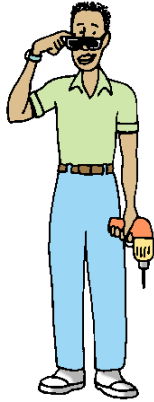


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## Lesson 1: Broadband Technologies

### At a Glance



Analog technology was the base on which telephone transmissions were built. Even today most telephones continue to use analog technology. There is a clear need now and in the future for a wider connection, one that has a greater capacity or bandwidth than the traditional technologies currently in use.

Digital solutions are expected to overcome many of the bandwidth problems associated with analog technologies.

Digital bandwidth is associated with how much information can be sent at one time, which is more accurately referred to as "throughput" or "data capacity." In this case, bandwidth is measured as the throughput in bits per second. The higher the bandwidth, the higher the rate of transmission.

This lesson reviews the concepts behind bandwidth and introduces emerging technologies that offer alternative solutions to the POTS or plain old telephone service for data transmissions.

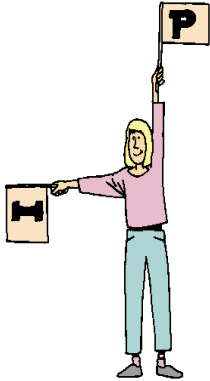
### What You Will Learn

After completing this lesson, you will be able to do the following:

- Identify the network design considerations of POTS, xDSL, ISDN, and Cable, as last-mile solutions
- Identify the network design considerations of T-carriers, SONET, ATM, Frame Relay, SMDS, DWDM, and ISDN, as WAN solutions
- Describe the basics of DWDM as a solution for exhausted SONET lines
- Determine bandwidth requirements and possible solutions as part of a network design

**Student Notes:**

## Tech Talk



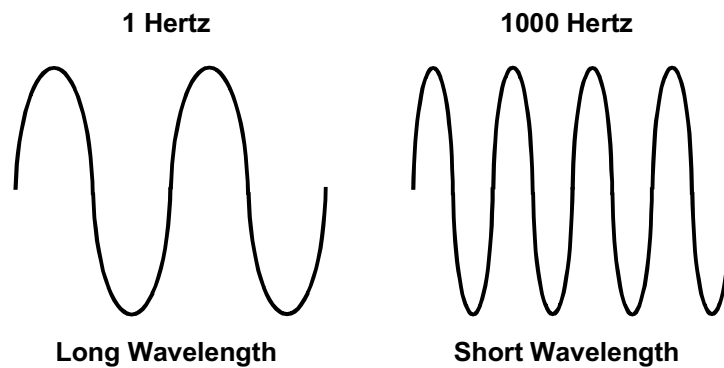
- **Asymmetric Committed Information Rate**—The minimum bandwidth at which a link commits to transfer data across one direction of a Frame Relay link is different than for the other direction.
- **Broadband**—Broadband describes multi-channel capacity of 45 Mbps or greater within the United States and 34 Mbps or greater in Europe.
- **Committed Information Rate (CIR)**—The minimum bandwidth at which a link commits to transfer data across a Frame Relay link.
- **Data Capacity**—How much information can be sent at one time over a transmission media.
- **Digital Subscriber Line Access Multiplexer (DSLAM)**—A special multiplexer used in DSL technology.
- **Line-Switched Ring**—A Synchronous Optical Network (SONET) topology using either two or four fiber lines in a ring formation. In the two-fiber arrangement, one fiber is used for transmitting and the other is used only as a backup. In the four-fiber arrangement, two fibers transmit in one direction and the other fibers transmit in the opposite direction.
- **Multilink PPP**—A modification of PPP that permits the combination of multiple PPP connections, thus increasing available bandwidth.
- **Multiplexer**—A hardware device that selects and funnels different data transmissions, arriving over the same communications line, to the appropriate destination.
- **Narrowband**—Narrowband transmissions occur on a single channel at speeds of  $\leq 64$ Kbps. The term is also used to mean several channels at this speed, as long the total is less than wideband.
- **Path-switched Ring**—A SONET topology using only two fibers, both transmitting signals in the same direction.
- **Point-to-Point Protocol (PPP)**—A data link protocol used for establishing telephone dial-up connections, such as between a computer and the Internet.
- **Throughput**—*See also* Data Capacity. Amount of information that can be sent at one time over a transmission media.
- **Time Division Multiplexing (TDM)**—A method used by SONET to divide time into smaller intervals resulting in more data transmitted per second.
- **Wideband**—Refers to transmissions along multiple channels in the range of 1.544 Mbps to 45 Mbps.

## Bandwidth Review

Prior to the digital age, bandwidth was measured as the difference between the highest and lowest frequencies of a transmission, measured in hertz. This definition still describes analog bandwidth. For example, the frequency range of analog voice transmissions is from 400 to 3,400 Hz, so the voice bandwidth is 3000 Hz. The length of an analog wave is proportional to its hertz measurement. Short wavelengths usually have higher hertz measurement and therefore a higher bandwidth.

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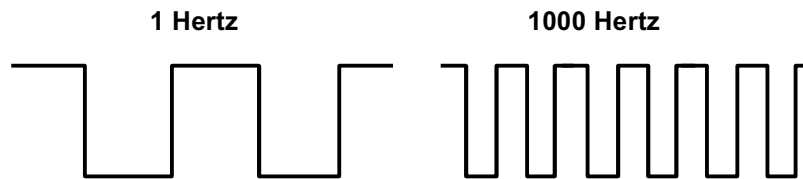
### Analog Bandwidth



Today, the term bandwidth is also associated with how much information can be sent at one time, which is more accurately referred to as "throughput" or "data capacity." Digital bandwidth is measured as the throughput in bits per second (bps). Digital signals are discrete rather than continuous. Either there is a signal or there isn't a signal. Each bit represents whether the signal is present (1) or is not present (0). The greater the bits per second, the greater the amount of information transmitted. Typically, digital transmissions carry a lot of information, so in reality digital bandwidth is usually expressed as bytes per second (Bps) or greater (i.e., kilobytes, megabits, or gigabits).

