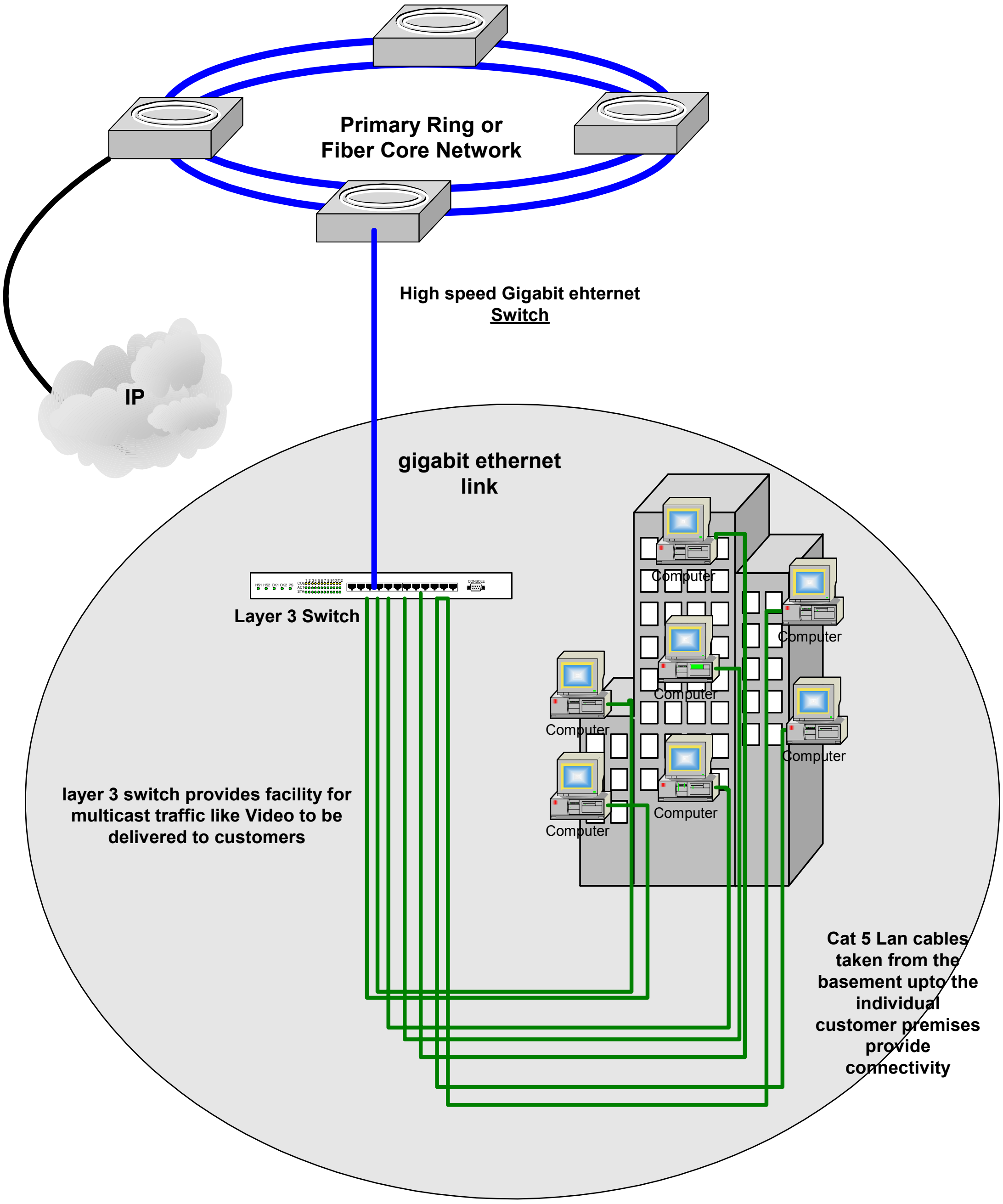


Figure 13-8

13.12.4 Residential Complex Network

Here as shown in figure 13-9 a primary core network is connected to the access network which is a secondary core network, where each high speed multi layer switch is placed in the buildings basement or telecom room fed by a fiber uplink to the core. The distribution can either be done using the existing copper infrastructure or Cat 5 LAN cables as shown below.

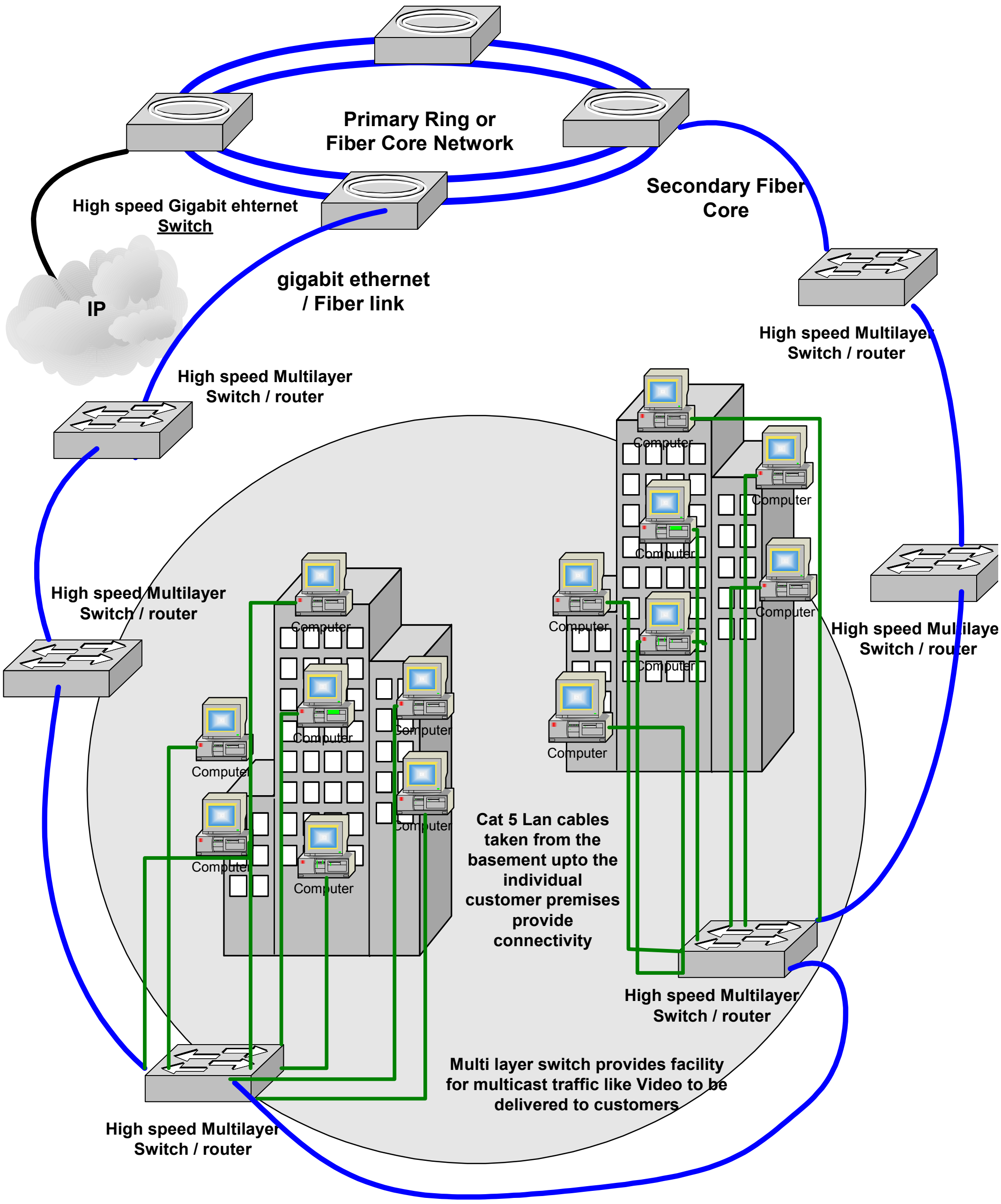


Figure 13-9

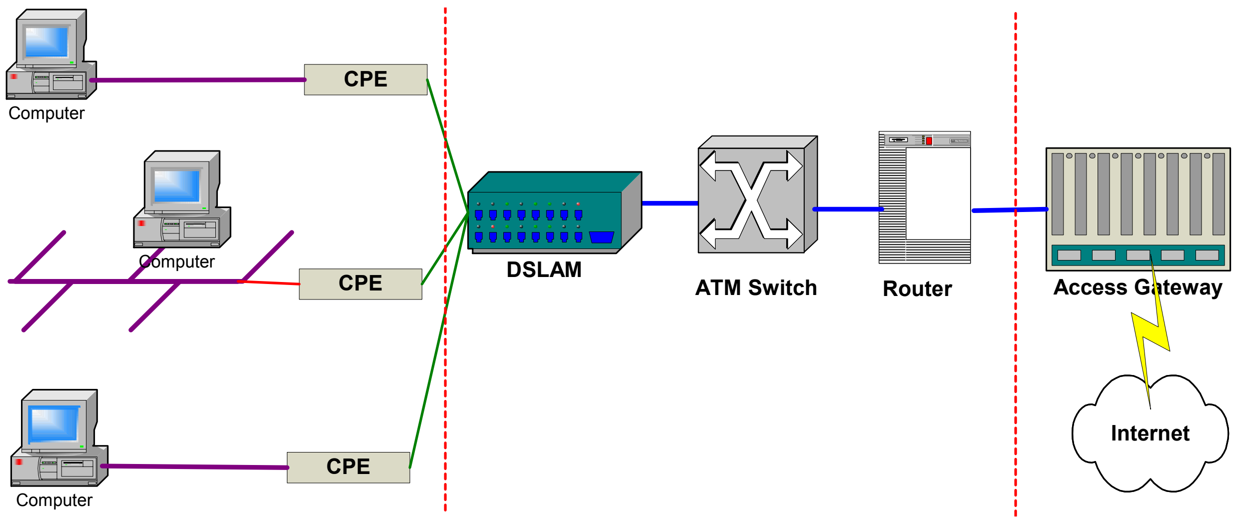
13.13 DSL Access Equipment options

There are many solutions for deploying DSL that fall under the category referred to as DSLAM. A traditional DSLAM will prove costly and burdensome to the implementers of the IRB solution. A DSLAR, on the other hand, may prove to be the implementers best friend.

13.13.1 DSLAM

When using a DSLAM, all lines from the various CPEs are aggregated at the DSLAM which is sent to the ISP. A situation that requires the ISP to maintain the information pertinent to each CPE like the IP address and the routing of these IP traffic through the core network to the internet, may prove to be cumbersome for performance and efficient. See figure 13-10.

Furthermore, this solution uses the bandwidth of the leased line between the ISP and the building inefficiently, unless the DSLAM and the router which does the routing of the traffic within the network is situated within the building itself. In other words, when the access network is situated closer to the distribution network, internal traffic do not have to leave the building which eventually increases the bandwidth utilization between the ISP and the building.



Customer premises Network access Point

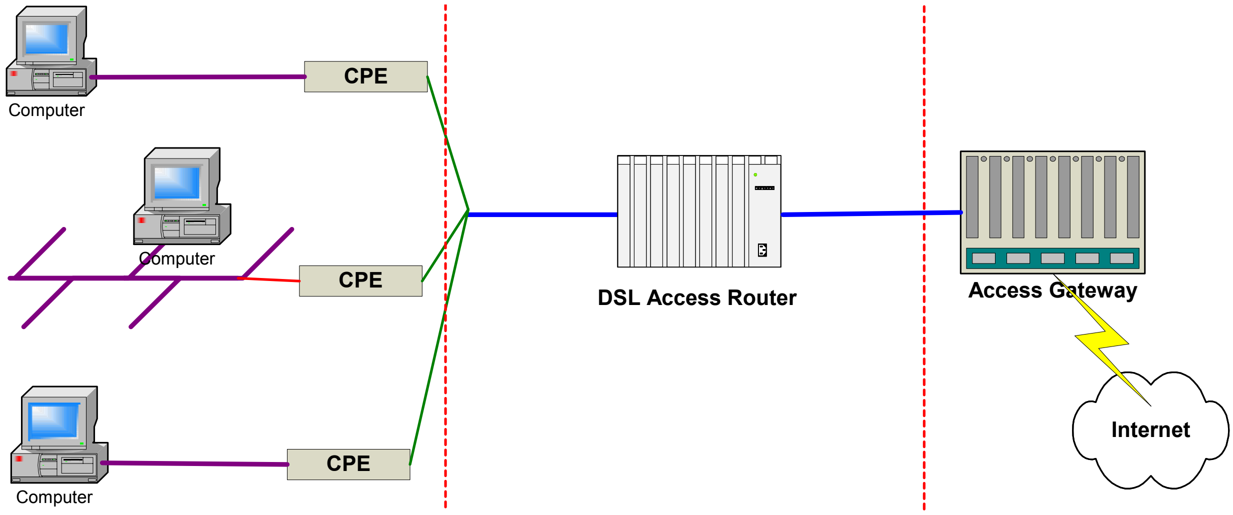
Service providers Facility (In the basement or the telecom room of the IRB)

Figure 13-10

Still the DSLAM alone is incapable of routing the traffic, thus the equipment cost is still more expensive than the next case since an additional router is required in the access network.

13.13.2 DSL Access Router (DSLAR)

All lines to the ISP is routed by the DSLAR so that all the intelligence needed to maintain proper and efficient transmission occurs at the DSLAR itself, thus eliminating the usage of the external link to the ISP for routing internal traffic.



Customer premises Network access Point

Service providers Facility (In the basement or the telecom room of the IRB)

Figure 13-11

13.14 Issues involved with converting a building into Internet-Ready

Creating a functional internet ready building is not a trivial task. The following is a list of issues raised when investigating the requirements and the functionalities needed by the tenants of various buildings:

13.14.1 Infrastructure Issues

1. Copper wiring category
2. number of twisted pairs for each tenant
3. distance from the basement to the customer premises
4. apartment internal wiring topology
5. Splitters and Filters

13.14.2 Networking Issues

1. bandwidth allocation
2. symmetrical versus asymmetrical
3. information caching
4. IP addressing
5. VPN, routing, tunneling, intra building switching, and virtual local-area networks (VLANs)
6. Frame versus Cell (IP Vs. ATM)

13.14.3 Operation Issues

1. Accounting and billing
2. distributed operations, administration, and maintenance (OAM)
3. User self configuration
4. Piracy prevention

13.14.4 Service Issues

1. Termination – Does the service provider support customer home area network (HAN)
2. regulation issues (ISP, CLECs, ILECs, ILEC.NET, Tariffing)
3. Integrated services (voice, internet video streaming, data): service consolidation.
4. dynamic Internet service selection
5. portal services
6. user analysis

13.15 Splitterless System installation

The advanced DSL modulation techniques usually use higher frequencies of the bandwidth. Transmitting low-frequency legacy voice at the same time with high-frequency broadband information requires splitting the signals. In the residential environment, the traditional ADSL techniques use a splitter at the root of the internal wiring of the apartment. As the topology of the internal wiring is unknown, being a star, bus, or daisy-chained, the only place to install the splitter is the root of this topology. This splitter eliminates the negative impacts of the internal wring on the broadband signals, including reflections.

However, by keeping the broadband signals far enough in the spectrum from the voice-signals, traditional splitter can be replaced with a micro low-pass filter in each of the telephone jacks in the apartment. This low ass filter eliminates the high-frequency spikes that occur during the on-hook/ off-hook transition of the handset. The penalty of moving the broadband signals far way from the voice is in the low achieved transmission bandwidth.

Installing a splitter in the user apartment requires additional wiring for sending the broadband signals to the customer premise equipment (CPE), which connects the users computing devices in one of the rooms in the apartment. A great advantage would be to create a splitterless environment, without the need for either splitters or filters. Splitterless installation avoices the need for truck roll- i.e. sending a technician to the customer- which increases the installation cost by hundreds of dollars.

Because the CPE modem offers a splitterless connectivity, the in-house wiring topology is transparent to the CPE modem installation, and can be installed by the customer- just like a regular telephone.

13.16 Service Switching - A new suggested model for creating IRB

13.16.1 The Target

In order to implement IRBs, a new concept defined as service switching has been introduced the service switching concept includes a low-level hardware and a higher-level software, which, when combined, create a service-switching system.

The access service switch implements a secured, switched, symmetrical, and full 10-Mbps Ethernet DSL per tenant, over the existing twisted copper pair, while carrying the legacy voice, in a splitterless fashion. Thus, it emulates a Local Area Network (LAN) environment over the existing legacy wiring in a building.

Installed in a building and complemented by a wireline or wireless uplink, the service-switching concept converts the building into a revenue opportunity for the service provider. Together with a service-layer software, if offers a flexible business model and control over IP services (ISP selection, bandwidth selection, portal activation, etc.) and billing.

Thereby addressing an untapped business opportunity for service providers and carriers (ILECs, CLECs, IXCs, ISPs, and PTT), and also provides the customers the flexibility to change their service providers with ease and to optimize their service requirements by self configuration.

13.16.2 The Market and Business Implications

Installing a service switching in a building enables the service provider to offer a flexible service model. This model is defined by the providers marketing requirements and enables advanced services, which maximize profits and decrease costs. All service providers have the freedom to create their own business and marketing surveys with their customers and configure the service switch to address specific customer needs.

In order to save expenses and cut costs on the service provider’s customer-support staff, the customer configures the service switch. This is accomplished as a result of the fact that the service switch has internal hyper text transfer protocol (HTTP) capabilities, which enables self-configuration by the customer. A customer initializes the service with any standard browser. An initial portal initiates the service options, which have been defined by the service provider. This includes such things as ISP selection, bandwidth requirements, and billing. After an authentication procedure, the user is connected according to the selected service.

This model creates a new, flexible business model for service providers- both new and traditional.

13.16.3 User Self-Configuration

User self-configuration for high-speed internet access presents a new approach and added value for service providers. User self configuration cuts service fees and tariffs associated with traditional high-speed, internet access solutions, which require customer-support staff. This decreases the cost of ownership and improves customer service from a provider point of view.

The ability to control the customer through a browser-based menu/portal enables the service provider to initiate the service according to its own business interests. This will allow the services provider to increase and maximize profits from the existing infrastructure.

13.16.4 Smooth Migration to ISP Billing Environments

Moving a service provider from a dial-up model to an always-on model requires support for a smooth billing mechanism migration. The service-layer software records the user activity and reports it to the billing infrastructure and database through the Remote Authentication Dial-In User service (RADIUS) server that provides the authentication, authorization, accounting (AAA) functionality. This is the existing billing and accounting database, which the ISP maintains for dial-up world.

As a result, the ISP need not ad anything to its existing service-provisioning model. Once a user’s usage information record is registered within the RADIUS database, different billing models can be applied. The usage information record may be recorded within the appropriate provider: CLEC, ISP, or the ILEC, which may help in creating a consolidated bill.

13.16.5 Other required functions from the Service-Layer Software

Servicing the residential community with always-on connections requires the development of a new and flexible service model that will address the service provider business and regulation requirements as well as operational and customer needs.

To implement these requirements a functional service layer software should be developed. This service-layer software enables such functions as the following:

- **Dynamic Service Selection –** this is the user ability to choose between different ISPs during a session initialization. This feature enables a CLEC to whole sale the Internet service to the tenants, creating competition over the building’s access.

- **Automatic user self configuration –** this is the user ability to change service profile, which may include billing schemes, ISP, uplink/downlink rate, etc. this is done without the intervention of the service providers support staff.

- **Flexible bandwidth allocation –** this is the user’s ability to choose the profile of his/her connection rate with parameters such as fixed rate, minimum rate, and maximum burst rate. A round robin mechanism between tenants might be applicable for such a requirement.

- **Security accounting and billing mechanism -** this is accomplished through the existing AAA-RADIUS server, which exists within the ISPs infrastructure.

- **Standard addressing and configuration model –** this uses the standard IP addressing and configuration protocols such as dynamic host configuration protocol (DHCP), NAT, etc.

- **Portal application –** this initializes session through the preferred portals.

- **Standard operation model –** this uses the standard OAM & Ps such as signaling network management protocol (SNMP), HTTP, Telnet, and RADIUS.

- **User statistics –** this involves gathering information regarding user activity (such as web surfing information) for traffic optimization as well as business-oriented applications.

- **Addressing regulation issues –** such issues include the building point of demarcation, CLEC / ISP relationship, tariffs, etc.

- **Other services –** these may include services such as Voice over IP (VoIP), virtual private networking (VPN), caching applications, piracy usage prevention, intelligent fault management, and much more.

13.16.6 The Architecture

The service switching approach is similar to an IP switching architecture. Instead of switching the IP packets according to the IP routing tables, the switching is done according to the IP service layer. This presents a whole new concept for servicing Internet Access.
See figure 13-12.

The Access Service Switch Concept

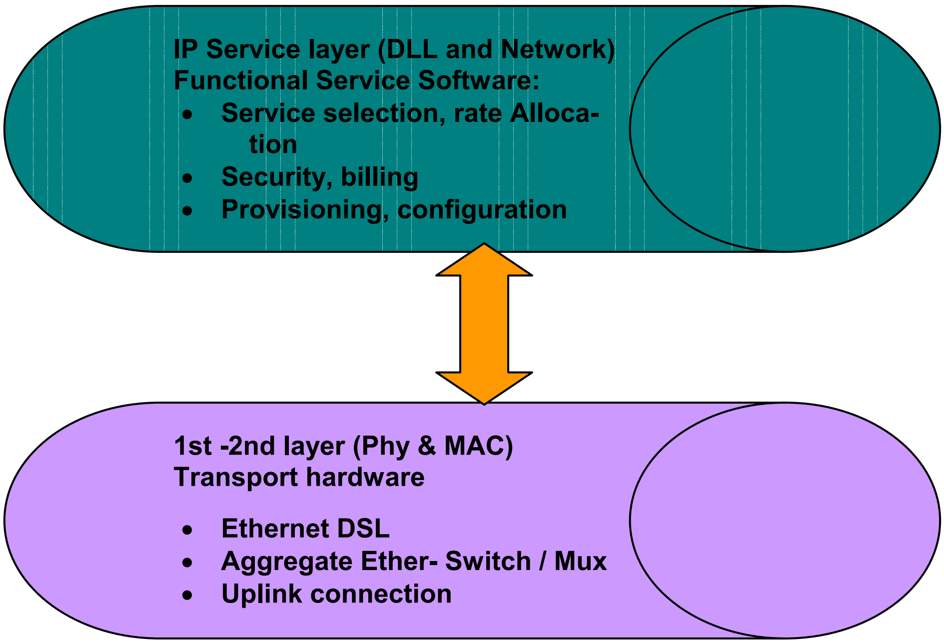


Figure 13-12

As the figure 13-12 reveals, to enable a flexible service –switching functionality, the service-switch system is designed in two layers:

- **Hardware layer –** that complies with the first and second layers of the OSI model. i.e., the DSL and Ethernet physical layer and the data link layer (DLL)

- **The functional software layers –** which implement the service layer software concept and enables switching to the required functionality by controlling the hardware layer.

Figure 13-13 demonstrates the service switching functionality in steps.

13.16.7 The service-switch in action

Step 1: Once the customers launch their browsers for a new service, the traffic is intercepted by the service switch that now controls the user’s traffic activity.

Step 2: The internal service switch which has the HTTP service capabilities replies with menu/ portal that reflects the service profile (such as ISP selection, bandwidth, billing, etc.) defined by the service provider.

Step 3: The user selects the required service by clicking the related requests in the menu/ portal and applying password.

Step 4: Authentication is requested

Step 5: Authentication is approved

Step 6: The service switch allocates the desired service

Step 7: Creates the connection

Form then on, the service switches the IP packets (Orange line in figure 13-13) according to the service profile.

Step 8: Accounting records are periodically sent to the RADIUS server for billing purposes

As it is seen the Service Switch reflects a new dynamic, self configured and flexible model for creating a real residential IRB.