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### Digital Bandwidth



One can think of bandwidth in terms of a road. A six-lane highway allows many more cars to reach their destination than a one-lane road, over the same time period. The highway has a higher bandwidth than the one-lane road.

### Balancing a Wider Connection

There are three categories of digital bandwidth: narrowband, wideband and broadband.

- **Narrowband**—Narrowband transmissions occur on a single channel at speeds of  $\leq 64$ Kbps. The term is also used to mean several channels at this speed, as long the total is less than wideband.
- **Wideband**—Wideband refers to transmissions along multiple channels in the range of 1.544 Mbps to 45 Mbps.
- **Broadband**—Broadband describes multi-channel capacity of 45 Mbps or greater within the United States and 34 Mbps or greater in Europe.

Many connection services exist today that fall into one of these categories. Each service offers advantages depending on the network requirements of the user. The challenge to providing a wider connection comes in the balance of bandwidth, quality of service, and cost.

**POTS**

Plain Old Telephone Service, or POTS, has been in existence for over 100 years. Nearly every household in developed countries throughout the world has telephone service. With the introduction of the analog modem, narrowband transmissions over pre-existing telephone lines rapidly became the norm for most home Internet users. But even with the best analog modem technology, the transmission rates are abysmal. Typically, a 3.5 MB file takes 14 minutes to download at 33.6 Kbps modem speeds. The same file downloads in 18 seconds at 1.5 Mbps.

The POTS and modem solution may be the only viable solution for many home users. Installation expenses are minimal since existing telephone lines are used and the price of a 56K modem has greatly reduced to below \$100. The average monthly charge for a telephone line is \$25 per month and the separate ISP service charge is approximately \$20 per month. A dedicated line is not necessary, unless the user wishes to make a voice call and still remain connected to the Internet.

This narrowband service simply does not provide enough bandwidth for the dollar for most businesses. A 14-minute download time is simply an inefficient use of employee time. Additionally, it is unrealistic for a business to provide separate telephone lines for each employee.

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**Network Design Considerations for POTS**

Transmission Media	Existing analog telephone copper wire and analog modem. No additional installation of wire.
Bandwidth	Maximum speed is 56 Kbps. Average speed is 33.6 Kbps.
Application Support	Voice and data transmission, but transmissions can not occur simultaneously. Poor performance for video or audio.
Distance Considerations	Long distance fees incurred if no local connection available to the ISP.
Network Function	Last-mile solution for home users, telecommuters, mobile users, and very small businesses requiring connection to the Internet and email services.
Cost	Modem prices <\$100. ISP fees average \$20/month.

## T-Carriers

To improve the speed of analog lines, phone companies began offering dedicated digital lines. The physical lines are the same copper wire that regular analog phone calls use but the data is transmitted as electrical impulses rather than as sound waves. The slowest digital line transmits data at 56 Kbps and has an average monthly charge of \$300.

The most commonly used digital lines are called T-carriers, also referred to as trunk lines. A T-carrier divides the line into many channels. Each channel can carry a single phone call or it can transmit data at 64 Kbps. Since a T1 line contains 24 channels, the total bandwidth is about 1.5 Mbps.

Smaller businesses that do not need a full T1 can lease one or more channels called fractional T1s. In this way, a single T1 line can carry connections for many networks. A T3 can carry 44.736 Mbps and costs several times the price of a T1. Large corporations and Internet service providers (ISPs) might use a T3.

Telephone companies lease T1 and T3 lines as dedicated lines for a very high price tag. The typical T1 installation ranges from \$500 to \$1100, with monthly fees potentially exceeding \$1000 for short distances and potentially over \$20,000 for long distance lines across the United States. Although large corporations may find T-carrier lines a suitable solution, such high fees are prohibitive for small to medium size businesses and home Internet access.

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**Network Design Considerations for T-Carriers**

Transmission Media	Dedicated digital transmission over copper wire. Higher speed lines have multiple channels over same line.
Bandwidth	The slowest is the Switched 56K line. T1 lines offer 1.5 Mbps. T3 offer 44.736 Mbps.
Application Support	Voice, data, video, and audio over a single line.
Distance Considerations	Fees for service increase greatly as the distance between connection points increase.
Network Function	Typically end-to-end connection (LAN switch to Telephone Company) for WANs (56K and T1), but may also connect directly corporate locations. ISP infrastructure (T3).
Cost	Switched 56K average \$300/month. T1 installation ranges from \$500-\$1100, with monthly fees > \$1000/month for local lines and >\$20,000/month for long distance lines.

## ISDN

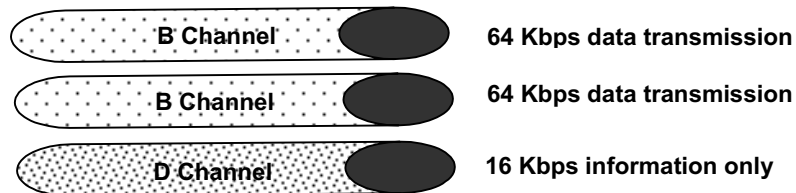
Another attempt by the telephone companies to provide higher speeds is Integrated Service Digital Network, or ISDN. ISDN provides support for simultaneous two-way voice conversations, data, and video connections over a single telephone line. Like a T-carrier, ISDN uses the same twisted pair copper wire used for standard analog telephone lines.