1. Browser conncetion-www.TenantCity.net- no special client s/w
2. "Pay-Per-Surf" Service PORTAL Reply (Billing scheme defined by the service provider)
3. Service Selection (Rate shapping, CIR, ISP, VPN, COst, Authentication, etc.)
4. AAA authentication request
5. AAA authentication Approval
6. "Service Switch" Self-Configuration according to the service selection Profile
7. User connection to the selected Service Provider
8. Accounting Record (Service Termination)

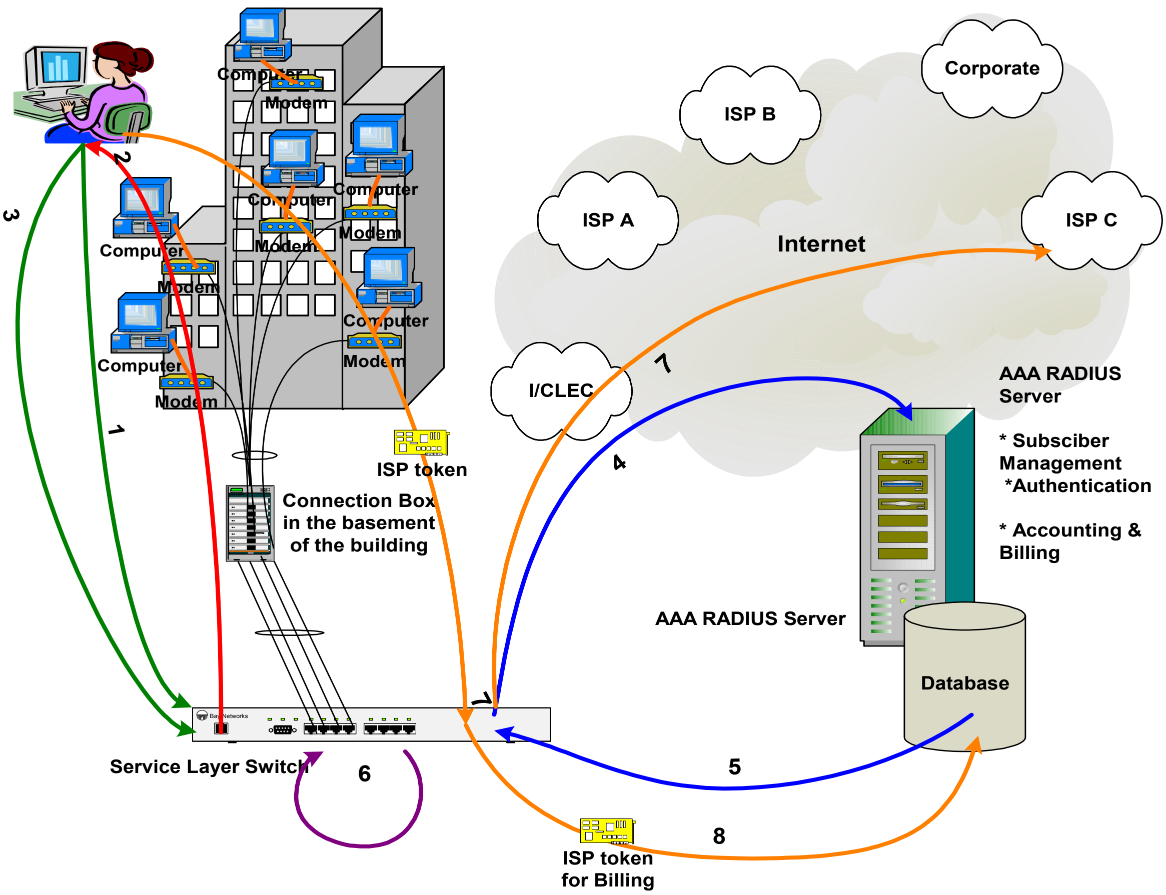


Figure 13-13

14 Optical Fibers

14.1 How Fiber Works

The main job of optical fibers is to guide lightwaves with a minimum of attenuation (loss of signal). Optical fibers are composed of fine threads of glass in layers, called the core and cladding, which can transmit light at about two-thirds the speed of light in a vacuum.

Though admittedly an oversimplification, the transmission of light in optical fiber is commonly explained using the principle of *total internal reflection*. With this phenomenon, 100 percent of light that strikes a surface is reflected.

By contrast, a mirror reflects about 90 percent of the light that strikes it. Light is either reflected (it bounces back) or refracted (its angle is altered while passing through a different medium) depending upon the angle of incidence (the angle at which light strikes the interface between an optically denser and optically thinner material).

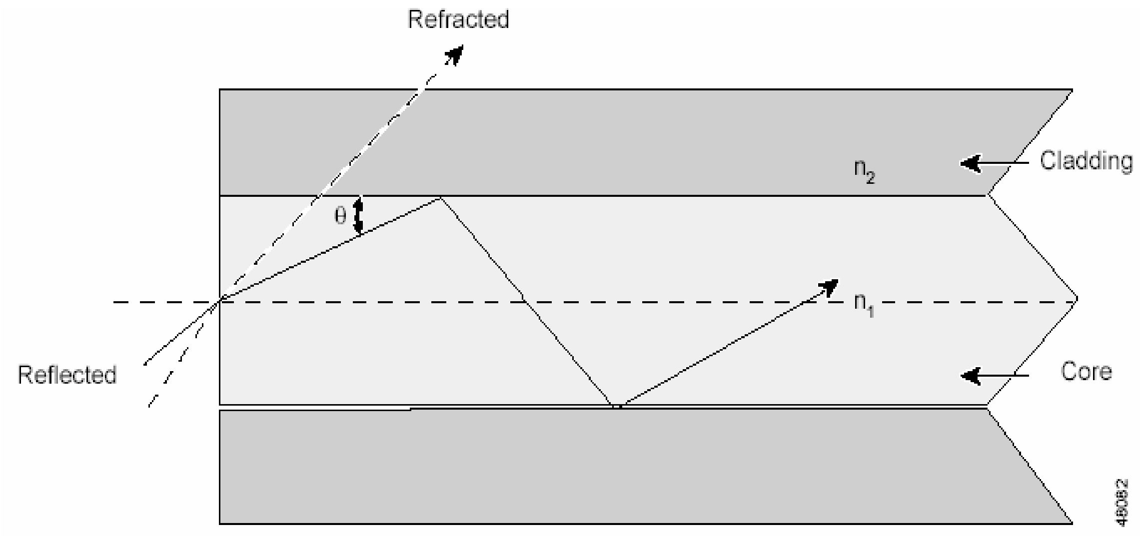
Total internal reflection happens when the following conditions are met:

- Beams pass from a denser to a less dense material. The difference between the optical density of a given material and a vacuum is the material’s refractive index.

- The incident angle is less than the critical angle. The critical angle is the maximum angle of incidence at which light stops being refracted and is instead totally reflected.

The principle of total internal reflection within a fiber core is illustrated in figure 14-1. The core has a higher refractive index than the cladding, allowing the beam that strikes that surface at less than the critical angle to be reflected. The second beam does not meet the critical angle requirement and is refracted.

Figure 14-1 Principle of Total Internal Reflection



An optical fiber consists of two different types of highly pure, solid glass (silica)—the *core* and the *cladding*—that are mixed with specific elements, called *dopants*, to adjust their refractive indices.

The difference between the refractive indices of the two materials causes most of the transmitted light to bounce off the cladding and stay within the core.

The critical angle requirement is met by controlling the angle at which the light is injected into the fiber. Two or more layers of protective coating around the cladding ensure that the glass can be handled without damage.

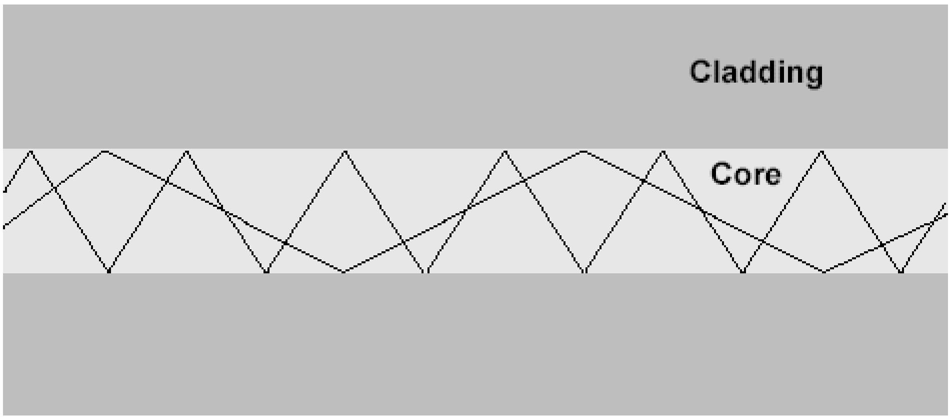
14.2 Multimode and Single-Mode Fiber

There are two general categories of optical fiber in use today, multimode fiber and single-mode fiber. Multimode, the first type of fiber to be commercialized, has a larger core than single-mode fiber. It gets its name from the fact that numerous *modes*, or light rays, can be carried simultaneously through the waveguide. figure 14-2 shows an example of light transmitted in the first type of multimode fiber, called *step-index*.

Step-index refers to the fact that there is a uniform index of refraction throughout the core; thus there is a step in the refractive index where the core and cladding interface. Notice that the two modes must travel different distances to arrive at their destinations.

This disparity between the times that the light rays arrive is called *modal dispersion*. This phenomenon results in poor signal quality at the receiving end and ultimately limits the transmission distance. This is why multimode fiber is not used in wide-area applications.

Figure 14-2 Reflected Light in Step-Index Multimode Fiber

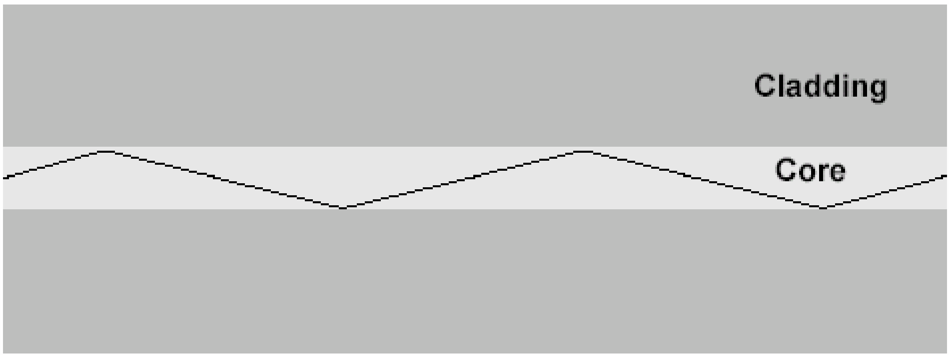


To compensate for the dispersion drawback of step-index multimode fiber, graded-index fiber was invented. *Graded-index* refers to the fact that the refractive index of the core is graded—it gradually decreases from the center of the core outward. The higher refraction at the center of the core slows the speed of some light rays, allowing all the rays to reach their destination at about the same time and reducing modal dispersion.

The second general type of fiber, single-mode, has a much smaller core that allows only one mode of light at a time through the core (see figure 14-3). As a result, the fidelity of the signal is better retained over longer distances, and modal dispersion is greatly reduced.

These factors attribute to a higher bandwidth capacity than multimode fibers are capable of. For its large information-carrying capacity and low intrinsic loss, single-mode fibers are preferred for longer distance and higher bandwidth applications, including DWDM.

Figure 14-3 Reflected Light in Single-Mode Fiber



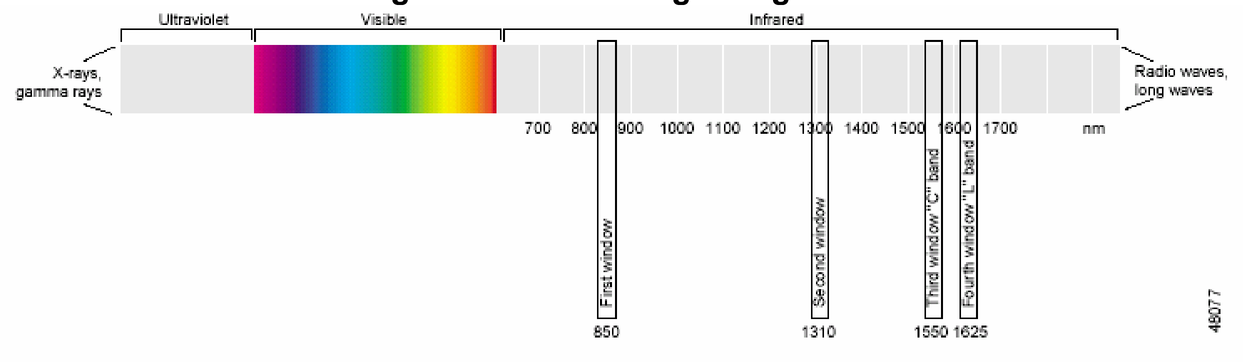
14.3 Single-Mode Fiber Designs

Designs of single-mode fiber have evolved over several decades. The three principle types and their ITU-T specifications are:

- Non-dispersion-shifted fiber (NDSF), G.652
- Dispersion-shifted fiber (DSF), G.653
- Non-zero dispersion-shifted fiber (NZ-DSF), G.655

As discussed later, and shown in figure 14-4, there are four windows have been exploited for fiber transmission. The first window is near 850 for short-range multimode applications. Non-dispersion-shifted fibers, commonly called the standard single-mode (SM) fibers, were designed for use in the second window, near 1310 nm.

Figure 14-4 Wavelength Regions



To optimize the fiber’s performance in this window, the fiber was designed so that chromatic dispersion would be close to zero near the 1310-nm wavelength As optical fiber use became more common and the needs for greater bandwidth and distance increased, a third window, near 1550 nm, was exploited for single-mode transmission.

The third window, or C band, offered two advantages: it had much lower attenuation, and its operating frequency was the same as that of the new erbium-doped fiber amplifiers (EDFAs).

However, its dispersion characteristics were severely limiting. This was overcome to a certain extent by using narrower linewidth and higher power lasers.

But because the third window had lower attenuation than the 1310-nm window, manufacturers came up with the dispersion-shifted fiber design, which moved the zero-dispersion point to the 1550-nm region.

Although this solution now meant that the lowest optical attenuation and the zero-dispersion points coincided in the 1550-nm window, it turned out that there are destructive nonlinearities in optical fiber near the zero-dispersion point for which there is no effective compensation. Because of this limitation, these fibers are not suitable for DWDM applications.

The third type, non-zero dispersion-shifted fiber, is designed specifically to meet the needs of DWDM applications. The aim of this design is to make the dispersion low in the 1550-nm region, but not zero.

This strategy effectively introduces a controlled amount of dispersion, which counters nonlinear effects such as four-wave mixing (see section on “Other Nonlinear Effects” which follows in subsequent pages) that can hinder the performance of DWDM systems.

14.4 Transmission Challenges

Transmission of light in optical fiber presents several challenges that must be dealt with. These fall into the following three broad categories:

- Attenuation—decay of signal strength, or loss of light power, as the signal propagates through the fiber
- Chromatic dispersion—spreading of light pulses as they travel down the fiber
- Nonlinearities—cumulative effects from the interaction of light with the material through which it travels, resulting in changes in the lightwave and interactions between lightwaves

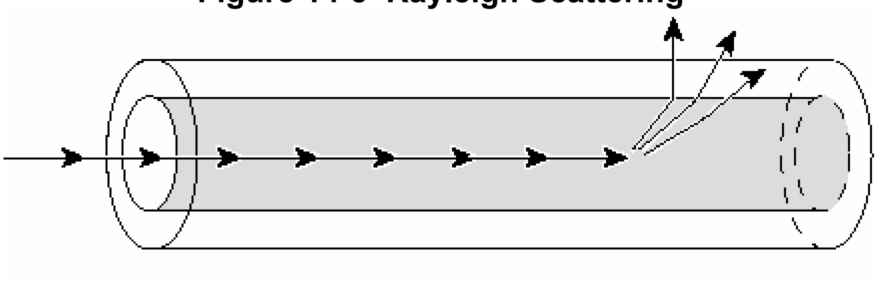
Each of these effects has several causes, not all of which affect DWDM. The discussion in the following sections addresses those causes that are relevant to DWDM.

14.4.1 Attenuation

Attenuation in optical fiber is caused by intrinsic factors, primarily scattering and absorption, and by extrinsic factors, including stress from the manufacturing process, the environment, and physical bending. The most common form of scattering, *Rayleigh scattering*, is caused by small variations in the density of glass as it cools.

These variations are smaller than the wavelengths used and therefore act as scattering objects (see figure 14-5). Scattering affects short wavelengths more than long wavelengths and limits the use of wavelengths below 800 nm.

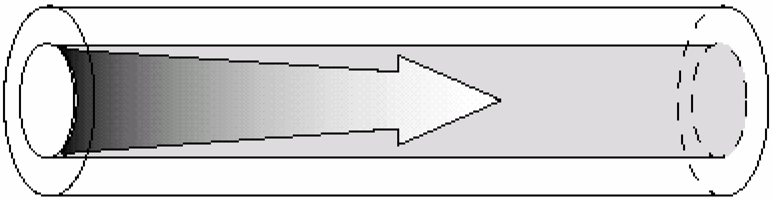
Figure 14-5 Rayleigh Scattering



Attenuation due to absorption is caused by the intrinsic properties of the material itself, the impurities in the glass, and any atomic defects in the glass. These impurities absorb the optical energy, causing the light to become dimmer (see Figure 14-6).

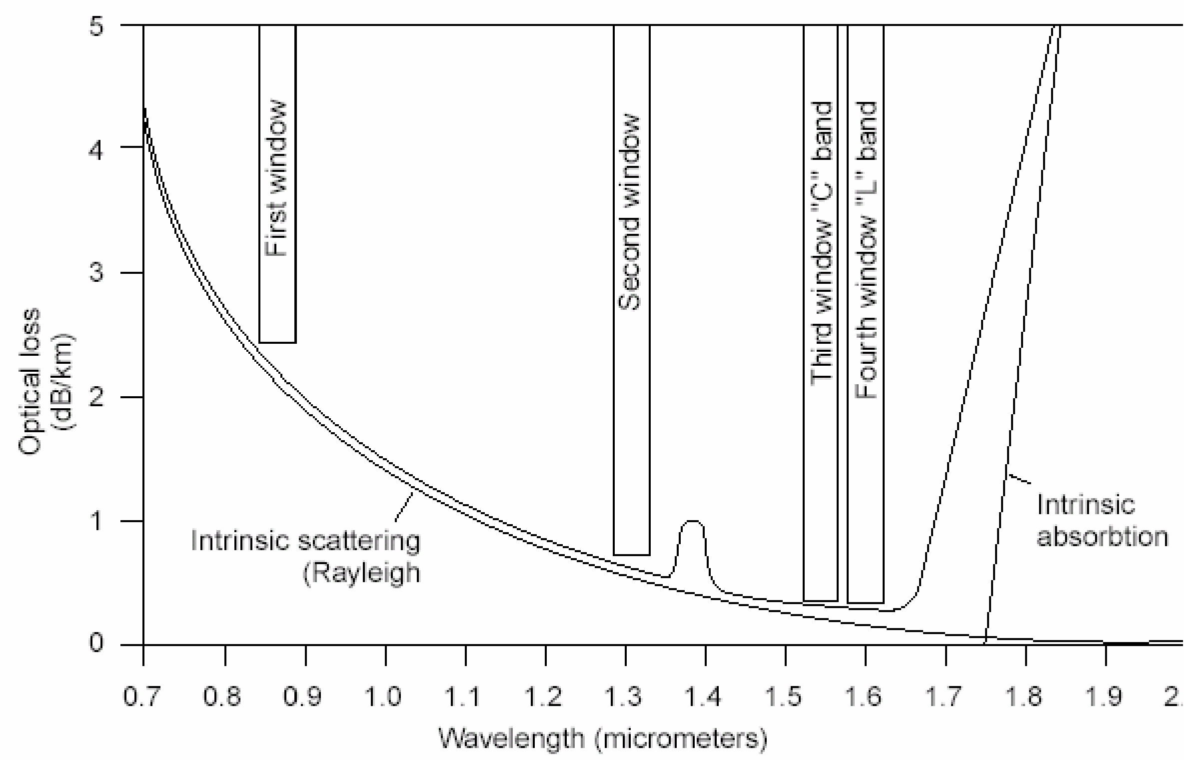
While Rayleigh scattering is important at shorter wavelengths, intrinsic absorption is an issue at longer wavelengths and increases dramatically above 1700 nm. However, absorption due to water peaks introduced in the fiber manufacturing process are being eliminated in some new fiber types.

Figure 14-6 Absorption



The primary factors affecting attenuation in optical fibers are the length of the fiber and the wavelength of the light. Figure 14-7 shows the loss in decibels per kilometer (dB/km) by wavelength from Rayleigh scattering, intrinsic absorption, and total attenuation from all causes.

Figure 14-7 Total Attenuation Curve

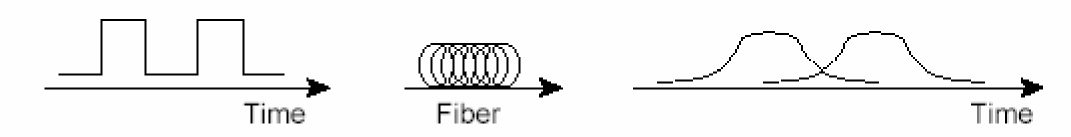


Attenuation in fiber is compensated primarily through the use of optical amplifiers, as in section on “Optical Amplifiers”.

14.4.2 Dispersion

Dispersion is the spreading of light pulses as they travel down optical fiber. Dispersion distortion of the signal (see figure 14-8), which limits the bandwidth of the fiber. Two general types of dispersion affect DWDM systems. One of these effects, chromatic dispersion, is linear while the other, polarization mode dispersion (PMD), is nonlinear.

Figure 14-8 Principle of Dispersion



14.4.2.1 Chromatic Dispersion

Chromatic dispersion occurs because different wavelengths propagate at different speeds. The effect of chromatic dispersion increases as the square of the bit rate. In single-mode fiber, chromatic dispersion has two components, material dispersion and waveguide dispersion. Material dispersion occurs when wavelengths travel at different speeds through the material.

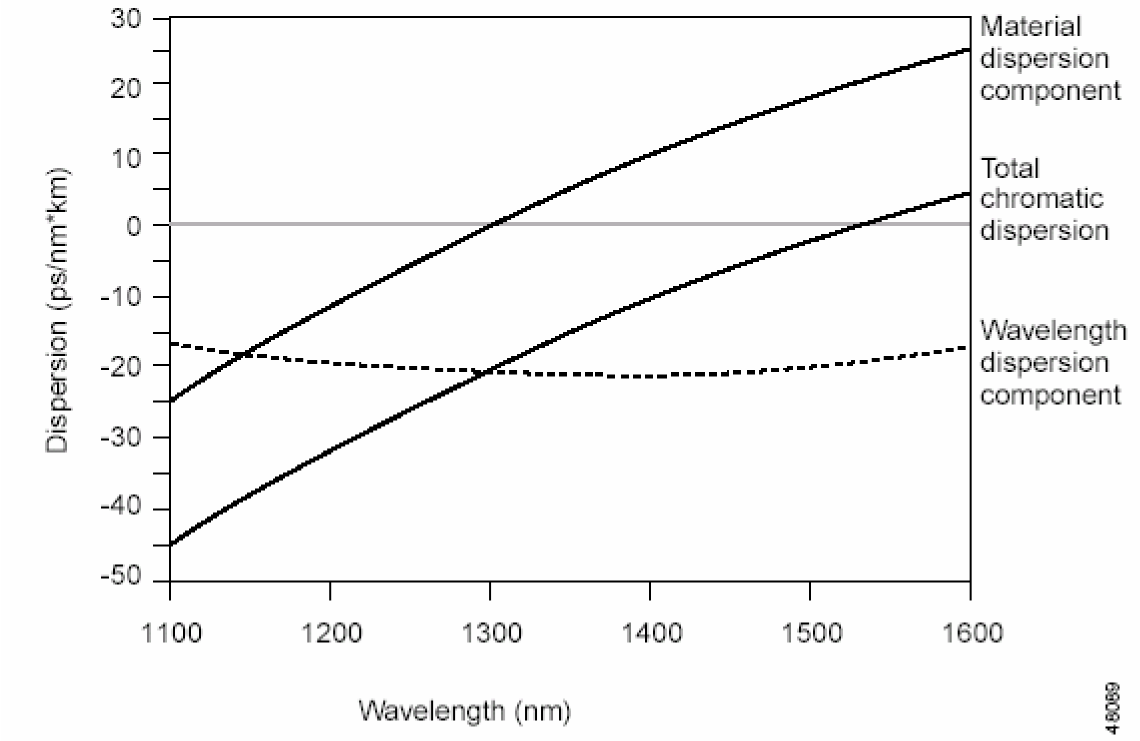
A light source, no matter how narrow, emits several wavelengths within a range. Thus, when this range of wavelengths travels through a medium, each individual wavelength arrives at a different time.