There are several versions of ISDN available. The most popular for those who work at home and small businesses is ISDN Basic Rate Interface (ISDN-BRI).

ISDN-BRI offers two B channels, each transmitting at 64 Kbps for data transmission and one D channel (16 Kbps) that sends information to the telephone company about the data traveling B channels. ISDN lines can be used for regular phone conversations on the two 64 Kbps channels, as well as for data transmission. Using Multilink PPP to combine the B channels, the total transmission rate is 128 Kbps. ISDN channels can be combined and separated when needed, an important advantage over T-carrier.

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### ISDN-BRI Channels



For the home user, the monthly fee averages around \$50 plus additional per minute rates around 1 cent per channel. An ISDN modem is required, which may cost upwards to \$300. Additional installation charges may range around \$100. Although possible, this price tag does not encourage the use of ISDN as a last-mile solution. If a two-channel connection were used for just one hour per day, the per-minute fee would add up to \$36 per month. Add that fee to the regular monthly fee and the total is \$86 per month. In addition to local usage fees, there can be long distance charges. Small businesses and telecommuters that absolutely require a wide connection to their office and the Internet have implemented ISDN, but the price tag is typically too high for most individuals.

A faster form of ISDN called ISDN Primary Rate Interface (PRI) contains 23 64-Kbps B channels and one additional 16 Kbps D channel and can transmit data at up to 1.52 Mbps. This is suitable for larger businesses with more data to transmit. It's no coincidence that T1 lines and ISDN-PRI lines have the same number of channels. ISDN PRI is designed to run over a T1. The pricing structure is more complicated for ISDN-PRI since, on a corporate level, there are many factors that influence the price of the service purchased. Generally, the month to month fees can easily top \$1000.

Both ISDN-BRI and ISDN-PRI are frequently used as backup solutions for ATM and Frame Relay WAN connections. ISDN also provides dial-on-demand and bandwidth-on-demand services.

- **Dial-On-Demand**—This service is used to establish a connection only on an "as-needed" basis.
- **Bandwidth-On-Demand**—This service is used to provide additional bandwidth to an existing connection on an "as-needed" basis. The fees vary depending on the amount of bandwidth consumed over time.

### **B-ISDN**

The newest form of ISDN is Broadband ISDN (B-ISDN) that can handle data rates of 155-622 Mbps. B-ISDN has over 1000 times the bandwidth of regular ISDN, enough to carry cable television, interactive videoconferences, and other high-bandwidth data.

The applications for B-ISDN are still in development. One of the most likely will be the transmission of High Definition Television (HDTV). HDTV is very clear, crisp television. B-ISDN will allow HDTV to be interactive. The viewer will have the ability to program television to be watched when he or she wants to watch it and also the ability to communicate directly with a host on a television program, such as a talk show.

The biggest down side to B-ISDN is the expectation that it will be very expensive. B-ISDN is a cell-switched technology, designed to run over ATM and SONET, which will require expensive telephone network upgrading.

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### Network Design Considerations for ISDN

Transmission Media	Digital line using copper wire. ISDN modem required.
Bandwidth	ISDN-BRI= 64 Kbps over one channel (128 Kbps for two channels); ISDN-PRI= 1.52 Mbps maximum; B-ISDN= 155-622 Mbps over ATM and SONET.
Application Support	Voice, data, video, and audio over the same wire. Video quality is poor over ISDN-BRI. Supports bandwidth-on-demand and dial-on-demand.
Distance Considerations	None.
Network Function	End-to-end connections for business. Last-mile solution for home users and telecommuters. Backup connection solution for large corporations.
Cost	Home user monthly fees average \$50/month plus per minute charges for ISDN-BRI. ISDN modem costs about \$300. ISDN-PRI >\$1000/month. B-ISDN even more expensive.

### Check Your Understanding

- ◆ Classify T1, T3, ISDN-BRI, ISDN-PRI, B-ISDN as narrowband, wideband, or broadband.
- ◆ What connection technologies would you recommend to a small business office for which bandwidth requirements averaged 0.8 Mbps? Explain your recommendations.

### Frame Relay

Frame Relay is a connection-oriented service in packet-switching networks that transmit data between 56Kbps to 44.736 Mbps. Frame Relay supports voice, video and data over the same line.

*Frames* in Frame Relay are packets that contain packets. When a data packet gets to the phone company switch, it is put into a frame that contains information about its destination. At the destination switch, the frame is stripped away and the packet goes on its way. Error checking and

flow control is handled by higher level protocols in the OSI model, thus speeding up the transmission rate for each frame.

Frame Relay provides low quality of service. Quality of service is dependent on maintenance provided by the user. Frame Relay can send large amounts of data in its frames, but this very fact is what can make Frame Relay have a high rate of transmission delay. Think of a frame as a large truck on a crowded highway. It is much harder to merge a truck into the traffic than it is to merge a small car. Significant delays can severely degrade the quality of a voice or video transmission.

Frame Relay uses software-defined paths called Permanent Virtual Circuits (PVC). PVCs are implemented over dedicated connections, frequently using T1, T3, ATM, or SONET.

Frame Relay is sold as a virtual link between points, and the bandwidth for this link is guaranteed to be a minimum size called the Committed Information Rate (CIR). Bandwidth is assigned to the PVC dynamically, which allows the customer to only pay for the amount of bandwidth needed, while still allowing for the occasional burst up to full bandwidth.

It is also possible to establish an asymmetric CIR, which allows the bandwidth in one direction to be different from the other direction over the same PVC. The amount of bandwidth needed to receive a large download far exceeds the bandwidth required to make the request. If a company's traffic consists of receiving large downloads, but otherwise there are only limited bandwidth requirements, then establishing an asymmetric CIR will save money. Since frame relay is charged by bandwidth used, it is considerably less expensive than technologies such as B-ISDN.