The second component of chromatic dispersion, waveguide dispersion, occurs because of the different refractive indices of the core and the cladding of fiber. The effective refractive index varies with wavelength as follows:

- At short wavelengths, the light is well confined within the core. Thus the effective refractive indexis close to the refractive index of the core material.
- At medium wavelengths, the light spreads slightly into the cladding. This decreases the effective refractive index.
- At long wavelengths, much of the light spreads into the cladding. This brings the effective refractive index very close to that of the cladding.

This result of the phenomenon of waveguide dispersion is a propagation delay in one or more of the wavelengths relative to others. Total chromatic dispersion, along with its components, is plotted by wavelength in figure 14-9 for dispersion-shifted fiber. For non-dispersion-shifted fiber, the zero dispersion wavelength is 1310 nm.

Figure 14-9 Chromatic Dispersion



Though chromatic dispersion is generally not an issue at speeds below OC-48, it does increase with higher bit rates due to the spectral width required. New types of zero-dispersion-shifted fibers greatly reduce these effects. The phenomenon can also be mitigated with dispersion compensators.

14.4.2.2 Polarization Mode Dispersion

Most single-mode fibers support two perpendicular polarization modes, a vertical one and a horizontal one. Because these polarization states are not maintained, there occurs an interaction between the pulses that results is a smearing of the signal.

Polarization mode dispersion (PMD) is caused by ovality of the fiber shape as a result of the manufacturing process or from external stressors. Because stress can vary over time, PMD, unlike chromatic dispersion, is subject to change over time. PMD is generally not a problem at speeds below OC-192.

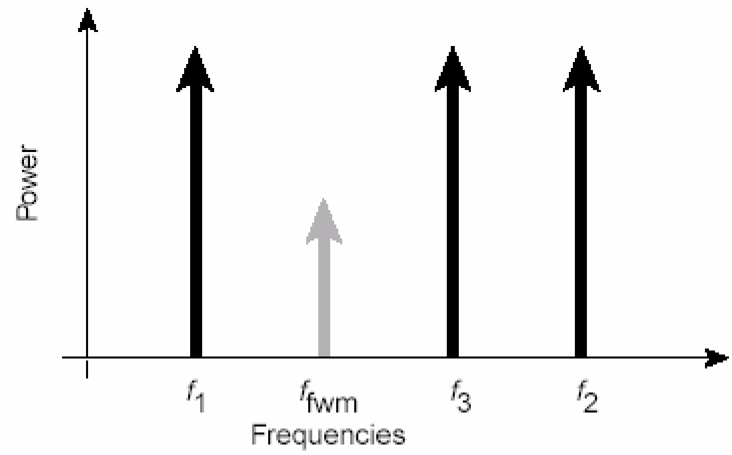
14.4.3 Other Nonlinear Effects

In addition to PMD, there are other nonlinear effects. Because nonlinear effects tend to manifest themselves when optical power is very high, they become important in DWDM. Linear effects such as attenuation and dispersion can be compensated, but nonlinear effects *accumulate*.

They are the fundamental limiting mechanisms to the amount of data that can be transmitted in optical fiber. The most important types of nonlinear effects are stimulated Brillouin scattering, stimulated Raman scattering, self-phase modulation, and four-wave mixing. In DWDM, four-wave mixing is most critical of these types.

Four-wave mixing is caused by the nonlinear nature of the refractive index of the optical fiber. Nonlinear interactions among different DWDM channels create sidebands that can cause interchannel interference. In figure 14-10 three frequencies interact to product a fourth frequency, resulting in cross-talk and signal-to-noise degradation.

Figure 14-10 Four-Wave Mixing



The effect of four-wave mixing is to limit the channel capacity of a DWDM system. Four-wave mixing cannot be filtered out, either optically or electrically, and increases with the length of the fiber. Due to its propensity for four-wave-mixing, DSF is unsuitable for WDM applications.

This prompted the invention of NZ-DSF, which takes advantage of the fact that a small amount of chromatic dispersion can be used to mitigate four-wave mixing.

Summary

In the long-distance network, the majority of embedded fiber is standard single-mode (G.652) with high dispersion in the 1550-nm window, which limits the distance for OC-192 transmission.

Dispersion can be mitigated to some extent, and at some cost, using dispersion compensators. Non-zero dispersion-shifted fiber can be deployed for OC-192 transport, but higher optical power introduces nonlinear effects. In the short-haul network, PMD and nonlinear effects are not so critical as they are in long-haul systems, where higher speeds (OC-192 and higher) are more common.

DWDM systems using optical signals of 2.5 Gbps or less are not subject to these nonlinear effects at short distances.

The major types of single-mode fibers and their application can be summarized as follows:

Non-dispersion-shifted fiber (standard SM fiber)—accounts for greater than 95 percent of deployed plant; suitable for TDM (single-channel) use in the 1310-nm region or DWDM use in the 1550-nm region (with dispersion compensators). This type of fiber can also support 10 Gigabit Ethernet standard at distances over 300 meters.

- Dispersion-shifted fiber—suitable for TDM use in the 1550-nm region, but unsuitable for DWDM in this region.
- Non-zero dispersion-shifted fiber—good for both TDM and DWDM use in the 1550-nm region.
- Newer generation fibers—includes types that allow the energy to travel further into the cladding, creating a small amount of dispersion to counter four-wave mixing, and dispersion-flattened fibers, which permit use of wavelengths farther from the optimum wavelength without pulse spreading.

Note As bit rates increase to 40 Gbps and beyond, the interdependence between system designs and fiber design will become increasingly important for strategic planning.

15 Wavelength Division Multiplexing

15.1 Introduction

The Need for Speed

While there are several contenders for the protocol and architecture standards (e.g. ATM), what is clear is the need for faster physical layer technology, to 1 Gbps and beyond. One key difficulty is that the most commonly installed fiber in local area networks does not support this bandwidth over distances of 500 meters due to modal dispersion, which limits the effective bandwidth distance product.

WDM offers an attractive solution to increasing LAN bandwidth without disturbing the existing embedded fiber, which populates most buildings and campuses, and continue to be the cable of choice for the near future. By multiplexing several relatively coarsely spaced wavelengths over a single, installed multimode network, the aggregate bandwidth can be increased by the multiplexing factor.

Multichannel optical systems were relatively unknown in 1980, but much technological progress has been achieved since then. The applications can include a multiplexed high-bandwidth library resource system, simultaneous information sharing, supercomputer data and processor interaction, a myriad of multimedia services, video applications, and many undreamed-of services.

As demands for more network bandwidth increase, the need will become apparent for multiuser optical networks, with issues such as functionality, compatibility, and cost determining which systems will eventually be implemented.

15.2 Fiber Bandwidth

The driving force motivating the use of multichannel optical systems is the enormous bandwidth available in optical fiber. The high-bandwidth characteristic of the optical fiber implies that a single optical carrier can be baseband modulated at ~25,000 Gbps, occupying 25,000 GHz surrounding 1.55 nano-meter, before transmission losses of the optical fiber would limit transmission.

Obviously, this bit rate is impossible for present-day optical devices to achieve, given that heroic lasers, external modulators, switches or detectors have bandwidths < 100 GHz. As such, a single high-speed channel takes advantage of an extremely small portion of the available fiber bandwidth.

15.3 Popular Multiplexing Methods

15.3.1 Time Division Multiplexing

The 100-Gbps channel mentioned in the previous section probably will be a combination of many lower-speed signals, since very few individual applications today utilize this high bandwidth. These lower-speed channels are multiplexed together in time to form a higher-speed channel.

This time-division multiplexing (TDM) can be accomplished in the electrical or optical domain, with each lower-speed channel transmitting a bit (or allocation of bits known as a packet) in a given time slot and the waiting its turn to transmit another bit (or packet) after all the other channels have had their opportunity to transmit (figure 15-1).

TDM is quite popular with today's electrical networks, and is fairly straightforward to implement in an optical network at < 100-Gbps speeds. This scheme by itself cannot hope to utilize the available bandwidth because it is limited by the speed of the time-multiplexing and -demultiplexing components.

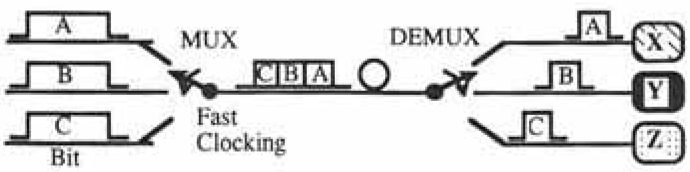


Figure 15-1 Several TDM channels with bit-interleaved multiplexing

15.3.2 Wavelength Division Multiplexing

To exploit more of the fiber’s THz bandwidth we seek solutions that complement of replace TDM. One obvious choice is WDM (wavelength division multiplexing), in which several baseband-modulated channels are transmitted along a single fiber but with each channel located at a different wavelength (figure 15-2).

Each of N different wavelength lasers is operating at the slower Gbps speeds, but the aggregate system is transmitting at N times the individual laser speed, providing a significant capacity enhancement. The WDM channels are separated in wavelength to avoid cross-talk when they are (de)multiplexed by a non-ideal optical fiber.

The wavelengths can be individually routed through a network or individually recovered by wavelength-selective components. WDM allows us to use much of the fiber bandwidth, although various device, system, and network issues will limit the utilization of the full fiber bandwidth. Note that each WDM channel may contain a set of even slower time-multiplexed channels.

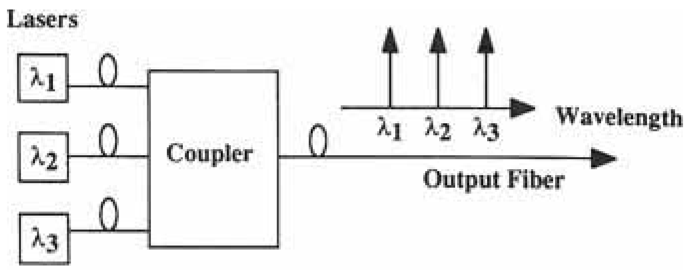


Figure 15-2 : Many WDM channels propagating in a single optical fiber.

15.3.3 SubCarrier Multiplexing

This is another method conceptually related to WDM is subcarrier multiplexing (SCM). Instead of directly modulating a ~terahertz optical carrier wave with ~100s Mbps baseband data, the baseband data are impressed on a ~gigahertz subcarrier wave that is subsequently impressed on the THz optical carrier. figure 15-3 illustrates the situation in which each channel is located at a different subcarrier frequency, thereby occupying a different portion of the spectrum surrounding the optical carrier.

SCM is similar to commercial radio, in which many stations are placed at different RF (Radio Frequency) such that a radio receiver can tune its filter to the appropriate subcarrier RF. The multiplexing and demultiplexing of the SCM channels is accomplished electronically, not optically.

The obvious advantage of cost-conscious users is that several channels can share the same expensive optical components; electrical components are typically less expensive than optical ones. Just as with TDM, SCM is limited in maximum subcarrier frequencies and data rates by the available bandwidth of the electrical and optical components.

Therefore, SCM must be used in conjunction with WDM if we want to utilize any significant fraction of the fiber bandwidth, but it can be used effectively for lower-speed, lower-cost multiuser systems.

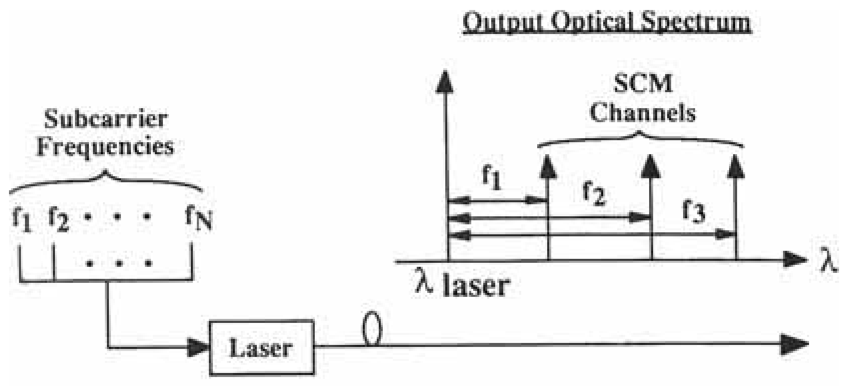


Figure 15-3 : Frequency spectrum of several SCM channels transmitted from a single laser

15.3.4 Code Division multiplexing

An additional method is the code-division multiplexing (CDM) (figure 15-4). Instead of each channel occupying a given wavelength, frequency or time slot, each channel transmits its bits as a coded channel-specific sequence of pulses.

This coded transmission typically is accomplished by transmitting a unique time-dependent series of short pulses. These short pulses are placed within chip times within the larger bit time. All channels, each with a different code, can be transmitted on the same fiber and asynchronously demultiplxed.

One effect of coding is that the frequency bandwidth of each channel is broadbanded, or “spread”. If ultra-short (<100 fs) optical pulses can be successfully generated and modulated, then a significant fraction of the fiber bandwidth can be used. Unfortunately, it is difficult for the entire system to operate at these speeds without incurring enormous cost and complexity.

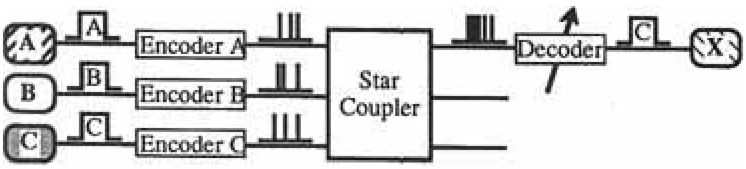


Figure 15-4 The basic concept of a coded pulse sequence for CDM, with each pulse located in a chip time and the entire code occupying a larger bit time slot.

15.3.5 Space division Multiplexing

Yet another optical multiplexing scheme is called space-division multiplexing (SDM), in which the channel-routing path is determined by different spatial position (i.e., a different output fiber). A simple example of this is shown in figure 15-5, in which the optical output of a fiber is split into N different and parallel optical beam paths.

Each of the N output beams is passed through a light-modulating switch and then coupled to a different output fiber. By controlling the transmissivity of each optical modulator, a signal on the input fiber can be routed to any fiber output port.

By extending this scenario, N input fiber ports can be fully interconnected with N output fiber ports by an array of N^2 optical switches. The technology for implementing moderate-speed systems is already commercially available. In contrast to all other methods, however, each channel occupies its own spatial coordinate, and all other channels cannot be transmitted simultaneously on the same fiber. In other words, we are not more fully utilizing the high bandwidth of the fiber, but we are creating a high-bandwidth space-switching matrix, with the result that a high overall switching capacity can be realized.

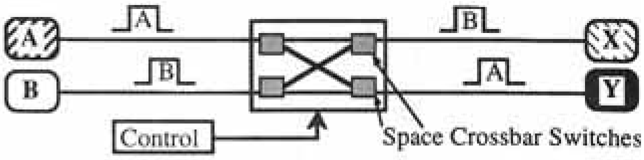


Figure 15-5 : A simple example of 1-by-N spatial multiplexing.

15.4 Wavelength Division Multiplexing

Until the late 1980s, optical fiber communications was mainly confined to transmitting a single optical channel. Because fiber attenuation was involved, this channel required periodic regeneration, which included detection, electronic processing, and optical retransmission. Such regeneration causes a high-speed optoelectronic bottleneck and can handle only a single wavelength.

After the new generation amplifiers were developed, it enabled us to accomplish high-speed repeaterless single-channel transmission. We can think of single ~Gbps channel as a single high-speed lane in a highway in which the cars are packets of optical data and the highway is the optical fiber. However, the ~25 THz optical fiber can accommodate much more bandwidth than the traffic from a single lane.

To increase the system capacity we can transmit several different independent wavelengths simultaneously down a fiber to fully utilize this enormous fiber bandwidth. Therefore, the intent was to develop a multiple-lane highway, with each lane representing data traveling on a different wavelength.

Thus, a WDM system enables the fiber to carry more throughput. By using wavelength-selective devices, independent signal routing also can be accomplished. The highway principle is illustrated in figure 15-6.

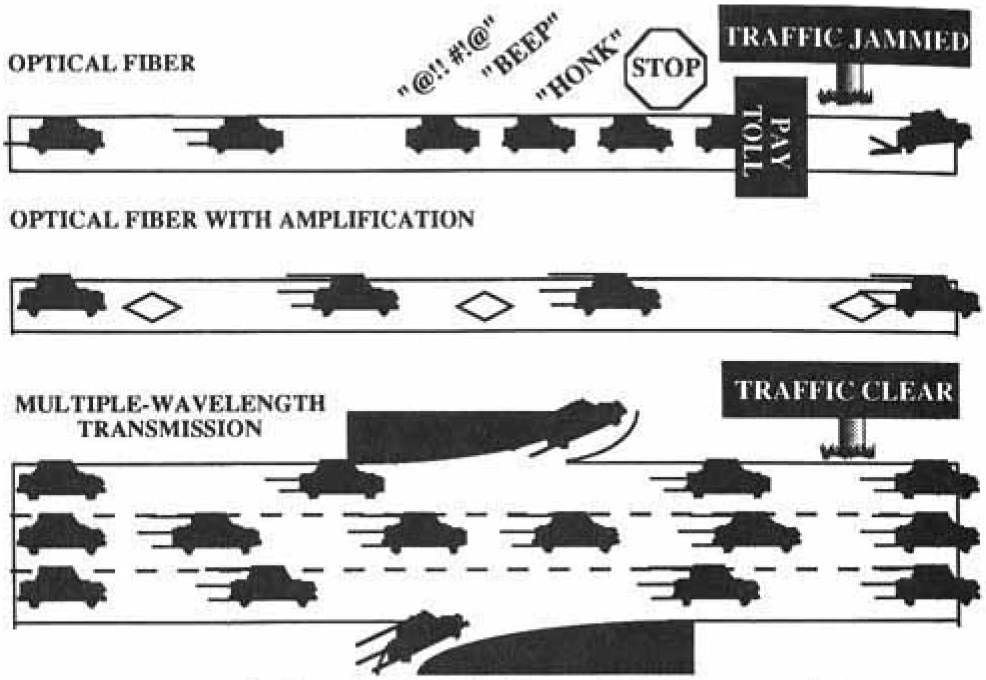


Figure 15-6 Multiwavelength optical transmission as represented by a multiple-lane highway.

It is expected that WDM will be one of the methods of choice for future ultra-high bandwidth multichannel systems. Of course, this could be changed as the technology evolves.

15.4.1 Basic Operation

As explained before, WDM enables the utilization of a significant portion of the available fiber bandwidth by allowing many independent signals to be transmitted simultaneously on one fiber, with each signal located at a different wavelength.

Routing and detection of these signals can be accomplished independently, with the wavelength determining the communication path by acting as the signature address of the origin, destination or routing. Components are therefore required that are wavelength selective, allowing for the transmission, recovery, or routing of specific wavelengths.

In a simple WDM system (figure 15-7), each laser must emit light at a different wavelength, with all the lasers' light multiplexed together onto a single optical fiber.

After being transmitted through a high-bandwidth optical fiber, the combined optical signals must be demultiplexed at the receiving end by distributing the total optical power to each output port and then requiring that each receiver selectively recover only one wavelength by using a tunable optical filter.

Each laser is modulated at a given speed, and the total aggregate capacity being transmitted along the high-bandwidth fiber is the sum total of the bit rates of the individual lasers.

An example of the system capacity enhancement is the situation in which ten 2.5-Gbps signals can be transmitted on one fiber, producing a system capacity of 25 Gbps.

This wavelength-parallelism circumvents the problem of typical optoelectronic devices, which do not have bandwidths exceeding a few gigahertz unless they are exotic and expensive.

The speed requirements for the individual optoelectronic components are, therefore, relaxed, even though a significant amount of total fiber bandwidth is still being utilized.

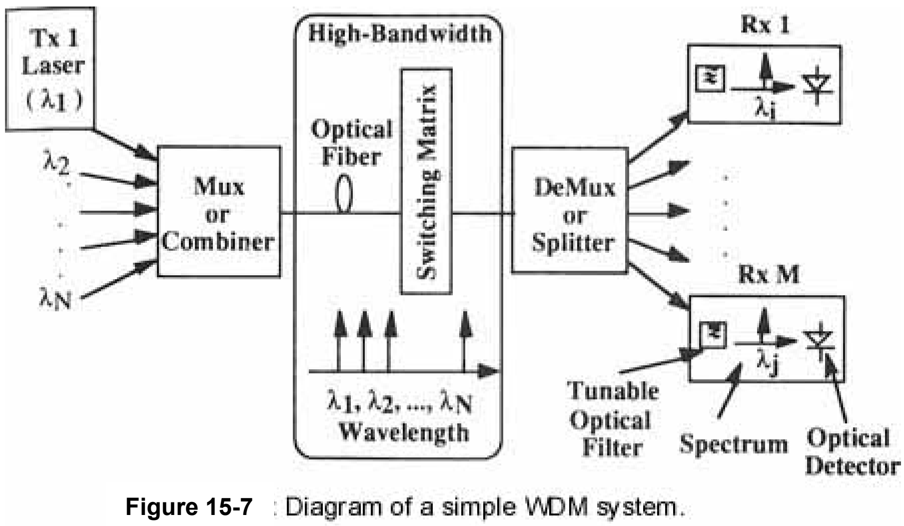


Figure 15-7 : Diagram of a simple WDM system.

The concept of wavelength demultiplexing using an optical filter is illustrated in figure 15-8. In the figure, four channels are input to an optical filter that has a nonideal transmission filtering function. The filter transmission peak is centered over the desired channel, in this case, l_3, thereby transmitting that channel and blocking all other channels.

Because of the nonideal filter transmission function, some optical energy of the neighboring channels leaks through the filter, causing interchannel, interwavelength cross-talk. This cross-talk has the effect of reducing the selected signal's contrast ratio and can be minimized by increasing the spectral separation between channels.

Although there is no set definition, a nonstandardized convention exists for defining optical WDM as encompassing a system for which the channel spacing is approximately 10 nm.

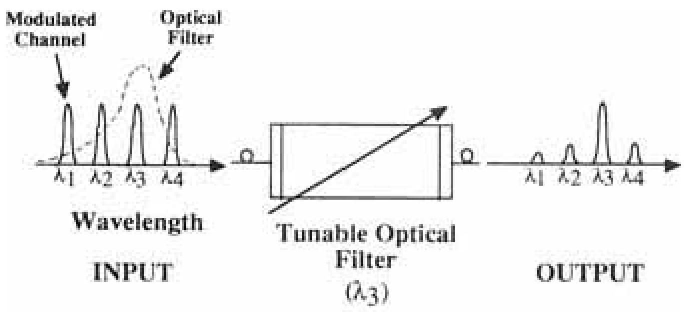


Figure 15-8 : Optical WDM channels being demultiplexed by an optical filter

15.4.2 Topologies and Architectures

Let us consider a simple point-to-point WDM system (figure 15-9(a)) in which several channels are multiplexed at one node, the combined signals are transmitted across some distance of fiber, and the channels are demultiplexed at a destination node. This facilitates high-bandwidth fiber transmission.

Additionally, high-bandwidth routing can be facilitated through a multiuser network (figure 15-9(b)). The wavelength becomes the signature address for either path through an optical network.

Because nodes will want to communicate with each other, either the transmitters or the receivers must be wavelength tunable to facilitate the proper link set-up (in this example, the transmitters were chosen to be tunable).