Implementation of Frame Relay typically requires Frame Relay Access Devices (FRAD), Frame Relay switches, and high-speed connections (T1, ATM, SONET). A FRAD may be a standalone device or it may be built into a bridge or router. Traditionally, Frame Relay service is priced on a case-by-case basis since there are many variables to consider, such as the CIR. As a general rule of thumb, the installation charges may run from \$700-\$1200 and the monthly fees may easily surpass \$1000.

The price tag on Frame Relay makes it, in general, a viable solution for WAN implementations only.

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### Network Design Considerations for Frame Relay

Transmission Media	Runs over T1, T3, ATM, and SONET. FRADs and FR switches required.
Bandwidth	56 Kbps to 44.736 Mbps depending on media.
Application Support	Voice, video, data, and audio over same line. Quality of service depends on user maintenance.
Distance Considerations	Cost of leased line (T1, etc.) increases with distance.
Network Function	MAN and WAN solution offered by the telephone company for large corporations using short end-to-end leased lines.
Cost	Rates dependent on contracted CIR, but easily > \$1000/month. Monthly leased rates apply to media (T1, etc). Installation costs from \$700-\$1200.

## SMDS

Switched Multimegabit Data Service (SMDS) is a connectionless method defined by IEEE 802.6 for connecting local area networks (LANs) across metropolitan area networks (MANs). This is accomplished by using fixed-length 53-byte cells, across a packet-switched, high-speed network. This cell technology is said to be an ideal manner of transmitting over high bandwidth for short periods of time.

SMDS is a wideband service offered by MCI. It provides rates between 1.544 Mbps and 44.736 Mbps over T1, T3, and SONET rings. Since SMDS is only capable of serving a maximum radius of 30 miles, it is considered less desirable than Asynchronous Transfer Mode (ATM). Additionally, only MCI currently supports SMDS, which means that there are few equipment manufacturers and suppliers to back them up.

Installation of SMDS involves the establishment of a dedicated connection, such as a T1 line, and SMDS capable routers, bridges, or switches. In 1996, the typical MCI monthly fees for a single port on a private line ranged from \$344 (64 Kbps) to \$12,100 (10 Mbps). (Horak, 1997)

The typical application for SMDS is data transmission, but it can also support digitized voice and video.

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### Network Design Considerations for SMDS

Transmission Media	Runs over T1, T3 and SONET.
Bandwidth	1.544 Mbps to 44.736 Mbps depending on media.
Application Support	Typically used for data, but also supports voice, video, and audio over same wire.
Distance Limitations	Maximum radius of 30 miles. Cost of leased line (T1, etc.) increases with distance.
Network Function	End-to-end connectionless service connecting LANs across MANs.
Cost	MCI service. Monthly lease rates apply to media (T1, etc.). Monthly fees depend on contracted bandwidth. For a single port over a private line, 1996 monthly fees ranged from \$344 (64Kbps) to \$12,100 (10 Mbps).

## ATM

One of the newest technologies for data transmission is Asynchronous Transfer Mode (ATM), which is similar to SMDS in that it converts packets into small cells that transmit at high speeds through the network. ATM cells can transmit at speeds of 155 to 622 Mbps.

ATM uses the 53-byte “cell” just as SMDS does. One of the unique aspects of ATM is that it can fill this cell with video or voice or data or almost any other type of electronic data. This fast technology is ideal for multimedia networks since all applications can be run over the same connection sharing the same bandwidth. These short, fixed-length cells also reduce transmission delays.

ATM is a connection-oriented protocol, and thus must establish a confirmed connection before data transmission occurs. This is done by establishing a virtual circuit, called a Virtual Channel (VC), which transports ATM cells between two end points. The VC can be a user to user connection, a user to network connection, or a network to network connection. This saves processing time because the cells all travel the same route that the initial cell travels. Since the virtual circuit is the same for every cell, there is no need for the software to check the path for each cell, nor does it have to ensure that the cells belong on the same channel.

ATM can be run on LANs as well as wide area networks (WANs). ATM is usually run over T3, SONET, or fiber distributed data interface (FDDI) lines. Unlike SMDS, ATM does not have distance limitations. ATM also offers bandwidth on demand capabilities and, as opposed to Frame Relay, ATM has built-in quality of service features.

There are four ATM service categories, each with specific quality of service features that match the performance requirements of the data traffic.

- **Constant Bit Rate (CBR)**—Supports applications where the number of bits passing through a particular point is constant, whether the cells are full or empty. CBR provides a highly predictable transmission rate and performance level.
- **Variable Bit Rate (VBR)**—Supports compressed data such as video or bursts of LAN traffic, which require varying rates of transmission. There are two types of VBR. VBR-RT provides support for real-time applications, such as video conferencing, that do not perform well with transmission delays. VBR-NRT support applications that tolerate transmission delays but require a short response time, such as airline reservations.
- **Available Bit Rate (ABR)**—Supports applications that require a high level of performance but can tolerate some variations in transmission rates and delay. ABR supports periods of bursts of LAN traffic since bandwidth is made available as needed.
- **Unspecified Bit Rate (UBR)**—UBR is also called “best-effort” ATM. It provides support for applications that are not sensitive to delay and do not have high performance requirements, such as FTP. Under UBR, if congestion occurs the UBR cells are the first to be discarded.

A network designer might suggest using any one or a mixture of services to accommodate the performance needs of the client's applications. For example, if the client's applications need constant availability of cells for data transmission, then CBR should be recommended. Voice transmission would fall into this category, since voice is very sensitive to delays in the network.