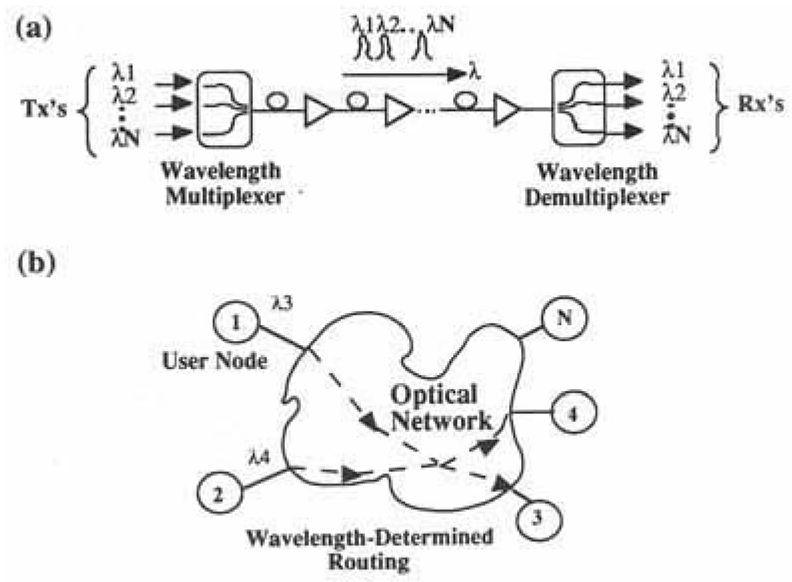


Figure 9: (a) A simple point-to-point WDM transmission system.
Figure 15-9 …eneric multiuser network in which the communications links and routing paths are determined by the wavelengths used within the optical switching fabric.

Two common network topologies can use WDM, namely, the star and the ring networks (figure 15-10). Each node in the star has a transmiter and a receiver, with the transmitter connected to one of the central passive star's inputs and the receiver connected to one of the star's outputs.

WDM networks can also be of the ring variety. Rings are popular because so many electrical networks use this topology and because rings are easy to implement for any network geographical configuration. In this example, each node in the unidirectional ring can transmit on a specific signature wavelength, and each node can recover any other node's wavelength signal by means of a wavelength-tunable receiver.

In both the star and the ring scenarios, each node has a signature wavelength, and any two nodes can communicate with each other by transmitting on that wavelength. This implies that we require N wavelengths to connect N nodes.

The obvious advantage is that data transfer occurs with an uninterrupted optical path between the origin and the destination, known as a single-hop network. The optical data start at the originating node and reach the destination node without stopping at any other intermediate node.

A disadvantage of a single-hop WDM network is that the network and all its components must accommodate N wavelengths, which may be difficult (or impossible) to achieve in a large network. Current fabrication technology cannot provide and transmission capability cannot accommodate 1,000 distinct wavelengths for a 1,000-user network.

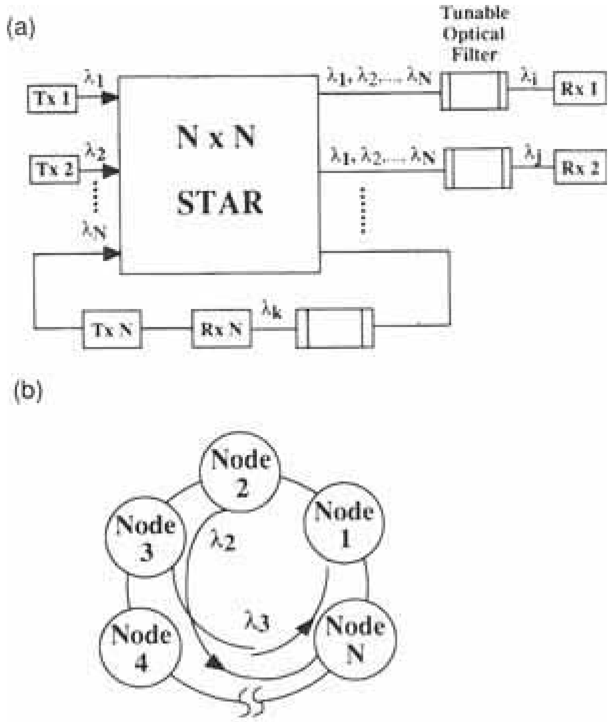


Figure 15-10 (a) Diagram of a simple star network in which WDM is used for routing and multiplexing purposes. (b) An example of a WDM unidirectional ring network.

An alternative to requiring N wavelengths to accommodate N nodes is to have a multihop network, in which two nodes can communicate with each other by sending through a third node, with many such intermediate hops possible.

A dual-bus multihop eight-node WDM network is shown in figure 15-11 for which each node can transmit on two wavelengths and receive on two other wavelengths. The logical connectivity is also shown.

As an example, if node 1 wants to communicate with node 5, it transmits on wavelength l_1 and only a single hop is required. However, if node 1 wants to communicate with node 2, it first must transmit to node 5, which then transmits to node 2, incurring two hops. Any extra hops are deleterious in that they:

1) Increase the transmit time between two communicating nodes, since a hop typically requires some form of detection and retransmission

2) Decrease the throughput, since a relaying node can transmit its own data while it is in the process of relaying another node's data

However, a multihop networks do reduce the required number of wavelengths and the wavelength tunability range of the components.

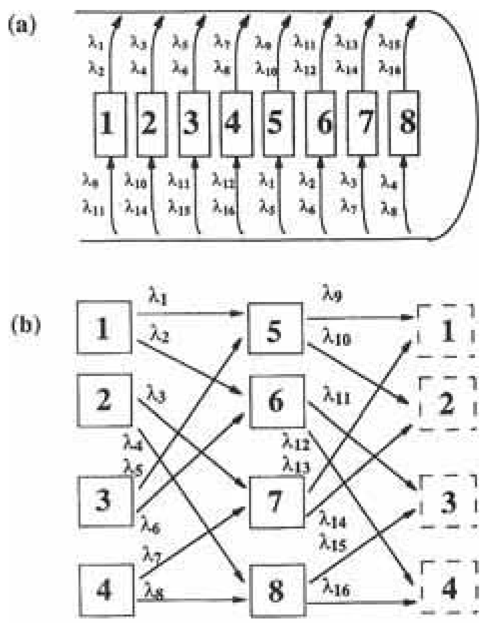


Figure 15-11 : (a) A dual-rail WDM bus multihop 8 node network and (b) the logical network connectivity.

15.5 Wavelength Shifting and Wavelength Reuse

In an ideal WDM network, each user would have its own unique signature wavelength. Routing in such a network would be straightforward. This situation may be possible in a small network, but it is unlikely in a large network whose number of users is larger than the number of provided wavelengths.

In fact, technologies that can provide and cope with 20 distinct wavelengths are the state of the art. There are some technological limitations in providing a large number of wavelengths, for instance: due to channel-broadening effects and non-ideal optical filtering, channels must have minimum wavelength spacing. Wavelength range, accuracy, and stability are extremely difficult to control.

Therefore, it is quite possible that a given network may have more users than available wavelengths, which will necessitate the reuse of a given set of wavelengths at different points in the network.

15.5.1 Passive Wavelength Routing

In case we have a limited number of available wavelengths, a network can use passive routing of a signal through the network based only on its wavelength. The routing is designed to reuse wavelengths in non-shared links.

For example, we can see in figure 15-12 that user **I** can use wavelength l_1 to establish a link with user **II**, while simultaneously user **V** can reuse the same wavelength, l_1, to establish a connection with user **III**. This functionality is accomplished by the proper arrangement of the cross-connects that route an input signal to a wavelength-determined output.

A simple example of the operation of a passive WDM cross-connect is shown in figure 15-13. The cross-connect is composed of wavelength demultiplexers for the input stage, wavelength multiplexers for the output stage, and fibers interconnecting the two stages. In the example, although there are only two wavelengths, there are four possible non-interfering routing paths based on both wavelength and origin. In general, instead of N wavelengths and N possible connection paths, now there are N wavelengths and N^2 connections.

The same wavelength could be reused by any of the input ports to access a completely different output port and establish an additional connection. This technique increases the capacity of a WDM network.

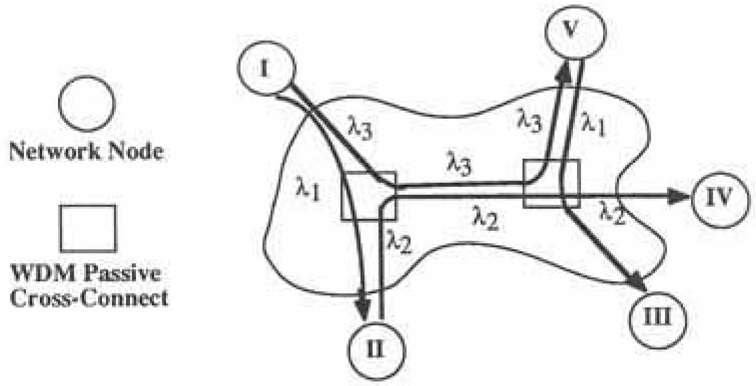


Figure 15-12 : Passive wavelength routing in a network utilizing wavelength reuse.

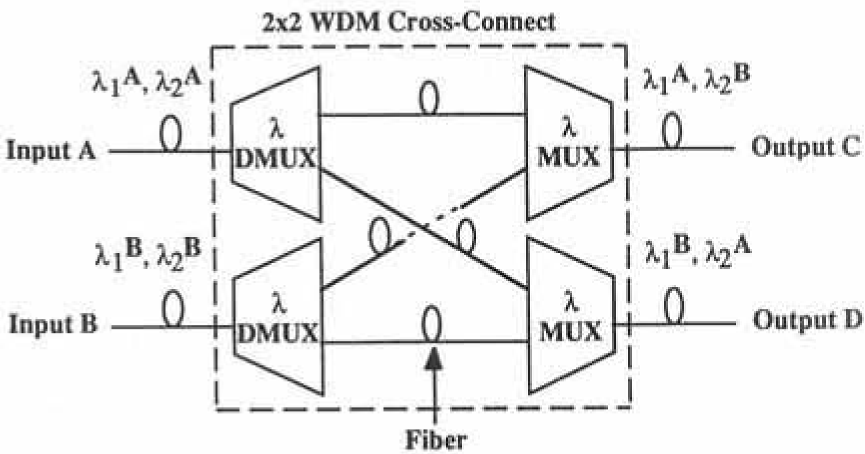


Figure 15-13 A 2-by-2 wavelength cross-connect in which output-port routing is determined both by the specific input wavelength and by the specific input port.

15.5.2 Active Wavelength Shifting

In contrast to passive routing, which is limited to a static network conditions, active wavelength shifting is dynamically deals with changes of the network condition. It does that by changing the routing depending on the available links and wavelengths. This concept of a network requiring active wavelength shifting is illustrated in figure 15-14. In the figure there are two small LANs connected to a larger WAN, and each LAN can transmit on only two available wavelengths ($\mathbf{I_a}$ and $\mathbf{I_b}$). Node **I** wishes to communicate with node **II**. When node **I** wishes to transmit, the only wavelength available is $\mathbf{I_a}$. However, when the signal reaches the right LAN, it is revealed that $\mathbf{I_a}$ is already being used by the right LAN. Therefore, the only way for the signal to reach node **II** is to be actively switched onto the available $\mathbf{I_b}$.

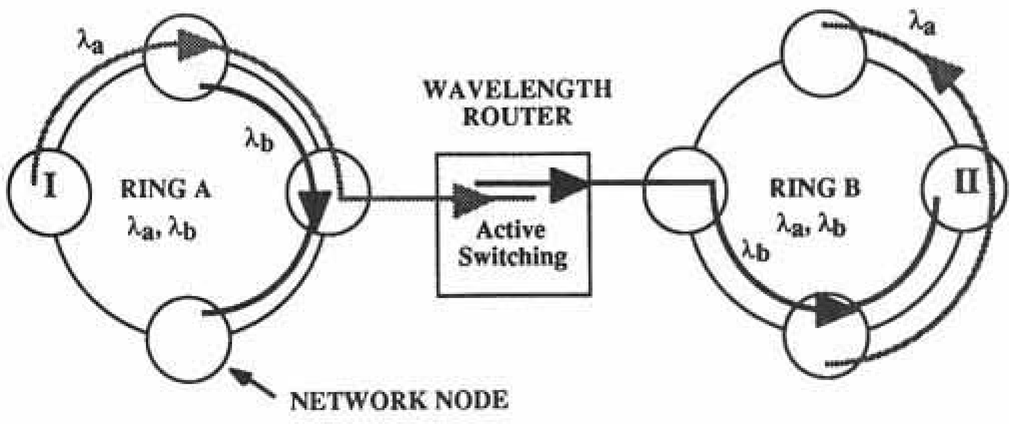


Figure 15-14 Active wavelength switching in a dynamic WAN in which two smaller LANs can transmit on only a limited set of wavelengths.

Another scenario that would require active wavelength switching is where one set of wavelengths are used exclusively by each LAN, whereas another set of wavelength is used exclusively for communication between LANs. The wavelengths that are used in a LAN can be reused by each LAN since it will not interfere with another LAN. This situation is demonstrated in figure 15-15.

Shifting one wavelength to another wavelength complexes the network functionality. One method to perform the active wavelength switching is to employ optoelectronic wavelength shifters. This method necessitates optoelectronic conversions and will cause an eventual optoelectronic speed bottleneck.

In order to overcome this problem the final goal is to achieve all-optical active wavelength shifting to retain a high speed data path. All-optical means that all the shifters are purely optical, i.e. not using optoelectronic conversion of the optical data. There are several methods for all-optical wavelength shifting. Each method has its advantages and disadvantages, and it is not clear if any method will eventually be implemented. There is room for more research in this area.

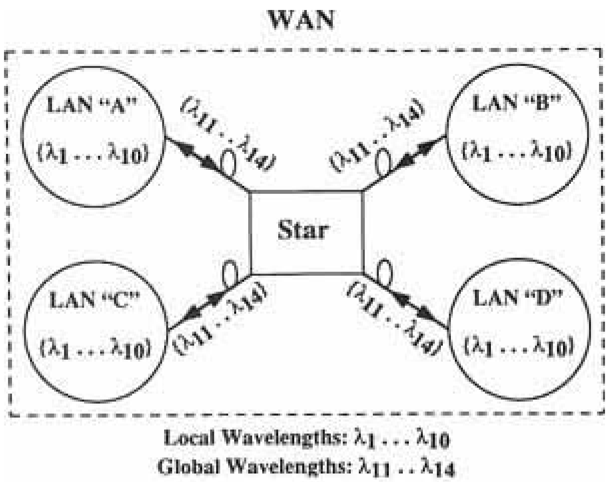


Figure 15-15 : A set of local wavelengths are reused by each LAN, and a set of global wavelengths are used to interconnect the LANs.

15.6 Switching

We know that networks establish communication links based on either circuit or packet switching. For high-speed optical transmission, packet switching holds the promise for more efficient data transfer.

Network packet switching can be accomplished in a straightforward manner by requiring a node to optoelectronically detect and transmit each and every incoming optical data packet.

As for the routing, all the switching functions can occur in the electrical domain prior to optical retransmission of the signal. Unfortunately, this approach suffers from an optoelectronic speed bottleneck.

Alternatively, much research is focused toward maintaining an all-optical data path and performing the switching functions all optically with only some electronic control of the optical components. However, there are many difficulties with optical switching, for instance:

1) A redirection of an optical path is not easy since photons do not have as strong interaction with their environment as electrons do.

2) Switching has to be extremely fast due to the high speed of the incoming signal.

3) Switching nodes cannot easily tap a signal and acquire information about the channel.

15.7 Contention Resolution

Consider a situation in which two or more input ports request a communications path with the same output port, known as output-port contention.

Since we are dealing with a high-speed system, a rapid contention resolution is required, in which one signal is allowed to reach its destination while the other signal is delayed or rerouted in some fashion. In our multiplexing scheme, the issue of contention exists when signals from two different input ports would request routing to the same output port and contain identical wavelengths. Several approaches exist for resolving contention.

One of them is buffering. The packet is retained locally at the switching node and then it is switched to the appropriate output port when that port is available. The local buffering can be implemented either in electrical or optical form. Electronic buffering is straightforward but requires undesirable optoelectronic conversions and may require very large buffers.

On the other hand, optical buffering is difficult because many buffering schemes require updating a priority bit (it is difficult to change a priority bit of an optical data stream), and optical memory is not an advanced art, consisting mostly of using an optical delay line.

15.8 Synchronization

A high-speed network transmitting digital signals must have adequate time synchronization to recover the data stream. Time synchronization is especially required with packet switching, asynchronous packet arrival times, and long-distance transmission.

In a WDM network, it is also possible that wavelength synchronization will be required in addition to time synchronization. In such a scenario, a wavelength standard could be broadcast through the network.

However, the hope is that the network wavelength stability and accuracy will be robust and will not require its own system overhead and complexity.

15.9 Data-Format Conversion

In a large network, it is quite possible that a combination of data formats will be used. This may occur, for instance, if some links may more efficiently use TDM signaling, whereas other links may more effectively use WDM. This explains the need for data-format conversion at network gateways, as illustrated in Figure 15-16.

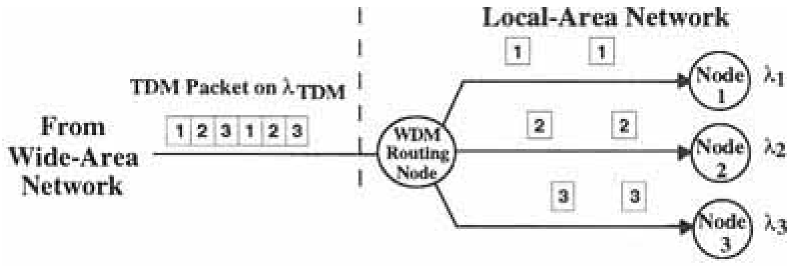


Figure 15-16 Data-Format conversion from one TDM signal to several lower-speed WDM signals at a network gateway.

15.10 Protocols

A standardized network protocol must be used to ensure that data packets are all formatted with recognizable routing information so that the packet can be switched through the network with full global compatibility. There are two standards that show the most promise of full adoption for a global optical network:

1) SONET - Synchronous Optical Network.

2) ATM - Asynchronous Transfer Mode.

These two standards can be combined in one network as follows: Data and header information are bounced into small ATM packets. These packets arrive at a switching node at random times and are grouped together into a large SONET frame (figure 15-17), which makes its way in predetermined synchronous time slots through the network.

The ATM packets are unloaded by the SONET frame when its direction is switched through the network and it can be placed into a different SONET frame. We can think of the ATM packets as people randomly boarding a time-scheduled SONET train.

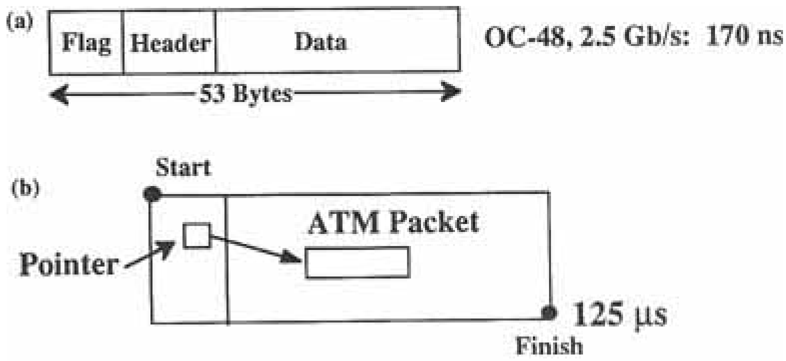


Figure 15-17 (a) An ATM packet and (b) a SONET frame containing many ATM packet and a header field.

15.11 Experimental Results

Experimental results on WDM point-to-point links can be divided into two groups based on whether the transmission distance is ~ 100 km or exceeds 1000 km. Since the 1985 experiment in which ten 2-Gbps channels were transmitted over 68.3 km, both the number of channels and the bit rate of individual channels have increased considerably.

By 1995, a capacity of 340 Gbps was demonstrated by transmitting 17 channels, each operating at 20 Gbps, over 150 km. This record was broken within a year by three experiments that used WDM to realize the total bit rate of 1 Tbps or more. By the end of 1996, a bit rate of 2.64 Tbps was demonstrated in a 132-channel WDM experiment using 0.27nm channel spacing. The following table lists several record-setting WDM transmission experiments performed after 1995.

The second group of WDM experiments worked on a transmission distance of more than 1000 km. A 1994 experiment realized transmission of 40 Gbps over 1420 km by multiplexing sixteen 2.5 Gbps channels while maintaining an amplifier spacing of about 100 km.

It was followed by many experiments that increased either the transmission distance or the bit rate. In one test-bed experiment, a transmission distance of 6000 km at 20 Gbps (8 channels at 2.5 Gbps) has been realized with an amplifier spacing of 75 km.

On the high-bit-rate end, a 1996 experiment multiplexed sixteen 10 Gbps channels to realize transmission at 160 Gbps, but the link length was only 531 km. Using very sophisticated techniques, 160 Gbps transmission over a transoceanic distance of 9100 km has been realized.

The development of WDM fiber links has led to the advent of the fourth generation of lightwave systems, which make use of the WDM technology to increase the bit rate and in-line optical amplifiers to increase the transmission distance.

Channels N	Bit rate B (Gbps)	Capacity NB (Gbps)	Distance L (km)	NBL Product [(Tbps)-km]
10	100	1000	40	40
16	10	160	531	85
32	10	320	640	205
32	5	160	9300	1488
50	20	1000	55	55
55	20	1100	150	165
132	20	2640	120	317

Table 15-1: Record-setting WDM transmission experiments

Four-channel WDM links, each channel operating at 2.5 Gbps, became available commercially in 1995. By 1996, WDM systems with a capacity of 40 Gbps (16 channels at 2.5 Gbps or 4 channels at 10 Gbps) were commercialized.

Recently, the Colt Telecom Group company decided to lay out a new communication network in Europe with a capacity of 1.6 Tbps (160 channels at 10 Gbps each). This network will spread across Europe from London on the west, to Turkey on the east, crossing many major cities like Paris and Amsterdam. The network will be built by the Nortel company and it will be working by the end of 2000. Needless to say that this WDM network will be the fastest network in the world.

16 CWDM

16.1 Introduction

Interest in coarse wavelength-division multiplexing, or CWDM, is running high. On the one hand, there’s huge pent-up demand for a low-cost way of adding capacity to metro networks without having to lay fiber. On the other hand, CWDM has come of age in the past year or so – improving its potential for meeting this demand – not only in metro networks but also for other applications.

There’s little question about this interest in CWDM. Obvious, upcoming, big applications for CWDM are in metro access and in enterprise networks and storage networks. Already, customers are looking at 1-Gbit/s links here, and within a couple of years 10-Gbit/s interfaces will be available on switches and routing infrastructure. And CWDM allows carriers to respond pretty flexibly to diverse customer needs in a region of the metro where fiber is often at a premium.

What’s more, in principle, CWDM can match the basic switching capabilities of dense wavelength-division multiplexing (DWDM), but with the inherent tradeoff of lower capacity for lower cost. So there is no intrinsic reason why CWDM should not be a viable technology in terms of performance and price for the coming generation of reconfigurable optical metro networks based on DWDM wavelength switching.

So does this put CWDM and DWDM head-to-head in parts of the metro? Not necessarily, because the two have different roles to play that depend very much on carrier requirements and circumstances. But it does mean that carriers have to be able to disentangle the alternatives and decide which one of them is the best for their needs.

One of the aims of this section is to look at some of the common cases where CWDM really does have a winning cost advantage over DWDM or plain, brute-force, multiple fiber.

And even CWDM isn’t as simple as it was, as carriers can now choose zero-water-peak fiber to cram in 16 instead of the eight channels that standard singlemode fiber supports. So another range of options opens. And this isn’t just of interest to greenfield sites, as increasing amounts of zero-water-peak fiber are going into the meter.

OFS, for instance, says that over 5 billion fiber meters of its Allwave zero-water-peak fiber have been installed to date, since shipping began in 1998, to more than 40 customers worldwide, covering metro access and cable TV networks.

For all these reasons it's important to understand what's new in CWDM technology, what it can do, and how the economics stack up for those crucial applications.

And, of course, the most important thing of all – how you can use it in practice. This section is a survey and analysis performed by Lightreading.com gives a quick rundown on these topics with the aid of input from some of the leading vendors in the CWDM field.

16.2 Reevaluating CWDM

A lot of carriers are in a big dilemma. The amount of traffic on the Internet and elsewhere is continuing to grow as technologies like DSL and cable modems are deployed in access networks – but metro capacity is still limited in many places, creating a bottleneck that extends well beyond the last mile. So carriers need to boost the capacity of their metro networks if they are to handle this traffic.

But here's the rub: Carriers are also desperate to cut costs to ride out today's harsh financial environment. So they won't add new capacity unless it is highly cost effective. And there's new evidence that a lot of carriers aren't convinced that the established DWDM technology is cost effective.

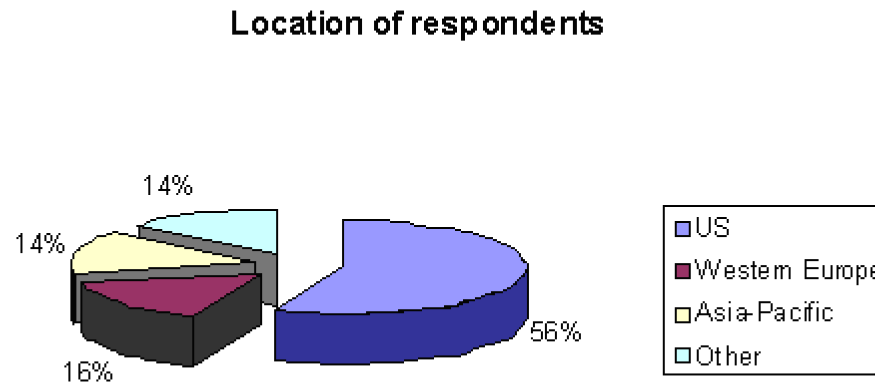
Light Reading.com gathered this evidence in a recent wide-ranging survey of carriers and service providers in October 2002.

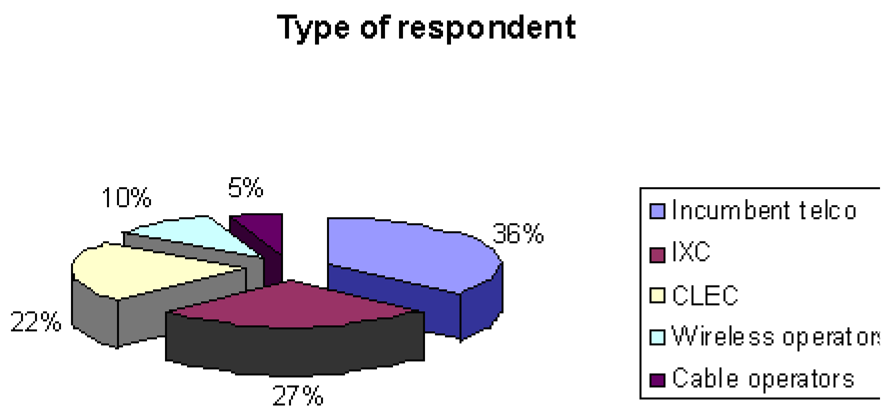
The survey elicited 221 responses, 75 percent of them from carriers and service providers of different types from all over the world.

Right now, the survey found, Wavelength Division Multiplexing (WDM) – dense *or* coarse – isn't widely deployed in metro networks. More than a quarter of respondents said they hadn't deployed it at all, and another 27 percent said that they had installed it in less than 10 percent of their network.

Of course, this could be taken as *good* news: There's a big market out there for a technology that wins wide acceptance by carriers.

Figure 16-1: *Light Reading* metro survey, October 2002





Asked to rate on a simple 1-to-5 scale the issues that were discouraging them from deploying metro WDM, the high cost came out as the leading negative factor. Behind it, and scoring pretty well equally, were:

- Lack of demand for high-bandwidth services
- Availability of other technologies to solve problems
- Immaturity of technology
- Availability of dark fiber

All the same, plenty of respondents said they were planning to deploy metro WDM in the foreseeable future. 28% said they would be doing this in the next six months, and another 21 percent said they would be doing so within a year.

Further *ad hoc* evidence for the growing interest in metro WDM came from the *Light Reading* Webinar on CWDM held in December 2002, when an audience poll showed that 43 percent of respondents expected CWDM to overtake DWDM in the metro.

16.3 CWDM vs DWDM

Both CWDM and DWDM create multiple optical channels on fiber by transmitting different channels on different wavelengths, thereby allowing one fiber to do the work of several that support only a single optical channel each. But the two technologies are aimed at rather different requirements, and this creates some crucial differences.

16.3.1 DWDM

DWDM was really designed for long-haul transmission, where Erbium Doped-Fiber Amplifiers (EDFAs) are needed at intervals to boost the power of the light. EDFAs work over only a fairly narrow range of frequencies, known as the C- and L-bands (between 1530 and 1620 nanometers). So the wavelengths have to be packed tightly together.

In fact, vendors have found ways to pack channels really tightly together, cramming 32, 64, 128, or even more wavelengths into a fiber pair. And the fact that all the wavelengths can be given a boost of power from a single EDFA makes DWDM very cost effective in long-haul networks.

However, packing channels close together has a couple of downsides, especially in the metro world where the network economics are a bit different from those for long-haul networks.

First, you need to have high-precision filters that can peel off a specific wavelength without interfering with the neighboring ones. These are not cheap.

Second, you need lasers capable of keeping each channel exactly on target – and that nearly always means the laser needs to be kept at a constant temperature. In other words, cooling systems are required. High-precision, high-stability lasers are naturally expensive.
The bottom line is: high costs, high power consumption, and a big footprint, compared to CWDM systems.

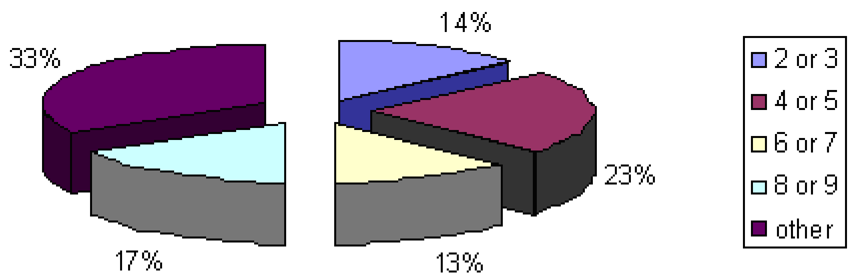
16.3.2 CWDM

The whole point of CWDM is that it’s designed for shorter distances, where EDFAs aren’t required. As a result, it uses a much wider range of frequencies – 1270 to 1610 nm – and it spreads the wavelengths a long way apart.

Initially, channel spacing wasn’t standardized; but now it is, at 20 nm. This allows for wavelengths to drift about a bit, as lasers heat up and cool down. As no cooling is required, CWDM equipment is considerably smaller than DWDM gear. And it’s also a lot less expensive.
CWDM naturally doesn’t stretch very far, since many systems are unamplified, which keeps down costs, and very long spans are not a common metro requirement. Vendors cite distances of 50 to 80 km, although distances of 160 km or more have been achieved using amplifiers.

The main downside is that CWDM doesn’t support a lot of channels. Right now, eight is the usual maximum, although 16-channel systems are becoming available. However, whether carriers currently want larger channel counts is questionable, as the *Light Reading* survey indicated that most of today’s metro WDM systems seem to be running half empty (see figure 16-2). The results were broadly the same for metro and enterprise deployments.

Figure 16- 2: Channels lit by respondents with metro WDM



What seems to be happening is that metro carriers prefer to start with a small handful of wavelengths, while retaining the possibility of later expansion as demand or applications require. So carriers may plump for an initial two to four wavelengths on an access ring to handle the immediate demand for sub-10-Gbit/s access, and then scale up later.

"We have a 16-channel system and it is upgradeable channel by channel from one to 16 channels without needing to break the traffic. Most of our customers deploy two to eight channels as a start, but they do, however, want to have access to upgrade capacity. And some of our customers are targeting this higher capacity from the start.", Says Johan Sandell, VP of R&D at Transmode Systems AB.

A carrier's specific circumstances play a key role here. Some consider that anything above eight wavelengths really belongs to their metro cores, for which DWDM, with its greater eventual capacity, would be the way to go.

Santanu Das, director of metro optical system engineering at OFS, points out that one advantage of higher channels is that if there is a single-fiber ring rather than a fiber pair, both the working and the protection channels can share a single fiber by using double the number of wavelengths. "So particularly CLECs who need fiber can thus reduce fiber costs with higher-wavelength-count systems," he says.

“And facilities-based providers can generate additional revenues from leasing surplus fiber they don’t use with higher-count systems.”

16.4 CWDM Economics

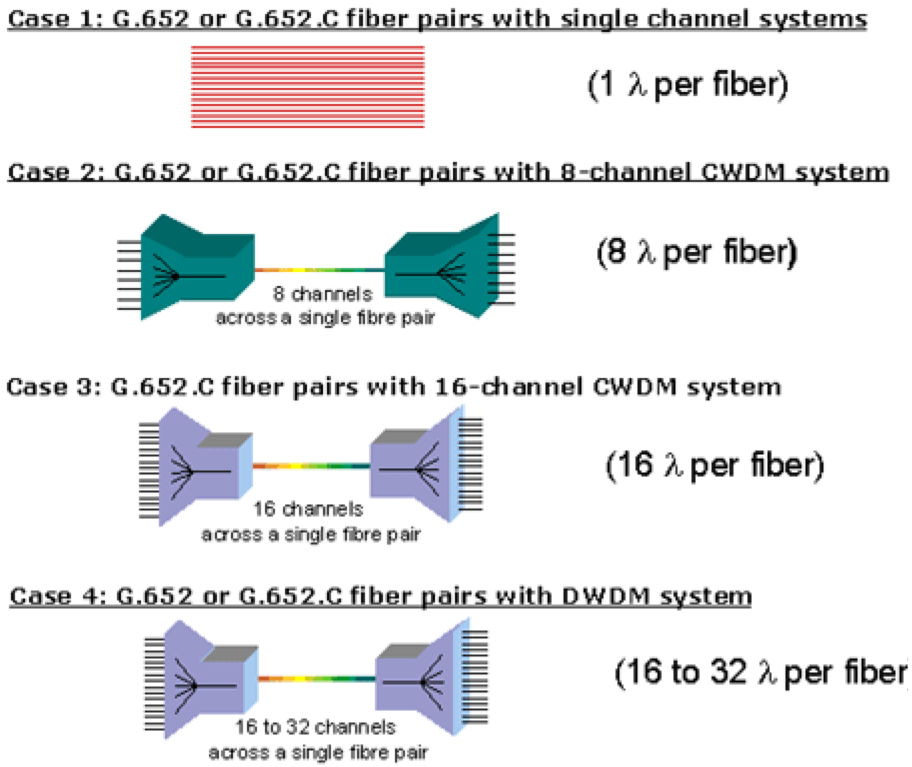
At the end of the day, one of the big, simple arguments for CWDM is cost – it is potentially cheaper than equivalent multi-fiber or DWDM solutions.

But how much cheaper? And under what circumstances?

To throw some light on these issues, here is OFS and Transmode Systems presented results of their joint network modeling of CWDM systems. This looked at four network scenarios.Four CWDM Scenarios

Figure 16-3 (below) compares four popular options for metro access networks, in which unprotected channels are assumed for simplicity. Two fiber types are used: ITU G.652 (conventional singlemode fiber – SMF) and the new G.652.C (low-water-peak fiber). SMF typically has a high water-peak loss in the 1400nm region, restricting the number of CWDM channels that can be transmitted. In contrast, G.652.C enables transmission of 16 or more CWDM channels.

Figure 16-3: Four scenarios for CWDM deployment

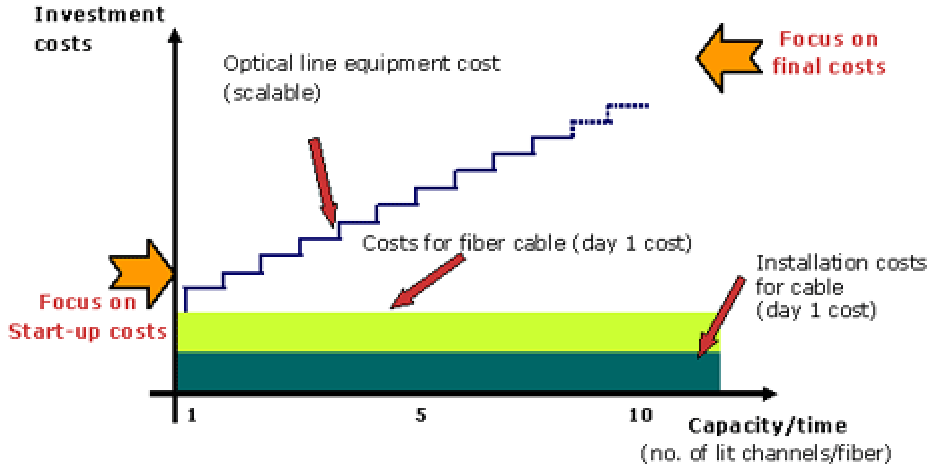


[source: OFS/Transmode Systems}

- **Case 1** shows each fiber type carrying a single wavelength per fiber, so one fiber pair is needed for each bidirectional fiber traffic channel. This is equivalent to adding a Sonet (Synchronous Optical NETwork) and SDH (Synchronous Digital Hierarchy) system on separate fibers.
- **Case 2** shows an eight-channel CWDM system with eight wavelengths per fiber; both fiber types work equally well here.
- **Case 3** extends the number of CWDM channels to 16, going from 1310 to 1610 nm at 20nm spacing; this can be done only over the G.652.C fiber.
- **Case 4** is the well-known DWDM alternative for 16 or more channels using the C- or L-bands, with wavelengths typically spaced at 200GHz for metro applications. Again, both fiber types are suitable here.

Figure 16-4 (below) is not to scale, but it serves to give a conceptual breakdown of the fixed and variable costs in the network.

Figure 16-4: How costs increase as channels are lit (not to scale)



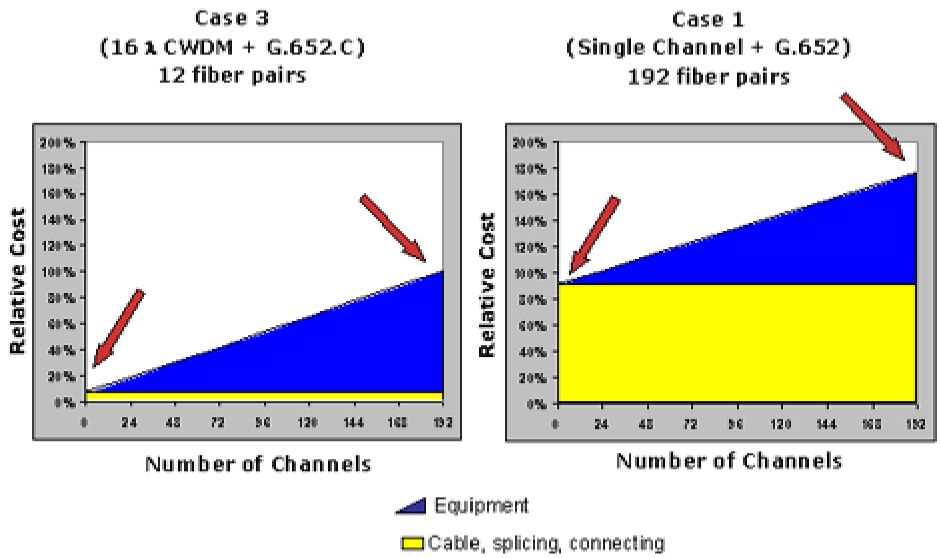
[source: OFS/Transmode Systems]

The fixed portion of the network cost before lighting any of the fibers includes construction or cable installation costs like digging, trenching, etc.; it also includes cost of fiber cable, splicing, and connecting. For simplicity, cable installation is an ignored cost, as it can be quite variable and skew the results.

Optical line costs also have fixed and variable components, but the model amortized fixed costs over equipment modularity.As channels are incrementally lit, the result is a staircase cost function, which is smoothed into a straight line in the subsequent graphs for simplicity's sake.

In figure 16-5, Case 1 (below, right) compares the cost of CWDM over single fiber against that of single-channel Sonet/SDH systems over multiple standard singlemode fibers. The x-axis shows the buildup of the number of channels. At the maximum number of channels (192 in this case) all fiber pairs will be exhausted.

Figure 16-5: CWDM vs. single-channel system (for 50km cable)



[source: OFS/Transmode Systems]

Case 3 (left) assumes G.652.C fiber, and hence can support 16-channel CWDM. The y-axis shows the related cost normalized to the fully built-out CWDM case at 100 percent; no discount has been taken for the cost of capital.

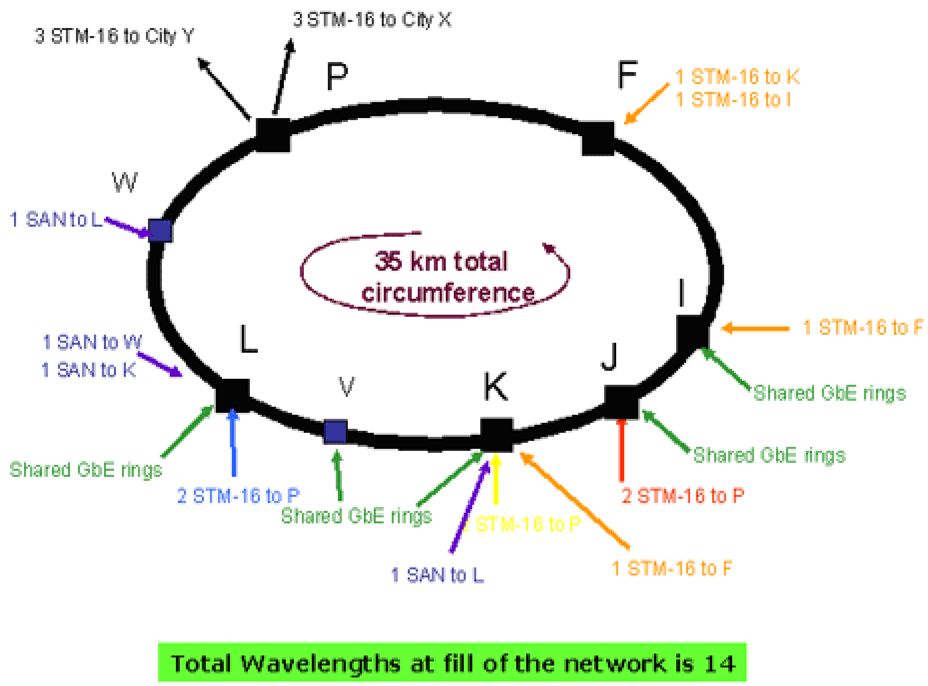
There are several bottom-line conclusions that may be drawn here:

- Because of the higher first cost of fiber cable, the initial investment prior to lighting channels would be approximately 15 to 20 times more expensive for the SMF solution compared to the use of CWDM.
- At a low channel counts (say, 48), the single-channel solution is approximately four times more expensive than the CWDM solution.
- When the cable is fully exhausted, the single-channel solution is still 75 percent more expensive than the CWDM case.
- This suggests that CWDM is a very worthwhile proposition for metro build, since it can significantly drive down the cost of transmission without exhausting fiber plant.

16.5 City Reality

The theory looks attractive, but how does it work in practice? The CWDM analysis continues with a look at a real application in a medium-sized European city with a metro backbone ring running close to its downtown and financial district (see figure 16-6 below).

Figure 16-6: Case study – CWDM vs. DWDM in Tier 1 European city

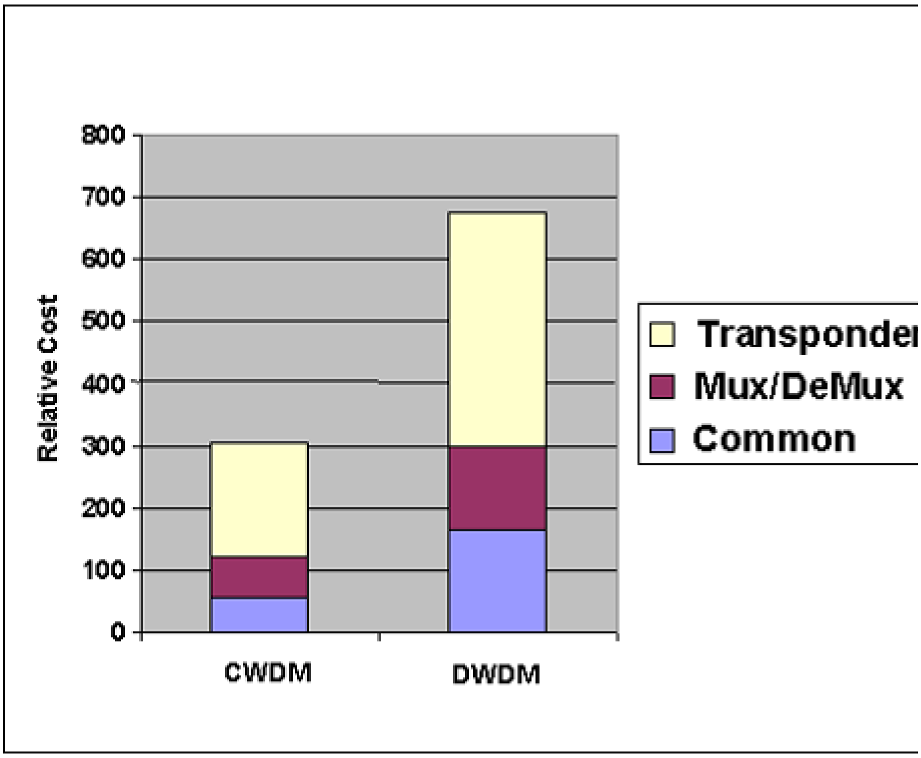


[source: OFS/Transmode Systems]

A typical distribution of services here includes Gigabit Ethernet LANs, SANs, dedicated wavelengths, and SDH. Traffic requirements for the ring are 14 wavelengths. An economic model was developed to compare the cost of DWDM over SMF and that of developing CWDM over G.652.C fibers.

Figure 16-7 (below) gives the results, which are pretty favorable to CWDM, as this solution is about 55 percent lower in capex compared with DWDM.

Figure 16-7: Results of economic modeling of city network



There are several factors contributing to savings from CWDM:

- Transponder cost savings for CWDM are of the order of 50 percent, owing to the use of uncooled lasers and pluggable optics such as GBICs and SFF (see CWDM Building Blocks).
- Similar savings apply to the CWDM mux/demux equipment because of the avoidance of having to have thin-film-filter tolerances, and also from the lower labor costs of assembly, owing to the lower angular sensitivity of the equipment.
- There are additional optics savings from lower power and space requirements.

A further point is that CWDM's cost savings over DWDM could be sustainable. "As volumes pick up, both technologies will decline in cost over time, but the relative cost differences are not likely to diverge," says Santanu Das of OFS.

But don’t forget that all these calculations are for *greenfield* networks – the situation can be very different for a carrier with an existing infrastructure. If such a carrier has enough spare fiber, it would normally use it instead of going straight WDM, since there will be no need to add mux/demux equipment.

If, on the other hand, a carrier *doesn’t* have enough fiber, then the issue of whether to go for CWDM or DWDM can become pretty complicated.And that will depend on a variety of issues, such as number of channels or wavelengths needed, distances (whether you have to amplify or not), and required future scaleability.

Says Cisco’s Thomas Scheibe: “This will all define whether you use CWDM or DWDM. There will be cases where CWDM will be cheaper than DWDM, and there will be cases where you can’t use CWDM.”

16.6 What's New in CWDM

In the last few years, two related developments have considerably enhanced CWDM’s status as a technology: an International Telecommunication Union (ITU) standard and a new type of fiber (also now an ITU standard), with a wider spectral window to support 16-channel systems.