Because of the greater capacity of its bandwidth, ATM is capable of supporting Broadband-ISDN. ATM was designed to support unified networking for data, voice, and fax over LANs, MANs, and WANs. Although the typical implementation of ATM is as a WAN backbone, it is possible for ATM to run from the desktop. Running ATM from the desktop requires a special ATM NIC, which cost approximately \$600-\$700 each.

ATM is very expensive to implement. It requires thousands of dollars to replace or upgrade equipment. Rates vary on a case-by-case basis due to the many factors that may influence costs. In general, installation costs from \$5000 (T3) to \$8000 (SONET OC3). Access to the line is determined by the amount of distance from end-to-end. A telephone company typically offers ATM service. Some telephone companies charge usage fees, while others charge a flat rate. Average access charge per port on a T1 line is \$3000. That rate increases to \$63,000 for a T3 line. (Horak, 1997)

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### Network Design Considerations for ATM

Transmission Media	Typically runs over T3, SONET, or FDDI lines.
Bandwidth	155 Mbps to 622 Mbps. Four different ATM services prioritize data to meet performance requirements.
Application Support	Voice, data, video and audio are supported over a single line. Application data are categorized and serviced by one of four ATM services. Supports bandwidth-on-demand.
Distance Limitations	Cost of leased line (T3, etc.) increases with distance.
Network Function	Typically used as an end-to-end WAN solution offered by the telephone company. Can be implemented to the desktop over gigabit technology with the installation of ATM NICs in the PCs.
Cost	Rates vary according to the contracted ATM service. Installation charges range from \$5000 (T3) to \$8000 (SONET OC-3). Monthly rates apply to leased lines (T3, etc.) and rates increase as the distance of the line increases. Average monthly per port charge for T1 is \$3000 and for T3 is \$63,000. ATM NICs cost about \$600-\$700.

### Check Your Understanding

- ◆ In what circumstances would ATM be implemented over Frame Relay?
- ◆ Describe the ATM service categories.

## The xDSL Family

The move toward faster access and more efficient connections to the Internet and beyond has recently focused on a tremendous asset that exists in almost every building in this country and much of the world—telephone lines. If there were a way to increase speed over existing telephone wires, there would be no need to re-wire or install new wire in homes or small businesses that needed access to the Internet at speeds greater than those currently available via an analog modem. That method has arrived in the form of Digital Subscriber Line (xDSL) technology. The "x" in xDSL is a placeholder for a specific member of the DSL family.

The primary issue around DSL is its distance limitations. DSL requires that the connection between home, or small business, and telephone office be approximately three miles or less. This is because the DSL signal will travel on the copper wire from home to telephone office, but once there, will not enter the traditional POTS network. Instead, the data will be channeled from telephone office to telephone office using digital T1, T3, ATM, or other technologies.

If the home or small business is close to a telephone office this may not be an issue, but in rural or suburban settings this will certainly be a limitation. Besides a faster connection, one major advantage to DSL is that it is an always on connection. There are no dial tones to wait for or busy signals.

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

HDSL is one of the earliest versions of DSL to be widely used. The HDSL transmission occurs in both directions, symmetrically, at up to 1.54 Mbps. That is, both transmission and receiving happens at this speed. HDSL has been used for several years over T1 lines. HDSL does not support POTS, so voice and data transmissions can not share the same line. The first version of HDSL did not use the standard two wires, rather it used all four wires. The newest version, HDSL-2 uses the standard two wires and can deliver the same bandwidth up to 18,000 feet.

**Asymmetric Digital Subscriber Lines (ADSL)**

ADSL allows the transmission of data across existing telephone wires in a manner that does not interfere with voice communications while providing traffic at higher speeds. An ADSL line can establish a connection that uses more than 100kHz of frequency. Voice conversations generally use from 0-4kHz.

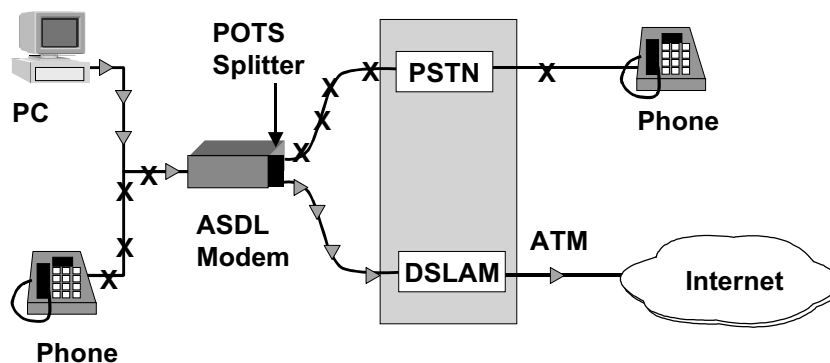
With ADSL, the speed of information coming from the Internet to the end user, downstream, is much faster than the transmissions from the end user to the Internet, upstream. Only a very small part of the available bandwidth is used for uploading, that is, moving data from the desktop to the Internet. ADSL service is available that can transmit data up to a rate of 8 Mbps, while transmitting back at no faster than 1 Mbps. As the speed increases, the distance over which data can travel decreases. For example, at a transmit rate of 6.1 Mbps the distance is reduced to only 9,000 feet. The minimum speed is 1.5 Mbps downstream and 64 Kbps upstream. Again, voice exchanges can continue to occur using the same physical line during these data transmissions.