16.7 Full-Spectrum CWDM

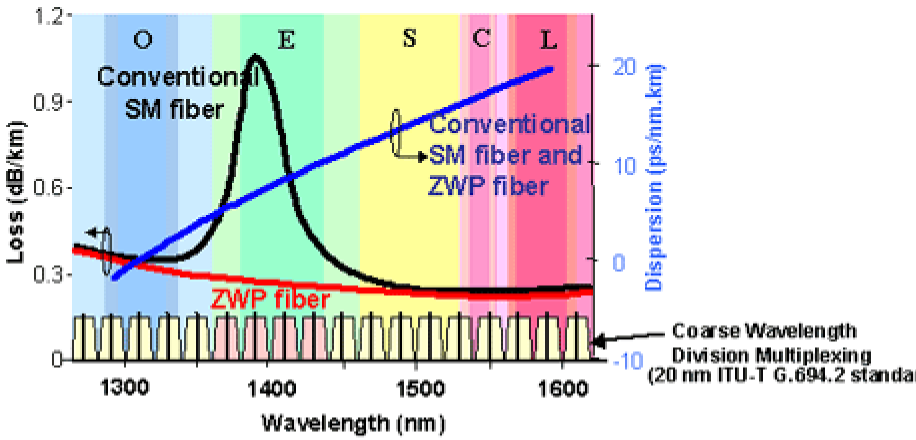
In June 2002, the ITU finalized a standard for what’s been dubbed Full-Spectrum CWDM, a.k.a. Recommendation G.694.2. This defines 18 discrete channels, 20nm apart. A couple of the channels at the edge aren’t of much use because they suffer from something called the Raleigh scattering effect. To make full use of the other 16 channels special low- or zero-water-peak fiber must be used.

16.8 Zero-Water-Peak Fiber

Conventional singlemode fiber suffers from a big attenuation problem in the 1400nm region, where the loss per kilometer increases roughly by a factor of three to four compared to that at 1310 or 1550 nm. This peak, known as the water peak because of its physical origin, effectively puts a big hole in the 1300-1600nm spectrum window used in telecommunications.

Figure 16-8 (below) shows this effect. In black is the loss curve of SMF, which has a high loss around the 1400nm water-peak region owing to the high initial loss from hydroxyl ions in manufacture and hydrogenizing loss that develops over time as the fiber ages.

Figure 16-8: Zero-water-peak fiber vs. singlemode fiber



[source: OFS]

The red curve below the black shows the loss of a zero-water-peak fiber like OFS's Allwave, which completely and permanently eliminates this source of loss, creating some 100nm of extra usable bandwidth. Compared to SMF, four to five extra CWDM channels are reclaimed by zero-water-peak fiber, and this is the reason that CWDM vendors are able to move from 8- to 16-channel systems.

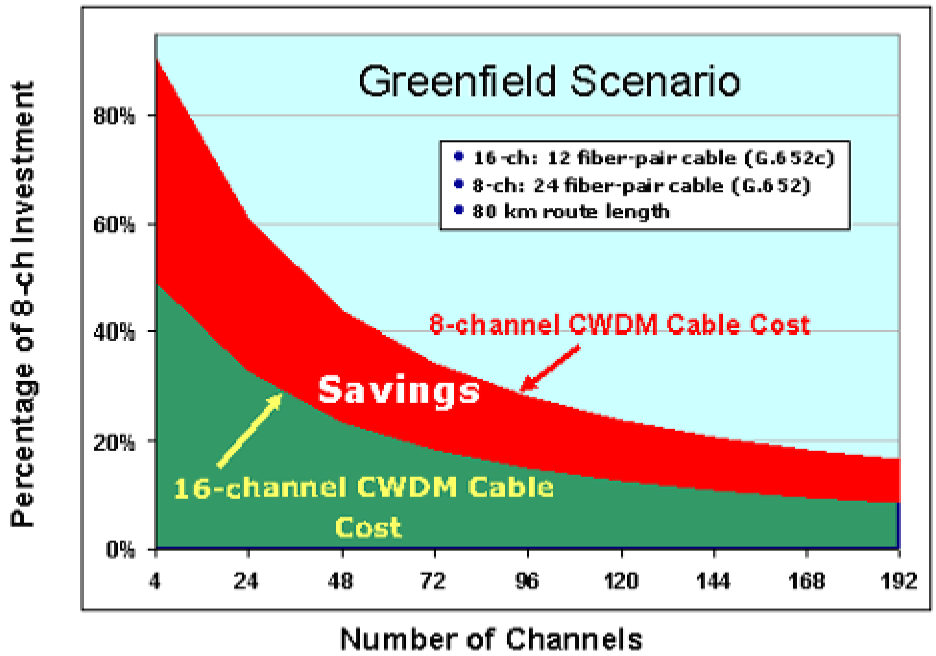
Note the blue curve for fiber dispersion on the right-hand y-axis, which is the same for both singlemode and zero-water-peak fibers in order to maintain backward compatibility with the installed base of equipment. This allows for support of all G.652 applications, such as Sonet/SDH, Ethernet, Broadband, and passive optical networks (PONs).

Zero- and low-water-peak fibers both conform to ITU Recommendation G.652.C, but there can be differences in performance. "The key parameter to watch out for is hydrogenizing loss over time, which is why it is extremely important to have fibers with low concentrations of silica defects," says OFS's Das. He also points out that zero-water-peak fiber has a slightly lower attenuation that SMF in the 1300 and 1550nm regions as well, which can be a further plus for carriers.

16.9 Greenfield Gains From Zero-Water-Peak Fiber

Unsurprisingly, greenfield deployments can show cost/benefits in using a 16-channel system on zero-water-peak fiber as compared to eight channels over SMF. This is shown in figure 16-9 (below), where the capacity or the total number of wavelength channels is fixed, so the zero-water-peak fiber uses only half as many fiber pairs as SMF does. The 16-channel savings result from lower overall fiber cable costs.

Figure 16-9: Cost savings with 16-channel CWDM, compared to 8-channel CWDM (as percentage of investment during buildout)



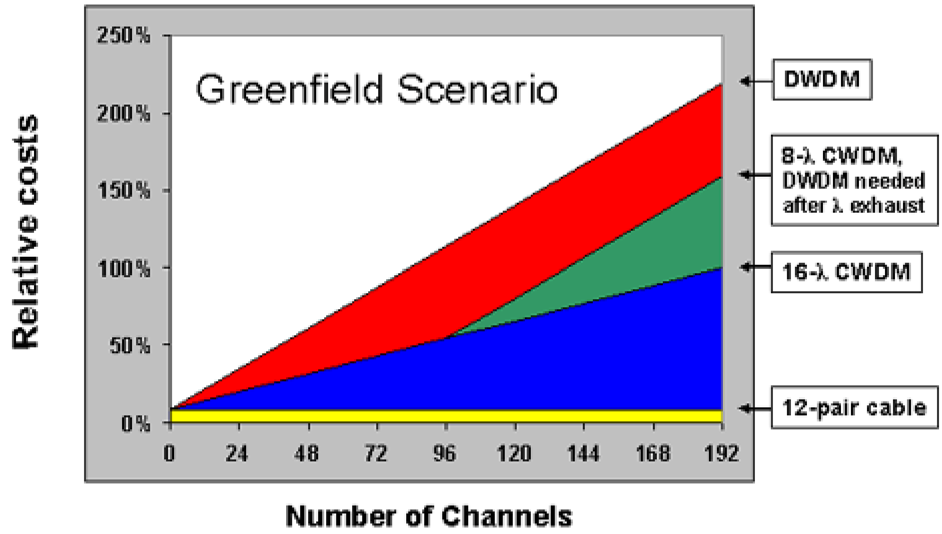
[source: OFS]

This fixed cost is shown in green as a percentage of the 8-channel investment, which includes both electronics and fiber cable. The top of the red trace represents normalized SMF cable costs, with related savings shown by the red band. So when four channels are lit, the SMF cable with 8-channel CWDM represents about 90 percent of the investment cost.

However, OFS's Allwave cable with 16-channel CWDM is only 50 percent of the total cost, implying about a 40 percent savings. When 96 or more channels are lit, the savings approach 10 percent. So, given that there is always a savings to be had of between 10 and 40 percent of the investment costs, it is more economical to deploy zero-water-peak fiber and 16-channel CWDM.

Sixteen-channel CWDM and zero-water-peak fiber can also tackle fiber exhaust, and figure 16-10 (below) explores the economic impact.

Figure 16-10: CWDM vs. DWDM (cases 2, 3, and 4; 80km route)



The cable count is fixed (unlike in figure 16-9, where it was different for the different fiber types) and assumes 12 pairs, with the cost shown in yellow. Electronics can be added, either as CWDM (the trace shown in blue) or DWDM (shown in red). If the fiber were SMF, it would reach exhaust after 96 channels (12x8), so one needs a DWDM upgrade at that point.

This is shown in green, with a similar slope to the red trace. If the cable were zero-water-peak, the cost trend would continue as in the blue trace; the 16-wavelength case at full buildout is the baseline 100 percent investment case.

The savings in using zero-water-peak fiber is quite pronounced, approaching 33 percent compared to a midterm DWDM upgrade on SMF.Of course, customers with older SMF may be forced towards

DWDM or to lighting another fiber after eight channels of CWDM are used up.

16.10 CWDM Building Blocks

Practical deployment of CWDM systems involves both the basic system building blocks, such as transceivers, and appropriate network architectures for typical customer applications. As always, there are some pretty fundamental choices that carriers need to discuss with their suppliers.

CWDM Building Blocks

The basic building blocks of CWDM are:

- **Transceivers**
- **Multiplexer/demultiplexers**
- **Optical add/drop multiplexers**
- **Optical amplifiers**

Transceivers are the modules that convert electrical signals into optical signals. They come in a variety of form factors, the main ones being Gigabit Interface Converter (GBIC) and Small Form Pluggable (SFP). They also support various data rates – typically, 1.25 and 2.5 Gbit/s.

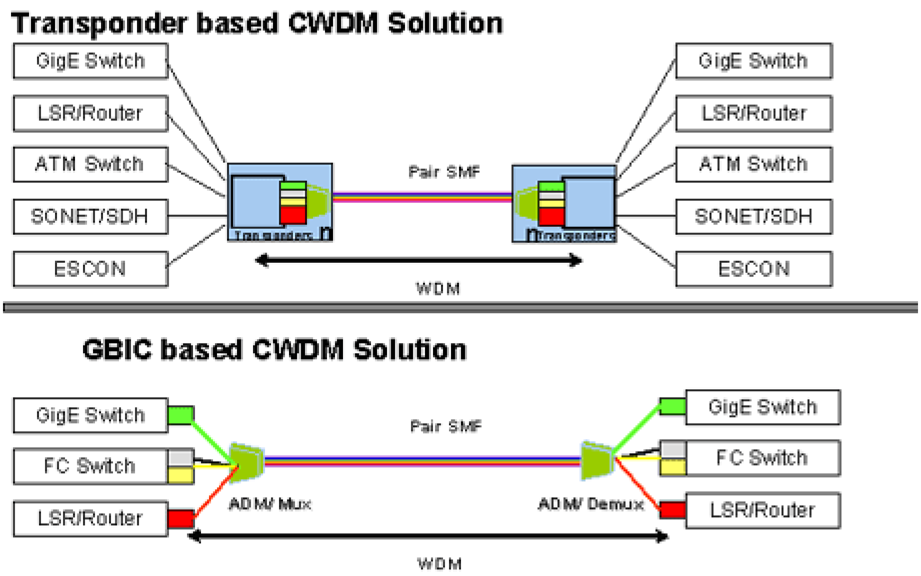
Next there are *mux/demuxes*, which combine different wavelengths into a single beam of light, and vice versa. Then there are *optical add/drop muxes*, which add and drop wavelengths to and from a bundle.

Finally, there are *optical amplifiers* to boost transmission distances. The only technology available for CWDM that has a bandwidth wide enough is provided by semiconductor optical amplifiers (including linear optical amplifiers from companies such as Genoa Corp.). Those available on the market will cover four channels, but multiple amplifiers can be used to cover the entire band. Currently, the longest ranges, of around 160 to 200 km, are still experimental.

Transmode's Sandell points out that customer requirements in the metro area vary quite a bit, so his company has to build a lot of different network topologies. "This puts some requirements on link spans and power budgets,” he says. “So we have developed a modularity in reach, giving 40, 80, or 120 km; and we use amplifiers at the longest distance. It gives us is the possibility of cost optimizing each network.”

There are two main types of CWDM system: transponder-based and GBIC-based (see figure 16-11).

Figure 16-11: CWDM systems options



The transponder-based systems typically connect to a switch or router by using 850 or 1310nm optics. They incorporate a transponder to convert these optics into the wavelengths used in the CWDM system.

One of the big pluses of this approach is that the equipment can connect to virtually any type of equipment: Sonet muxes, Gigabit Ethernet switches, Fiber Channel boxes – you name it, it can connect to it.

So it can handle multiple services such as video, voice, Internet access, LAN-to-LAN, storage... over equipment from many different vendors. Adherents say that this gives a flexible, fully managed transmission system with a very clear demarcation point and the ability to perform signal monitoring.
Transponder-based systems can also funnel different types of traffic into a single wavelength – for instance, shunting one Gigabit Ethernet connection plus a couple of OC12 connections into a single channel. This is known as "muxponding."

The downside, however, is that transponders aren’t cheap.

GBIC-based solutions eliminate the transponder by plugging a GBIC straight into the switch or router. So they’re lower cost. The downside here is that this solution only works with equipment that has a GBIC port – which can limit the gear that can be connected.

On top of that, muxponding isn’t possible, so it’s only one protocol per wavelength. However, Cisco’s Scheibe says that Cisco adopted GBICs because GBIC ports are widely deployed today (perhaps around 10 million of them) and they are shipping at high volumes, giving a good base for using GBICs to leverage WDM.

Further, in the market for metro enterprise solutions, the need the muxpond multiple services to one wavelength is not the primary driver, because customers typically need only three or four channels.

“CWDM GBICs are GBICs like any other GBICs, from a switch perspective. They are completely transparent to the switch or Layer-2/3 configuration, and there’s no separate management necessary for these GBICs. It’s a plug-and-play solution,”

Scheibe says – and a way of extending the service offering beyond simple transport to a Layer-2- or Layer-3-based service. Monitoring of optical link performance is also doable with GBICs, as diagnostics are included.

16.11 CWDM Networks

Putting the Blocks Together to Build Networks

One of the surprising things about CWDM is the diversity of network applications to which the technology can be applied. Figures 12 and 13 show just a couple of examples.

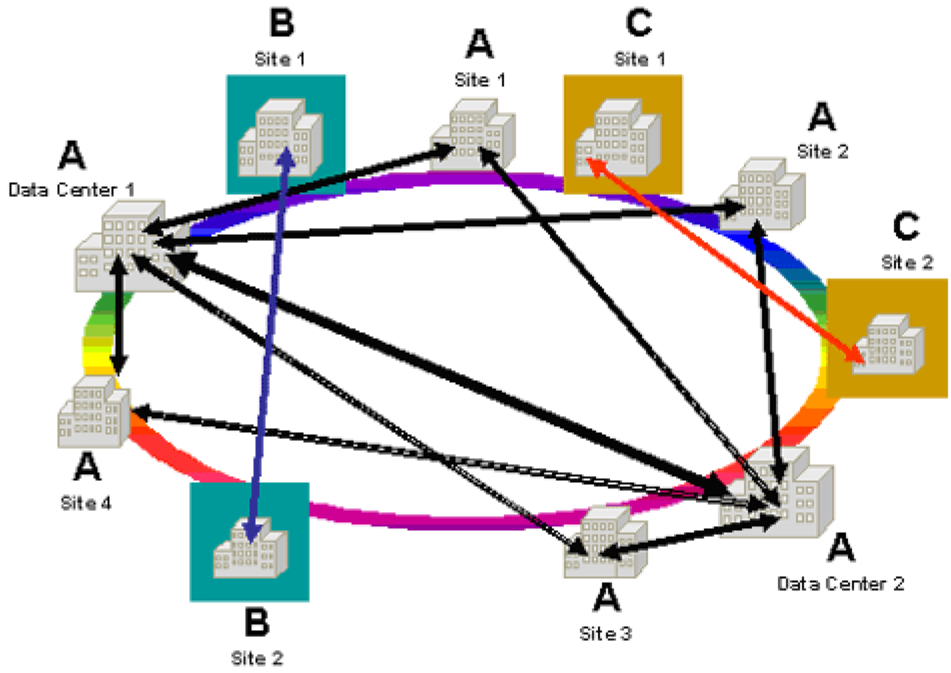
Figure 16-12 (below) shows a real application Cisco designed for a customer, and it shows that you can do pretty complex scenarios with CWDM, because of the flexibility provided by multiple wavelengths.

Three customers, A, B, and C share a single 2-fiber ring on which six out of the eight wavelengths are used. Customers B and C just need 2-Gbit/s point-to-point links between their sites over the Layer 1 optical ring. Customer A’s needs are more exacting, embracing a redundant data center (4-Gbit/s Ethernet link) and dual homing of the four enterprise sites with each data center (1-Gbit/s Ethernet links).

Figure 16-13 (below) shows a scenario from Transmode wherein the customer is running out of fiber and uses CWDM for fiber relief. The customer uses equipment from different vendors for the data storage and the LAN-to-LAN connection.

Says Sandell: “In this case, you see one application where muxponding is economical, and that is where you have a lot of ESCON channels. These channels are rather low speed – 200 Mbit/s – so by multiplexing them you make a more economical solution.”

Figure 16-12: Data-center interconnect using GBIC solution



[source: Cisco Systems]

16.12 DWDM Over CWDM for Further Scalability

There’s an easy answer to concerns over the scalability of CWDM. Just eliminate CWDM wavelengths in the C band and replace them with a whole bunch of DWDM bandwidths. This way, you end up with the best of both worlds – low initial costs and no sacrifice in scalability.

This is not just a nice theoretical idea, as customers have already deployed such systems. Figure 16-14 (below) shows the basic idea. This approach does not really depend on whether you are using GBIC or transponders.

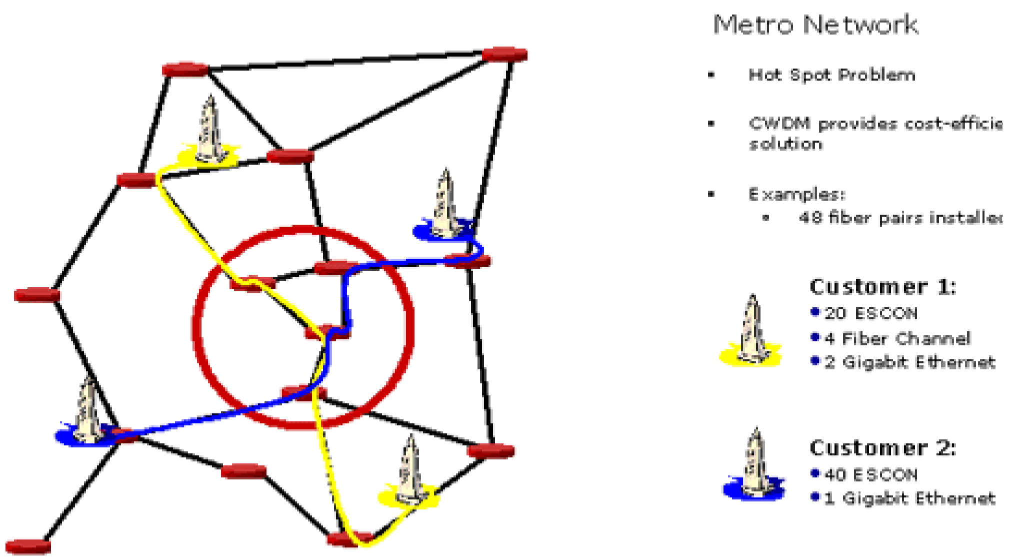
Two wavelengths in the CWDM spectrum are replaced with an overlay DWDM, either by cascading the CWDM and DWDM filters (as shown in the upper left) or by putting them in series on the ring and using a free CWDM channel.

"The nice thing about this one is you can extend you channel count on the same fiber from eight or 16 by adding additional DWDM channels in the middle, with eight DWDM channels per CWDM channel, so you can go up to 24 or 30 channels per fiber," says Scheibe.

The same idea works with 16-channel CWDM, but with a greater range of upgrade options. Says Transmode's Sandell: "We are doing basically the same thing with a 16-channel system and remove one of the CWDM channels, adding, for example, eight DWDM channels, which gives you a very nice upgrade path.

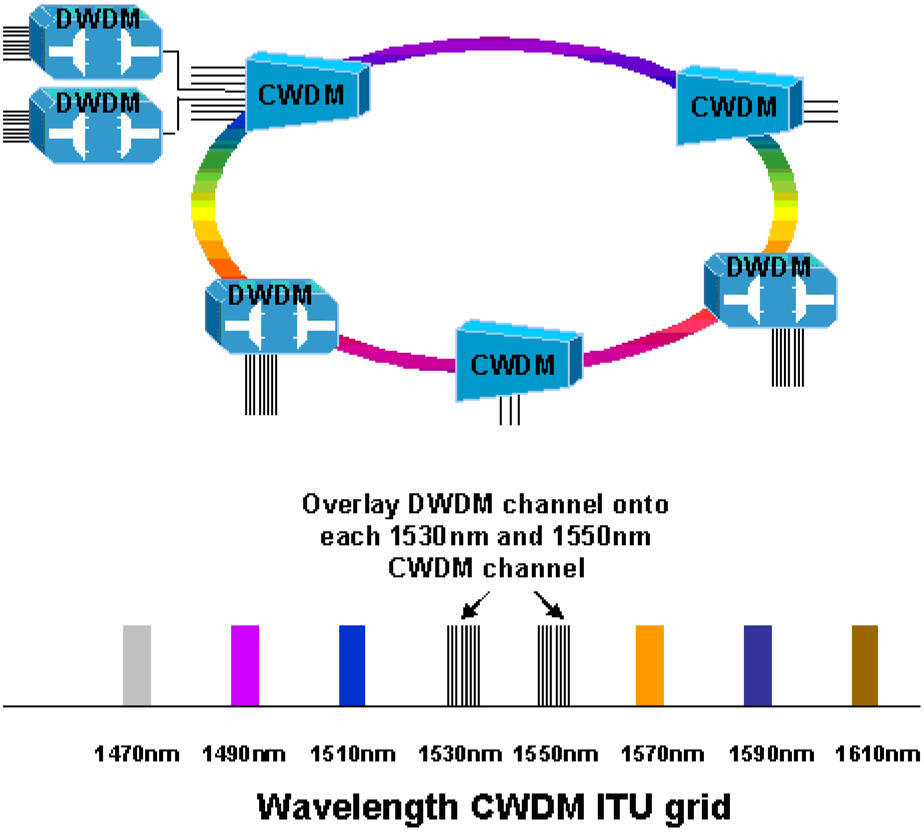
The thing you need to keep in mind is that CWDM components are cheaper than DWDM components, so you must compare [using over-laid DWDM] to adding another CWDM fiber, and see which is sensible costwise."

Figure 16-13: Metro network supporting LAN interconnect and storage networking applications



[source: Transmode]

Figure 16-14: DWDM can be used to scale CWDM systems



[source: Cisco Systems]

16.13 Next Stop: 10 Gbit/s... and the PON

So what’s next? Pushing CWDM systems to handle 10 Gbit/s is likely to be the next big step in the technology, although significant progress will continue in lowering mux/demux losses and in extending spans through amplification.

Vendors are already announcing uncooled lasers for 10 Gbit/s in the 1550nm region, and migration to the 1300nm region will follow. Says OFS’s Das: “I think that is very encouraging, because we have a real potential to reduce the cost, even for 10 Gbit/s, although dispersion and attenuation will be the limiting factors there.”

But, in application terms, the next step may bring CWDM closer to you – literally. CWDM’s cost characteristics make it viable for smaller distribution access networks serving small businesses and larger residential applications, such as Fiber to the Curb – precisely the last-mile area where fiber bandwidth is at a premium.

“In PONs, CWDM gives a very nice way of upgrading,” says Das. Wavelength services could be offered over zero-water-peak fiber on top of the standard ITU PON TDM/TDMA protocol. “One could, say, use six extra wavelengths between 1370 and 1470 nm in order to connect three businesses on top of the 12 residences that are typically connected by a PON.”

17 DWDM (Dense WDM)

17.1 Fundamentals of DWDM Technology

The emergence of DWDM is one of the most recent and important phenomena in the development of fiber optic transmission technology. In the following discussion we briefly trace the stages of fiber optic technology and the place of DWDM in that development.

We then examine the functions and components of a DWDM system, including the enabling technologies, and conclude with a high-level description of the operation of a DWDM system.

17.2 Evolution of Fiber Optic Transmission

The reality of fiber optic transmission had been experimentally proven in the nineteenth century, but the technology began to advance rapidly in the second half of the twentieth century with the invention of the fiberscope, which found applications in industry and medicine, such as in laparoscopic surgery.

After the viability of transmitting light over fiber had been established, the next step in the development of fiber optics was to find a light source that would be sufficiently powerful and narrow.

The light-emitting diode (LED) and the laser diode proved capable of meeting these requirements. Lasers went through several generations in the 1960s, culminating with the semiconductor lasers that are most widely used in fiber optics today.

Light has an information-carrying capacity 10,000 times greater than the highest radio frequencies. Additional advantages of fiber over copper include the ability to carry signals over long distances, low error rates, immunity to electrical interference, security, and light weight.

Aware of these characteristics, researchers in the mid-1960s pro posed that optical fiber might be a suitable transmission medium.

There was an obstacle, however, and that was the loss of signal strength, or *attenuation*, seen in the glass they were working with.

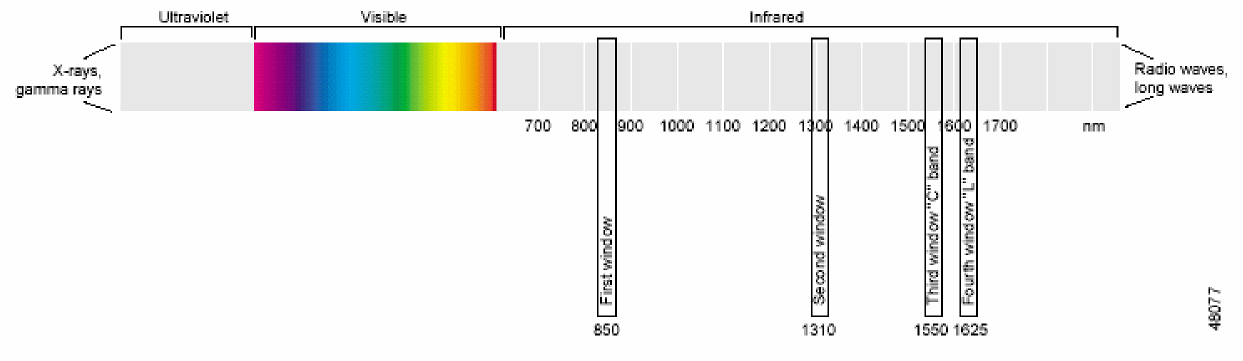
Finally, in 1970, Corning produced the first communication-grade fibers. With attenuation less than 20 decibels per kilometer (dB/km), this purified glass fiber exceeded the threshold for making fiber optics a viable technology.

Innovation at first proceeded slowly, as private and government monopolies that ran the telephone companies were cautious. AT&T first standardized transmission at DS3 speed (45 Mbps) for multimode fibers. Soon thereafter, single-mode fibers were shown to be capable of transmission rates 10 times that of the older type, as well as spans of 32 km (20 mi).

In the early 1980s, MCI, followed by Sprint, adopted single-mode fibers for its long-distance network in the U.S. Further developments in fiber optics are closely tied to the use of the specific regions on the optical spectrum where optical attenuation is low.

These regions, called *windows*, lie between areas of high absorption. The earliest systems were developed to operate around 850 nm, the first window in silica-based optical fiber. A second window (S band), at 1310 nm, soon proved to be superior because of its lower attenuation, followed by a third window (C band) at 1550 nm with an even lower optical loss. Today, a fourth window (L band) near 1625 nm is under development and early deployment. These four windows are shown relative to the electromagnetic spectrum in figure 17-1.

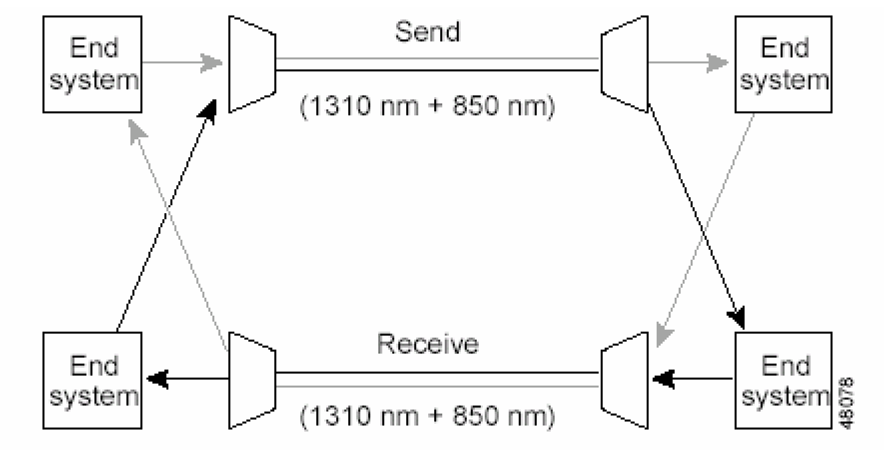
Figure 17-1 Wavelength regions



17.3 Development of DWDM Technology

Early WDM began in the late 1980s using the two widely spaced wavelengths in the 1310 nm and 1550 nm (or 850 nm and 1310 nm) regions, sometimes called *wideband WDM*. Figure 17-2 shows an example of this simple form of WDM. Notice that one of the fiber pair is used to transmit and one is used to receive. This is the most efficient arrangement and the one most found in DWDM systems.

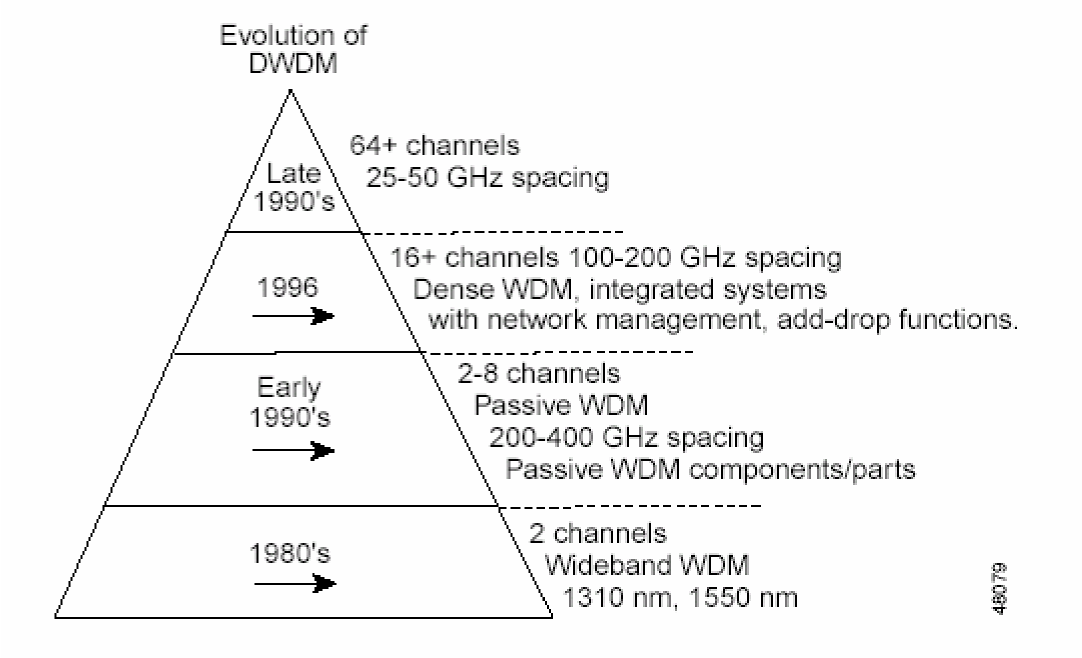
Figure 17-2 WDM with 2 channels



The early 1990s saw a second generation of WDM, sometimes called *narrowband WDM,* in which two to eight channels were used. These channels were now spaced at an interval of about 400 GHz in the 1550-nm window. By the mid-1990s, dense WDM (DWDM) systems were emerging with 16 to 40 channels and spacing from 100 to 200 GHz. By the late 1990s DWDM systems had evolved to the point where they were capable of 64 to 160 parallel channels, densely packed at 50 or even 25 GHz intervals.

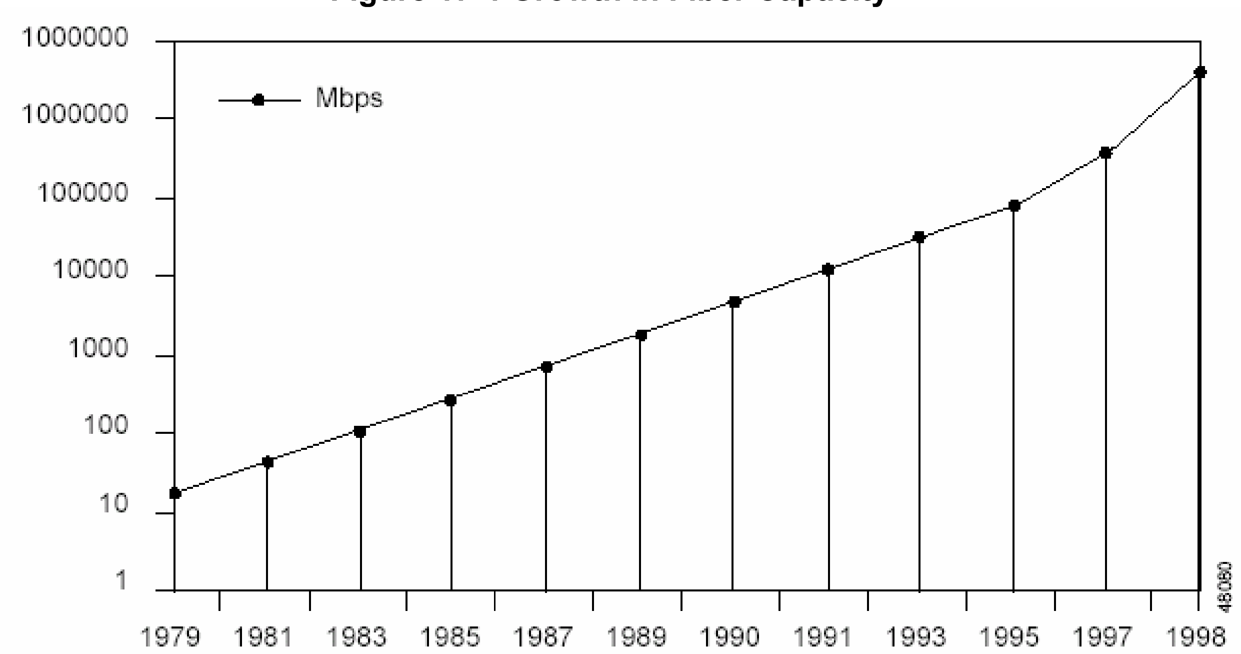
As Figure 17-3 shows, the progression of the technology can be seen as an increase in the number of wavelengths accompanied by a decrease in the spacing of the wavelengths. Along with increased density of wavelengths, systems also advanced in their flexibility of configuration, through add-drop functions, and management capabilities.

Figure 17-3 Evolution of DWDM



Increases in channel density resulting from DWDM technology have had a dramatic impact on the carrying capacity of fiber. In 1995, when the first 10 Gbps systems were demonstrated, the rate of increase in capacity went from a linear multiple of four every four years to four every year (see Figure 17-4).

Figure 17-4 Growth in Fiber Capacity

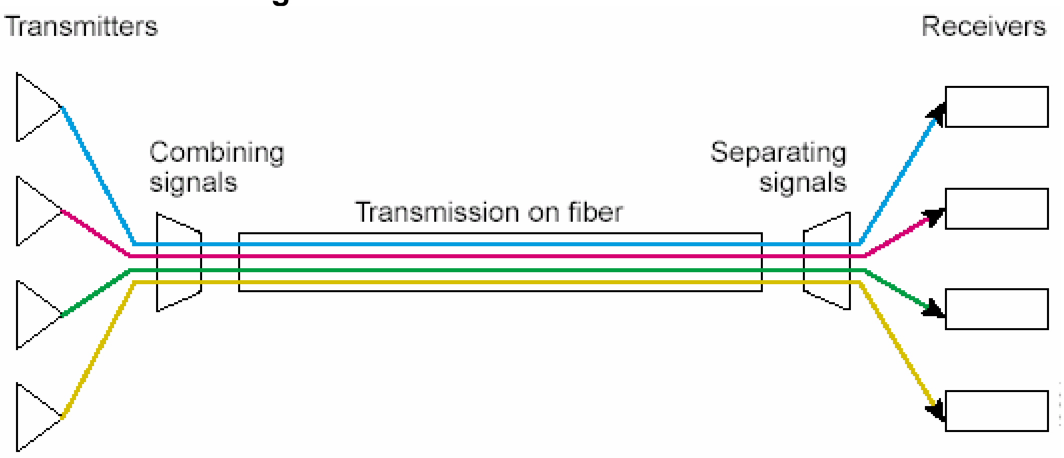


17.4 DWDM System Functions

At its core, DWDM involves a small number of physical-layer functions. These are depicted in figure 17-5, which shows a DWDM schematic for four channels. Each optical channel occupies its own wavelength.

Note: *Wavelength is expressed (usually in nanometers) as an absolute point on the electromagnetic spectrum. The effective light at a given wavelength is confined narrowly around its central wavelength.*

Figure 17-5 DWDM Functional Schematic



The system performs the following main functions:

- Generating the signal—The source, a solid-state laser, must provide stable light within a specific, narrow bandwidth that carries the digital data, modulated as an analog signal.
- Combining the signals—Modern DWDM systems employ multiplexers to combine the signals.
- There is some inherent loss associated with multiplexing and demultiplexing. This loss is dependent upon the number of channels but can be mitigated with optical amplifiers, which boost all the wavelengths at once without electrical conversion.
- Transmitting the signals—The effects of crosstalk and optical signal degradation or loss must be reckoned with in fiber optic transmission. These effects can be minimized by controlling

variables such as channel spacings, wavelength tolerance, and laser power levels. Over a transmission link, the signal may need to be optically amplified.

- Separating the received signals—At the receiving end, the multiplexed signals must be separated out. Although this task would appear to be simply the opposite of combining the signals, it is actually more technically difficult.

- Receiving the signals—The demultiplexed signal is received by a photodetector. In addition to these functions, a DWDM system must also be equipped with client-side interfaces to receive the input signal. This function is performed by transponders (see section on “Interfaces to DWDM”). On the DWDM side are interfaces to the optical fiber that links DWDM systems.

17.5 Enabling Technologies

Optical networking, unlike SONET/SDH, does not rely on electrical data processing. As such, its development is more closely tied to optics than to electronics. In its early form, as described previously, WDM was capable of carrying signals over two widely spaced wavelengths, and for a relatively short distance. To move beyond this initial state, WDM needed both improvements in existing technologies and invention of new technologies.

Improvements in optical filters and narrowband lasers enabled DWDM to combine more than two signal wavelengths on a fiber. The invention of the flat-gain optical amplifier, coupled in line with the transmitting fiber to boost the optical signal, dramatically increased the viability of DWDM systems by greatly extending the transmission distance.

Other technologies that have been important in the development of DWDM include improved optical fiber with lower loss and better optical transmission characteristics, EDFAs, and devices such as fiber Bragg gratings used in optical add/drop multiplexers.

17.6 Components and Operation

DWDM is a core technology in an optical transport network. The essential components of DWDM can be classified by their place in the system as follows:

- On the transmit side, lasers with precise, stable wavelengths and optical wavelength multiplexers
- On the link, optical fiber that exhibits low loss and transmission performance in the relevant wavelength spectra, in addition to flat-gain optical amplifiers to boost the signal on longer spans
- On the receive side, optical demultiplexers using thin film filters or diffractive elements and photodetectors
- Optional optical add/drop multiplexers and optical cross-connect components

These and other components, along with their underlying technologies, are discussed in the following sections. While much of this information, particularly the pros and cons of various competing technologies, may be of more importance to a system designer than to an end user or network designer, it may also be of interest to other readers. Note as well that this is summary information and is not intended to be complete or authoritative.

17.7 Light Sources and Detectors

Light emitters and light detectors are active devices at opposite ends of an optical transmission system. Light sources, or light emitters, are transmit-side devices that convert electrical signals to light pulses.

The process of this conversion, or modulation, can be accomplished by externally modulating a continuous wave of light or by using a device that can generate modulated light directly.

Light detectors perform the opposite function of light emitters. They are receive-side opto-electronic devices that convert light pulses into electrical signals.

17.7.1 Light Emitters—LEDs and Lasers

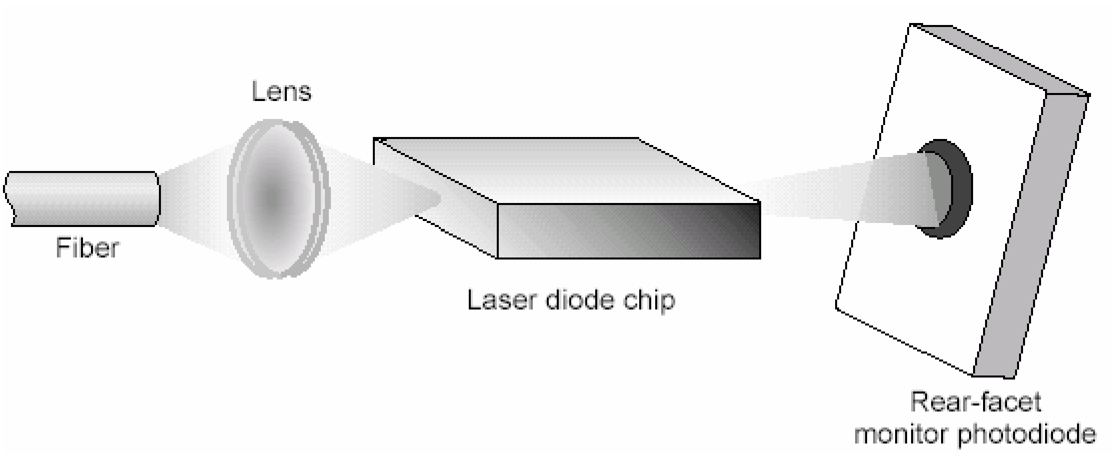
The light source used in the design of a system is an important consideration because it can be one of the most costly elements. Its characteristics are often a strong limiting factor in the final performance of the optical link. Light emitting devices used in optical transmission must be compact, monochromatic, stable, and long-lasting.

Note Monochromatic is a relative term; in practice there are only light sources within a certain range. Stability of a light source is a measure of how constant its intensity and wavelength are.

Two general types of light emitting devices are used in optical transmission, light-emitting diodes (LEDs) and laser diodes, or semiconductor lasers. LEDs are relatively slow devices, suitable for use at speeds of less than 1 Gbps, they exhibit a relatively wide spectrum width, and they transmit light in a relatively wide cone. These inexpensive devices are often used in multimode fiber communications. Semiconductor lasers, on the other hand, have performance characteristics better suited to single-mode fiber applications.

Figure 17-6 shows the general principles of launching laser light into fiber. The laser diode chip emits light in one direction to be focused by the lens onto the fiber and in the other direction onto a photodiode. The photodiode, which is angled to reduce back reflections into the laser cavity, provides a way of monitoring the output of the lasers and providing feedback so that adjustments can be made.

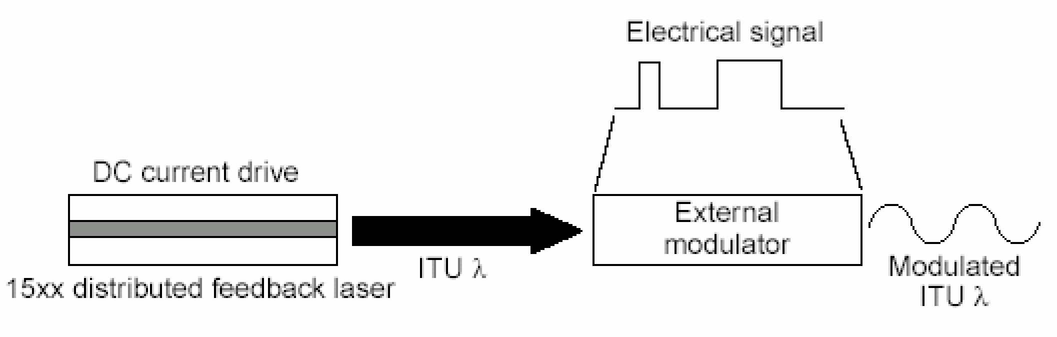
Figure 17-6 Typical Laser Design



Requirements for lasers include precise wavelength, narrow spectrum width, sufficient power, and control of chirp (the change in frequency of a signal over time). Semiconductor lasers satisfy nicely the first three requirements. C*hirp*, however, can be affected by the means used to modulate the signal.

In directly modulated lasers, the modulation of the light to represent the digital data is done internally. With external modulation, the modulation is done by an external device. When semiconductor lasers are directly modulated, chirp can become a limiting factor at high bit rates (above 10 Gbps). External modulation, on the other hand, helps to limit chirp. The external modulation scheme is depicted in figure 17-7.

Figure 17-7 External Modulation of a Laser



Two types of semiconductor lasers are widely used, monolithic Fabry-Perot lasers, and distributed feedback (DFB) lasers. The latter type is particularly well suited for DWDM applications, as it emits a nearly monochromatic light, is capable of high speeds, has a favorable signal-to-noise ratio, and has superior linearity. DFB lasers also have center frequencies in the region around 1310 nm, and from 1520 to 1565 nm. The latter wavelength range is compatible with EDFAs. There are many other types and subtypes of lasers. Narrow spectrum tunable lasers are available, but their tuning range is limited to approximately 100-200 GHz. Under development are wider spectrum tunable lasers, which will be important in dynamically switched optical networks.

ITU Grid

Cooled DFB lasers are available in precisely selected wavelengths. The ITU draft standard G.692 defines a laser grid for point-to-point WDM systems based on 100-GHz wavelength spacings with a center wavelength of 1553.52 nm (see Table 17-1).

Table 17-1 ITU Grid

Frequency (THz[1])	Wavelength (nm[2])	Frequency (THz)	Wavelength (nm)	Frequency (THz)	Wavelength (nm)
196.1	1528.77	164.6	1540.56	193.1	1552.52
196.0	1529.55	194.5	1541.35	193.0	1553.33
195.9	1530.33	194.4	1542.14	192.9	1554.13
195.8	1531.12	194.3	1542.94	195.8	1554.94
195.7	1531.9	194.2	1543.73	192.7	1555.75
195.6	1532.68	194.1	1544.53	192.6	1556.56
195.5	1533.47	194.0	1545.32	195.5	1557.36
195.4	1534.25	193.9	1546.12	192.4	1558.17
195.3	1535.04	193.8	1546.92	192.3	1558.98
195.2	1535.82	193.7	1547.72	192.2	1559.79
195.1	1536.61	193.6	1548.51	192.1	1560.61
195.0	1537.40	193.5	1549.32	192.0	1561.42
194.9	1538.19	192.4	1550.12	191.9	1562.23
194.8	1538.98	193.3	1550.92	191.8	1563.05
194.7	1539.77	193.2	1551.72	191.7	1563.86

While this grid defines a standard, users are free to use the wavelengths in arbitrary ways and to choose from any part of the spectrum. In addition, manufacturers can deviate from the grid by extending the upper and lower bounds or by spacing the wavelengths more closely, typically at 50 GHz, to double the number of channels. The closer the spacing, the more channel crosstalk results.

In addition, the impact of some fiber nonlinearities, such as FWM, increases. Spacing at 50 GHz also limits the maximum data rate per wavelength to 10 Gbps. The implications of the flexibility in implementation are twofold: There is no guarantee of compatibility between two end systems from different vendors, and there exists a design tradeoff in the spacing of wavelengths between number of channels and maximum bit rate.

17.7.2 Light Detectors

On the receive end, it is necessary to recover the signals transmitted at different wavelengths on the fiber. Because photodetectors are by nature wideband devices, the optical signals are demultiplexed before reaching the detector.

Two types of photodetectors are widely deployed, the positive-intrinsic-negative (PIN) photodiode and the avalanche photodiode (APD). PIN photodiodes work on principles similar to, but in the reverse of, LEDs. That is, light is absorbed rather than emitted, and photons are converted to electrons in a 1:1 relationship. APDs are similar devices to PIN photodiodes, but provide gain through an amplification process: One photon acting on the device releases many electrons. PIN photodiodes have many advantages, including low cost and reliability, but APDs have higher received sensitivity and accuracy. However, APDs are more expensive than PIN photodiodes, they can have very high current requirements, and they are temperature sensitive.