ADSL works as follows:

1. The desktop computer connects to the phone line via an ASDL modem.
2. The modem has a POTS splitter, which separates signals between voice and data.
3. A second chip separates these two signals into a larger channel for downstream data and a smaller one for upstream.
4. At the Telephone Company's central office, another ADSL modem separates the voice transmissions from the data transmissions on the copper wire.
5. Voice calls are directed to their traditional route, the Public Switched Telephone Network, or PSTN.
6. The data transmission is an always on connection. There are no dial tones to wait for or busy signals. The data from the PC is directed by the Telephone Company's ADSL modem to a special multiplexer, called a Digital Subscriber Line Access Multiplexer (DSLAM). A multiplexer is a hardware device that selects and funnels different data transmissions, arriving over the same communications line, to the appropriate destination.
7. Several DSLAMs link data together and send the data on to its destination using a high-speed ATM line
8. Data received by the PC travels the reverse route.

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## ADSL



There are currently no standards for ADSL. It is expected that the version of ADSL that will become the most common for homes and small businesses is "G.Lite," also called "DSL Lite," "splitterless ADSL," or "universal ADSL."

G.Lite does not "split" the voice line at the user's end but rather waits to split the communication at the telephone office. Without the need for a splitter, the installation charges are reduced. However, there is a trade-off with G.Lite in that the speeds are expected to only approach 1.5 Mbps downstream and 384Kbps upstream.

Since an ADSL modem can be as inexpensive as \$100 and the service uses the existing telephone lines, installation is very inexpensive. Fees for the service depend on the contracted speed, with rates as low as \$50 per month for downstream speeds of 640 Kbps and upstream speeds of 90 Kbps. This rate is very competitive for home use in areas where ADSL is available. For the small business, rates of approximately \$200 per month will buy download speeds of 7.1 Mbps and upload speeds of 680 Kbps.

Although the "always on" feature of ADSL is attractive, there are security issues that should be addressed. With a line "always on", the host is far more vulnerable to outside attacks by unscrupulous individuals. At least for business clients, it is recommended that a firewall be implemented to prevent uninvited snooping about the network.

### **Very high-speed Digital Subscriber Line (VDSL)**

Increases in speed usually result in shorter reliable distances for data to travel. This is the case with VDSL.

VDSL can offer transmission speeds of up to 52 Mbps downstream and upstream rates from 1.6 to 2.3 Mbps. At the higher speed, VDSL can only travel about 1000 feet. Unless the home or office is less than three football field's lengths from the Telephone Company's office, it won't be able to take advantage of VDSL in the near future. However, efforts to bring VDSL to the public are currently focusing on the distance issues, and attempts are being made to provide some type of repeater that will allow VDSL to extend the distance for transmission beyond 300 meters.

Perhaps the most viable use of VDSL in the future will come in combination with fiber installations to the neighborhood (Fiber to the Neighborhood or FTTN). As telephone companies upgrade lines from the central office to the neighborhoods with fiber optic cables, VDSL could be implemented using the existing copper to the home as a last leg solution.

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### Network Design Considerations for xDSL

Transmission Media	Existing POTS for ADSL, G.Lite, and VDSL. T1 lines for HDSL. DSL modem required.
Bandwidth	HDSL = up to 1.54 Mbps downstream and upstream; ADSL = up to 8 Mbps downstream and 1 Mbps upstream; G.Lite = 1.5 Mbps downstream and 384 Kbps upstream. VDSL = 52 Mbps downstream and 1.6-2.3 Mbps upstream.
Application Support	Voice, data, video and audio over same line for ADSL, G.Lite, and VDSL. HDSL does not support POTS. Always On.
Distance Limitations	Bandwidth reduces as distance increases between the end user and the telephone office. Maximum distance for any xDSL service is approximately 3 miles.
Network Function	HDSL already in use for telephone company backbones. Use ADSL and G.Lite (and in the future VDSL) for last-mile solutions for homes and businesses. Some security risks.
Cost	ADSL modem = \$100. Monthly fees vary with contracted bandwidth. For 640 Kbps downstream and 90 Kbps upstream, monthly fees range around \$50. Monthly business rates for 7.1 Mbps download range around \$200. Installation for G.Lite is less expensive.

## SONET and SDH

Synchronous Optical Network (SONET) and Synchronous Digital Hierarchy (SDH) are merely different names for the same thing. Many telephone companies now use optical fiber for their trunk lines instead of copper wire. SONET and SDH are the standards for synchronous data transmission over the optical fiber trunk lines. The standards define the physical infrastructure of an optical fiber network that can transmit data at over 1Gbps. Typically, the transmission speed of a single fiber pair is 2.5 Gbps. SONET is the U.S. version and SDH is the international equivalent. The fact that they are the same allows easy intercommunication between networks within the United States and networks outside of the U.S.

This standard optical transmission method is becoming the physical backbone for most ATM networks. SONET allows for international links without any requirement that transmissions be translated from one protocol to another. These transmissions occur at speeds  $\geq 51.84$  Mbps, and the upper limit of these transmission speeds is currently not known. In 1997 there were implementations that achieved 9.95 Gigabits per second, and it may soon be possible to reach transmissions rates as high as 13 Gbps.

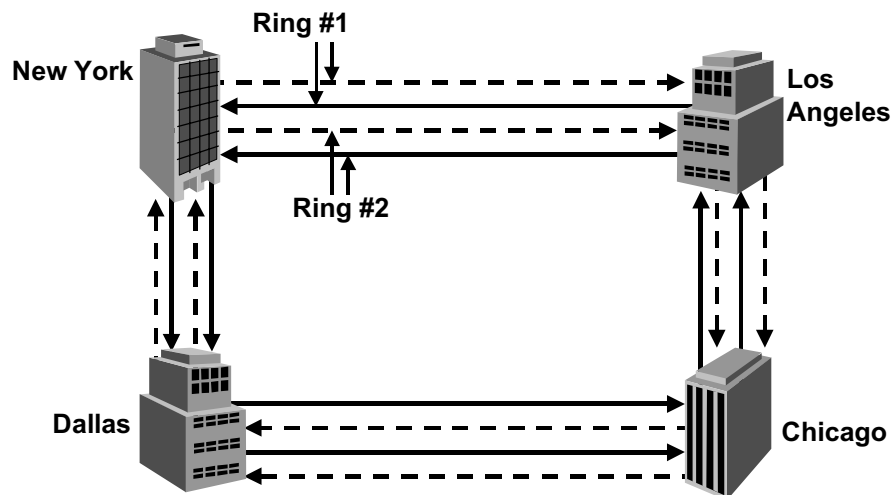
SONET increases the capacity of a fiber using time division multiplexing (TDM). TDM divides time into smaller intervals that allows more data to be transmitted per second. Speeds in SONET are classified by codes. The lowest speed, 51.84 Mbps, is known as OC-1; other speeds are multiples of this speed. Thus, OC-3 is 155.52 Mbps (OC-1 times 3), which is the transmission rate for B-ISDN.