17.8 Optical Amplifiers

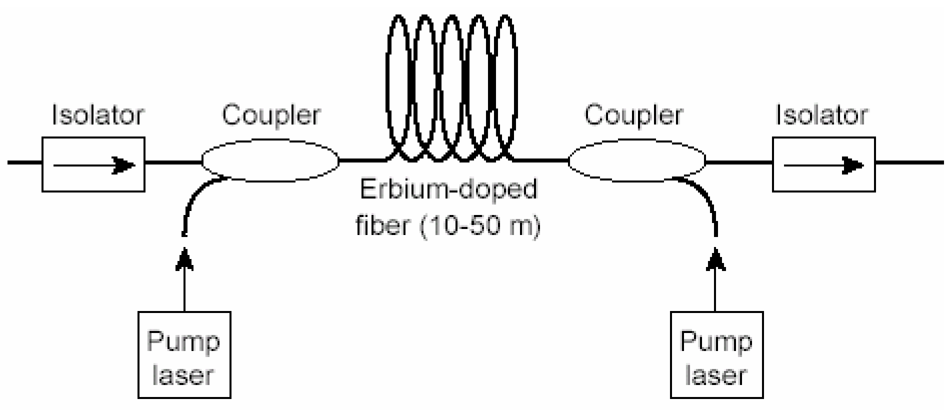
Due to attenuation, there are limits to how long a fiber segment can propagate a signal with integrity before it has to be regenerated. Before the arrival of optical amplifiers (OAs), there had to be a repeater for every signal transmitted. The OA has made it possible to amplify all the wavelengths at once and without optical-electrical-optical (OEO) conversion. Besides being used on optical links, optical amplifiers also can be used to boost signal power after multiplexing or before demultiplexing, both of which can introduce loss into the system.

Erbium-Doped Fiber Amplifier

By making it possible to carry the large loads that DWDM is capable of transmitting over long distances, the EDFA was a key enabling technology. At the same time, it has been a driving force in the development of other network elements and technologies. Erbium is a rare-earth element that, when excited, emits light around 1.54 micrometers—the low-loss wavelength for optical fibers used in DWDM. Figure 17-8 shows a simplified diagram of an EDFA. A
weak signal enters the erbium-doped fiber, into which light at 980 nm or 1480 nm is injected using a pump laser. This injected light stimulates the erbium atoms to release their stored energy as additional 1550-nm light. As this process continues down the fiber, the signal

grows stronger. The spontaneous emissions in the EDFA also add noise to the signal; this determines the noise figure of an EDFA.

Figure 17-8 Erbium-Doped Fiber Amplifier Design



The key performance parameters of optical amplifiers are gain, gain flatness, noise level, and output power. EDFAs are typically capable of gains of 30 dB or more and output power of +17 dB or more. The target parameters when selecting an EDFA, however, are low noise and flat gain. Gain should be flat because all signals must be amplified uniformly. While the signal gain provided with EDFA technology is inherently wavelength-dependent, it can be corrected with gain flattening filters.

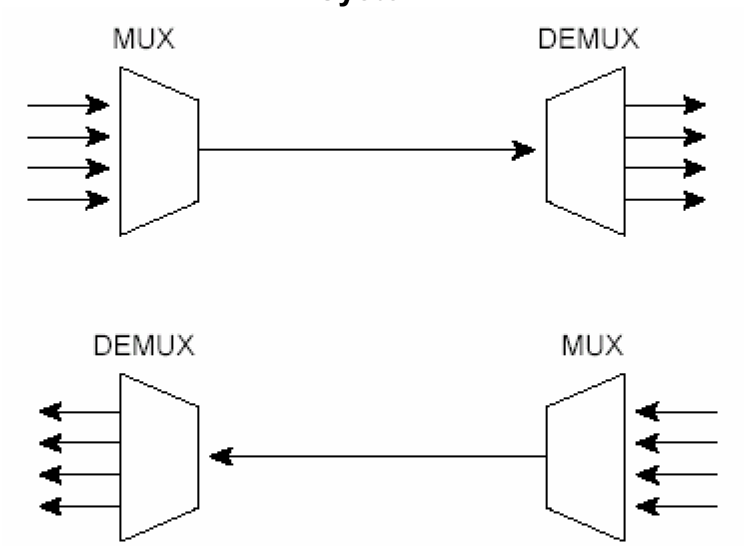
Such filters are often built into modern EDFAs. Low noise is a requirement because noise, along with signal, is amplified. Because this effect is cumulative, and cannot be filtered out, the signal-to-noise ratio is an ultimate limiting factor in the number of amplifiers that can be concatenated and, therefore, the length of a single fiber link. In practice, signals can travel for up to 120 km (74 mi) between amplifiers. At longer distances of 600 to 1000 km (372 to 620 mi) the signal must be regenerated. That is because the optical amplifier merely amplifies the signals and does not perform the 3R functions (reshape, retime, retransmit). EDFAs are available for the C-band and the L-band.

17.9 Multiplexers and Demultiplexers

Because DWDM systems send signals from several sources over a single fiber, they must include some means to combine the incoming signals. This is done with a multiplexer, which takes optical wavelengths from multiple fibers and converges them into one beam. At the receiving end the system must be able to separate out the components of the light so that they can be discreetly detected. Demultiplexers perform this function by separating the received beam into its wavelength components and coupling them to individual fibers. Demultiplexing must be done before the light is detected, because photodetectors are inherently broadband devices that cannot selectively detect a single wavelength.

In a unidirectional system (see figure 17-9), there is a multiplexer at the sending end and a demultiplexer at the receiving end. Two system would be required at each end for bidirectional communication, and two separate fibers would be needed.

Figure 17-9 Multiplexing and Demultiplexing in a Unidirectional System



In a bidirectional system, there is a multiplexer/demultiplexer at each end (see figure 17-10) and communication is over a single fiber, with different wavelengths used for each direction.

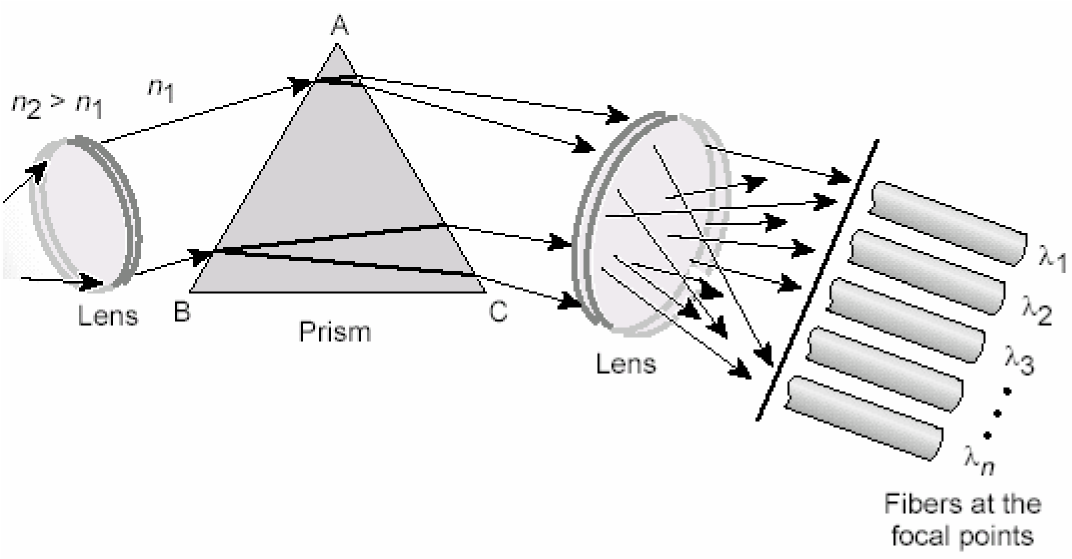
Figure 17-10 Multiplexing and Demultiplexing in a Bidirectional System

Multiplexers and demultiplexers can be either passive or active in design. Passive designs are based on prisms, diffraction gratings, or filters, while active designs combine passive devices with tunable filters. The primary challenges in these devices is to minimize cross-talk and maximize channel separation. Cross-talk is a measure of how well the channels are separated, while channel separation refers to the ability to distinguish each wavelength.

17.10 Techniques for Multiplexing and Demultiplexing

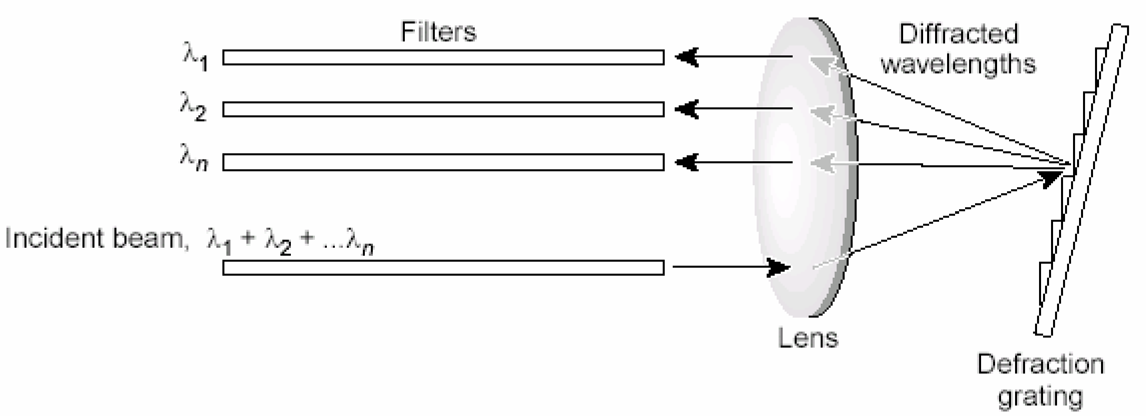
A simple form of multiplexing or demultiplexing of light can be done using a prism. Figure 17-11 demonstrates the demultiplexing case. A parallel beam of polychromatic light impinges on a prism surface; each component wavelength is refracted differently. This is the "rainbow" effect. In the output light, each wavelength is separated from the next by an angle. A lens then focuses each wavelength to the point where it needs to enter a fiber. The same components can be used in reverse to multiplex different wavelengths onto one fiber.

Figure 17-11 Prism Refraction Demultiplexing



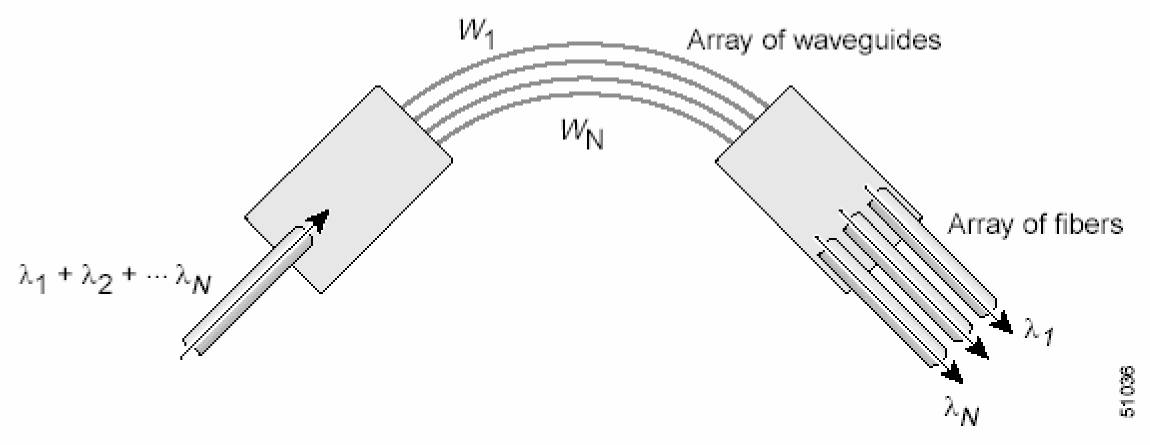
Another technology is based on the principles of diffraction and of optical interference. When a polychromatic light source impinges on a diffraction grating (see figure 17-12), each wavelength is diffracted at a different angle and therefore to a different point in space. Using a lens, these wavelengths can be focused onto individual fibers.

Figure 17-12 Waveguide Grating Diffraction



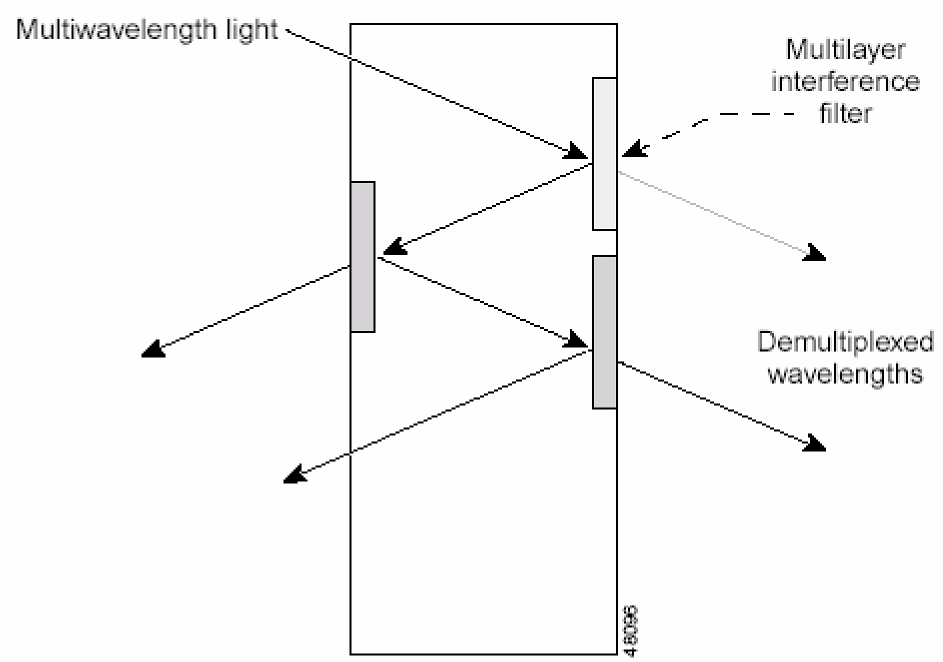
Arrayed waveguide gratings (AWGs) are also based on diffraction principles. An AWG device, sometimes called an optical waveguide router or waveguide grating router, consists of an array of curved-channel waveguides with a fixed difference in the path length between adjacent channels (see figure 17-13). The waveguides are connected to cavities at the input and output. When the light enters the input cavity, it is diffracted and enters the waveguide array. There the optical length difference of each waveguide introduces phase delays in the output cavity, where an array of fibers is coupled. The process results in different wavelengths having maximal interference at different locations, which correspond to the output ports.

Figure 2-13 Arrayed Waveguide Grating



A different technology uses interference filters in devices called *thin film filters* or *multilayerinterference filters*. By positioning filters, consisting of thin films, in the optical path, wavelengths can be sorted out (demultiplexed). The property of each filter is such that it transmits one wavelength while reflecting others. By cascading these devices, many wavelengths can be demultiplexed (see figure 2-14).

Figure 2-14 Multilayer Interference Filters



Of these designs, the AWG and thin film interference filters are gaining prominence. Filters offer good stability and isolation between channels at moderate cost, but with a high insertion loss. AWGs are polarization-dependent (which can be compensated), and they exhibit a flat spectral response and low insertion loss. A potential drawback is that they are temperature sensitive such that they may not be practical in all environments. Their big advantage is that they can be designed to perform multiplexing and demultiplexing operations simultaneously. AWGs are also better for large channel counts, where the use of cascaded thin film filters is impractical.

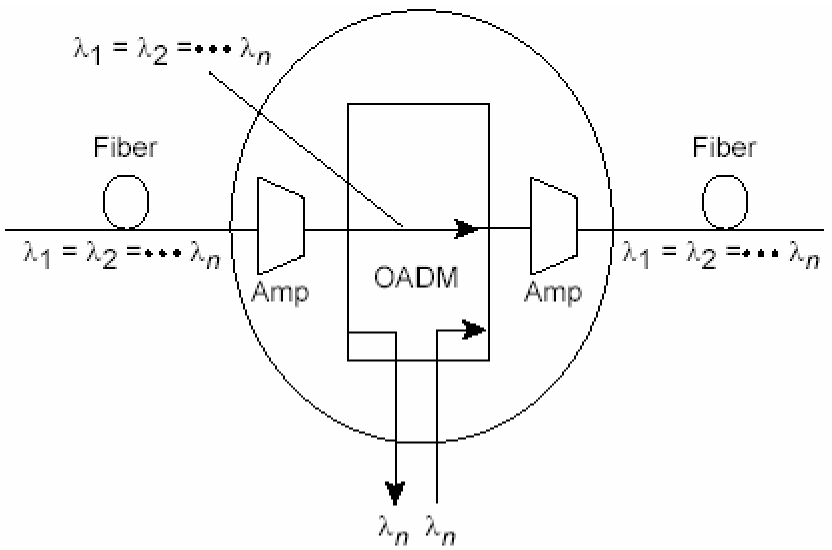
17.11 Optical Add/Drop Multiplexers

Between multiplexing and demultiplexing points in a DWDM system, as shown in figure 17-9, there is an area in which multiple wavelengths exist. It is often desirable to be able to remove or insert one or more wavelengths at some point along this span. An optical add/drop multiplexer (OADM) performs this function. Rather than combining or separating all wavelengths, the OADM can remove some while passing others on.

OADMs are a key part of moving toward the goal of all-optical networks. OADMs are similar in many respects to SONET ADM, except that only optical wavelengths are added and dropped, and no conversion of the signal from optical to electrical takes place.

Figure 17-15 is a schematic representation of the add-drop process. This example includes both pre- and post-amplification; these components that may or may not be present in an OADM, depending upon its design.

Figure 17-15 Selectively Removing and Adding Wavelengths



There are two general types of OADMs. The first generation is a fixed device that is physically configured to drop specific predetermined wavelengths while adding others. The second generation is reconfigurable and capable of dynamically selecting which wavelengths are added and dropped. Thin-film filters have emerged as the technology of choice for OADMs in current metropolitan DWDM systems because of their low cost and stability. For the emerging second generation of OADMs, other technologies, such as tunable fiber gratings and circulators, will come into prominence.

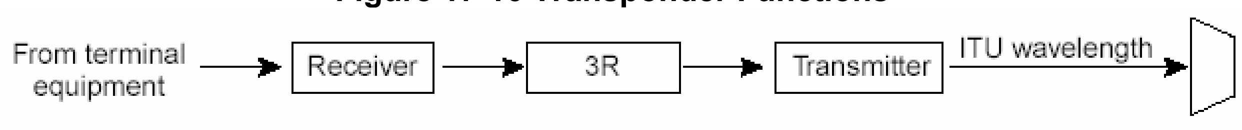
17.12 Interfaces to DWDM

Most DWDM systems support standard SONET/SDH short-reach optical interfaces to which any SONET/SDH compliant client device can attach. In today's long-haul WDM systems, this is most often an OC-48c/STM-16c interface operating at the 1310-nm wavelength. In addition, other interfaces important in metropolitan area and access networks are commonly supported: Ethernet (including Fast Ethernet and Gigabit Ethernet), ESCON, Sysplex Timer and Sysplex Coupling Facility Links, and Fibre Channel.

The new 10 Gigabit Ethernet standard is supported using a very short reach (VSR) OC-192 interface over MM fiber between 10 Gigabit Ethernet and DWDM equipment. On the client side there can be SONET/SDH terminals or ADMs, ATM switches, or routers. By converting incoming optical signals into the precise ITU-standard wavelengths to be multiplexed, *transponders* are currently a key determinant of the openness of DWDM systems.

Within the DWDM system a transponder converts the client optical signal from back to an electrical signal and performs the 3R functions (see figure 17-16). This electrical signal is then used to drive the WDM laser. Each transponder within the system converts its client's signal to a slightly different wavelength. The wavelengths from all of the transponders in the system are then optically multiplexed. In the receive direction of the DWDM system, the reverse process takes place. Individual wavelengths are filtered from the multiplexed fiber and fed to individual transponders, which convert the signal to electrical and drive a standard interface to the client.

Figure 17-16 Transponder Functions

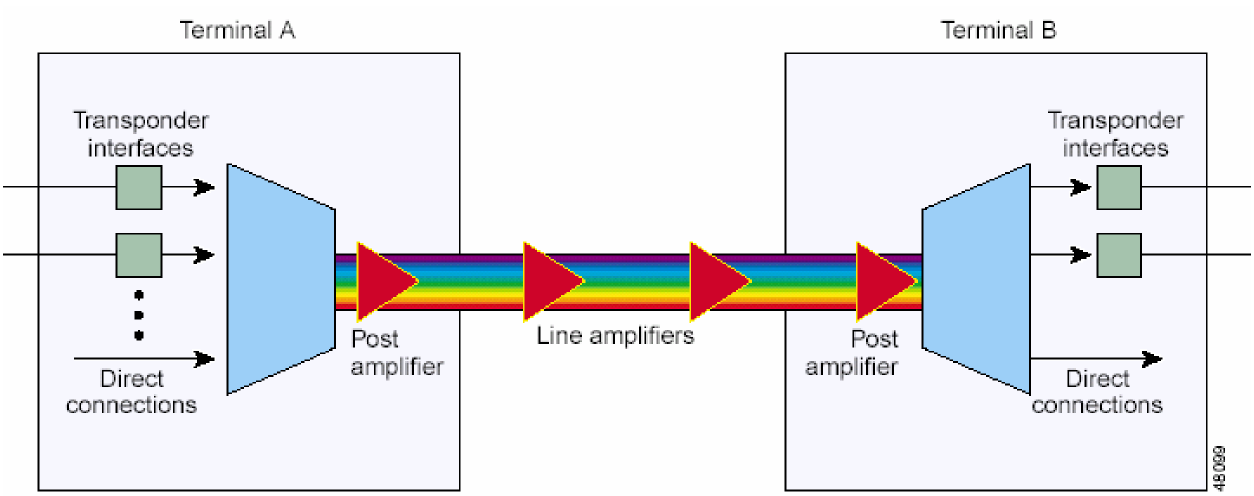


Future designs include passive interfaces, which accept the ITU-compliant light directly from an attached switch or router with an optical interface.

17.13 Operation of a Transponder Based DWDM System

Figure 17-17 shows the end-to-end operation of a unidirectional DWDM system.

Figure 17-17 Anatomy of a DWDM System



The following steps describe the system shown in figure 17-17:

1. The transponder accepts input in the form of standard single-mode or multimode laser. The input can come from different physical media and different protocols and traffic types.
2. The wavelength of each input signal is mapped to a DWDM wavelength.
3. DWDM wavelengths from the transponder are multiplexed into a single optical signal and launched into the fiber. The system might also include the ability to accept direct optical signals to the multiplexer; such signals could come, for example, from a satellite node.
4. A post-amplifier boosts the strength of the optical signal as it leaves the system (optional).
5. Optical amplifiers are used along the fiber span as needed (optional).
6. A pre-amplifier boosts the signal before it enters the end system (optional).

7. The incoming signal is demultiplexed into individual DWDM lambdas (or wavelengths).

8. The individual DWDM lambdas are mapped to the required output type (for example, OC-48 single-mode fiber) and sent out through the transponder.

18 Source List

18.1 Borderlights Network in Sweden

Material for this report have been collected during 6 months of studies in Borderlights Swedish operations 2002 – 2003. This report cover experiences from:

- Metropolitan Area of Uppsala
- Tenders to 120 municipalities for a value of >500 MUSD

18.2 Interviews

Personal have been intervieved from the following companies:

- Ericsson Network Systems
- Transmode
- Future Instruments

18.3 WEB Sites

Material from the following WEB sites have been used in this report:

- www.cisco.com
- www.itpapers.com
- www.lightreading.com
- www.iec.com
- www.InformIT.com
- www.About.com
- www.itworld.com

18.4 Litterature

Material have been used from the following literature:

"Fiber-Optic Communication Systems - Second Edition"
Written by Govind P. Agrawal

"Photonic Networks - Advances in Optical Communications"
Written by Giancarlo Prati (Ed.)

"Optical Fiber Communication Systems" Written by Leonid Kazovsky, Sergio Benedetto & Alan Wilner