The typical SONET topology is a counter-rotating ring using two fibers, one transmitting counter clockwise and the other transmitting clockwise. There are two primary physical arrangements for SONET ring topology, path-switched rings and line-switched rings.

- **Path-switched Rings**—Both fibers in a path-switched ring carry transmissions in the same direction. This arrangement provides protection against network failure since both fibers may function as back-ups to the other. Since the receiving end examines both incoming transmissions, it can choose the clear transmission, which improves performance.
- **Line-switched Rings**—This arrangement may use either two or four fibers. In a two-fiber arrangement, only one fiber is used for transmissions. The other fiber is reserved as a backup and only activated when there is a network failure. In a four-fiber arrangement, there are two rings. Within each ring, one fiber transmits clockwise and the other counter clockwise. The second fiber in each ring acts as a backup in a network failure by also supporting transmissions in the reverse direction.

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### SONET Line Switched Ring Topology



Currently, SONET is used for the backbone for many telephone networks. With the high speeds and high level of redundancy, SONET will be a major player in the efforts to unify network applications, such as data, voice, and fax. Implementation of SONET does not come without a high price tag. Coast-to-coast SONET circuits operating at OC-3 can run over \$400,000 per month. (Horak, 1997) Although there are experimental efforts underway around the world to bring fiber to the home (FTTH) using SONET technologies, the price must reduce drastically before FTTH can become a viable reality.

**Network Design Considerations for SONET**

Transmission Media	Optical fiber. Classified by bandwidth starting at OC-1 for 51.84 Mbps.
Bandwidth	Ranges from 51.84 Gbps(OC-1) to 9.95 Gbps (OC-192).
Application Support	Voice, data, video, and audio over the same line.
Distance Limitations	Fees increase as distance increases.
Network Function	Typically the telephone company's backbone. Use for WAN solutions over leased lines for large corporations.
Cost	Very expensive. Monthly fees for OC-3 coast-to-coast > \$400,000.

**Check Your Understanding**

- ◆ Complete the chart below.

Technology	Bandwidth Offered
POTS	
Frame Relay	
ATM	
ADSL	
SONET OC-3	
T1	
ISDN-BRI	

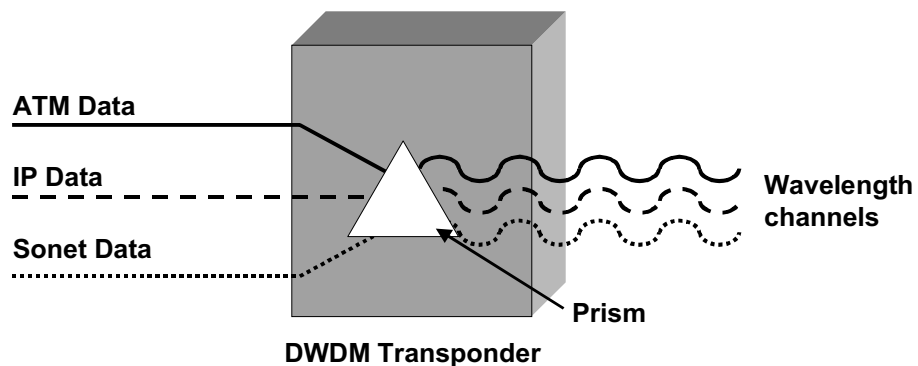
## DWDM

SONET transmission speeds are typically 2.5 Gbps over a fiber pair, with a maximum bandwidth total of 10 Gbps. Even with the wide connections that SONET provides, telephone companies are beginning to experience capacity issues within their backbones. One solution is to lay more fiber, but this is a very expensive solution. Another solution is to increase the bit rate using Time Division Multiplexing (TDM). This can only be done in chunks of bandwidth, which potentially wastes bandwidth if the Telephone Company does not need the full bandwidth now available.

Dense Wavelength Division Multiplexing is a new technology that increases the capacity of optical fiber by combining many optical signals and transmitting them as a group over multiple wavelengths on a single optical fiber.

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## DWDM



Using DWDM transponders that contain lasers, an optical fiber can be divided into as many as 80 different wavelengths, each capable of transmitting data at different rates. Optical amplifiers are used to boost the wavelength. Additionally, each wavelength can support differing data types, such as ATM, IP, and SONET. The number of wavelengths and amount of available bandwidth is dependent on the OC rating of the fiber. For example, OC-48 fiber will support up to 80 wavelengths with a total bandwidth of 200 Gbps, but OC-192 will only support 40 wavelengths. However, using DWDM, OC-192 will yield 400 Gbps.

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**Network Design Considerations for DWDM**

Transmission Media	Optical fiber with up to 80 channels or wavelengths for data transmission.
Bandwidth	Multiple bandwidth rates on a single fiber. OC-192 with 40 channels = 400 Gbps.
Application Support	Voice, video, data, and audio over same line. Supports multiple data formats (IP, ATM, SONET) transmitted simultaneously on the same fiber.
Distance Limitations	Optical amplifiers necessary to boost wavelength signals.
Network Function	Replacement solution for exhausted SONET resources in telephone company's backbone network.
Cost	Rates unknown. A great savings over laying more fiber.

## Check Your Understanding

- ◆ What would be the OC code for 10 Gigabits per second?
- ◆ What ATM service would best support voice transmissions? Why?
- ◆ What is meant by the term "always on"? What advantages do you see "always on" technology has over dial-up services?

## Cable

Traditional modems connect a computer to a telephone line, convert the digital data to analog waves, and carry the signal through the PSTN (the Public Switched Telephone Network.) When it reaches its destination, another modem receives the signal and converts it back to a digital signal for the computer it is connected to. The limitations of the PSTN make the development of traditional modems irrelevant beyond 56 Kbps, as the signal will not travel any faster on the PSTN. There is, however, a high-capacity cable connected to many homes in North America, and that is the coaxial television cable.

Cable companies now offer cable modems to their customers, realizing that cable access allows broadband transmission. The speeds with which a cable modem can transfer data far exceed that for traditional modems. For example, MediaOne, a nationally recognized cable company, offers service that provides up to 1.5 Mbps for transmissions from the Internet to the home, and 300 Kbps going back. The fastest traditional modems run at 56 Kbps.

In addition to the speed of the cable modem, cable is an "always on" service, although most services will disconnect a connection that has not had any activity in 30 minutes.

Currently, there are two types of service available from cable companies, one-way and two-way. While there are cables to many homes, older coaxial is only equipped to handle transmission in one direction. Newer cable can handle communications in both directions. Since the greater need is for speed from the Internet to the home, one-way service uses the cable modem to receive signals from the Internet and sends data to the Internet (requests for pages, etc.) by using a phone line. Two-way service is true transmission on the cable in both directions, and cable providers are rapidly converting existing lines to the newer cable to offer this service.

Installation is very simple. The PC must have a network interface card (NIC) typically with an RJ-45 connection slot. Category 5 cable, the same as used in Ethernet networks, attaches the PC NIC and the cable modem. The cable modem is then attached to the coaxial cable brought in from the street. Installation is often free or very inexpensive. The Cable Company

may provide the cable modem, or the customer may purchase it separately. Monthly fees for the service average between \$40-\$50 per month.

Essentially, the desktop PC becomes connected to the Cable Company's WAN. For this reason, the customer must understand that there is always a chance that others on the WAN may have access to his/her files. Cable Companies have implemented filters to help prevent individuals from wandering into the files of others, but security is very low. Any small business using cable for Internet access should implement a firewall.

Since customers are sharing the WAN connection, the bandwidth is also being shared. The potential for heavy network congestion is inevitable, which will result in less available bandwidth to each customer at any given time.

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### Network Design Considerations for Cable

Transmission Media	Coaxial cable. Same cable used for cable television. Cable modem required. Ethernet NIC for PC required.
Bandwidth	1.5 Mbps downstream and 300 Kbps upstream. Bandwidth shared over WAN.
Application Support	Video, data, and audio on same line. Voice is separate. Always on.
Distance Limitations	None. Cable must be available in neighborhood.
Network Function	Last-mile solution via the cable company for Internet and email access for the home and small business. Some security risks.
Cost	Cable modem is included in installation. NIC cost <\$100. Monthly fees average \$40-\$50.

### Check Your Understanding

- ◆ Compare cable to ADSL as a last-mile solution for the home owner or small business.

## Try It Out: Calculating Bandwidth

### Materials Needed:

- Windows 95 PC
- Any Word Processor (e.g., MS Word)
- Calculator (optional)
- Student Portfolio
- Pen/Pencil and Paper



Network designers must consider the bandwidth requirements for their clients before an appropriate design can be made. The requirements may be different for different branches of an organization. For example, the headquarters may have the largest number of users and it may also support other office locations for Internet access and storage of important databases (i.e., all the grades of all the students within a school district). Some calculations of bandwidth can be very simple, others more complicated.

In this activity, you will learn how to calculate the bandwidth requirements to support video conferencing applications.

### Calculation Techniques

1. Determine the number of bits required to support each video conferencing screen.
  - a. To do this, the number of bits per pixel must be known. Pixels are tiny dots of color or variation of gray arranged in rows and columns on a computer screen. For a 16 level gray scale, the number of bits per pixel is 4. For a 256-color scale, the number of bits per pixel is 8.
  - b. The number of rows of pixels represents the size of a screen. For example, 512 x 384 pixels represent 384 rows with 512 pixels each.
  - c. A video is a compilation of individual frames and each frame is individually displayed on the screen. Think of it as an animation flip-book. As each page is flipped, a new action is perceived. Each page represents a frame in the animation. The frame rate for computer video is calculated by multiplying the number of rows on a screen by the number of pixels in each row. For example, 512 x 384 equals 196,608 pixels per frame.

- d. The number of bits to support that frame is then calculated by multiplying the frame rate by the number of bits per pixel. For example, for a 16 level gray scale on a 512 x 384 screen, the calculation is 196,608 pixels/frame times 4 bits/pixel, which equals 786,432 bits/frame.
  - e. As stated before, a video is a compilation of multiple frames. The quality of the video is often expressed as the number of frames displayed over one second. The higher the number of frames per second, the higher the quality of the video. To determine the bit rate of a video, multiply the bits/frame by the number of frames per second. For example, 786,432 bits/frame times 10 frames/second equals 7,864,320 bits/second. Remember that bits per second is the measurement used for digital bandwidth.
2. If there is only one video station and there is no compression of the video, then the bandwidth requirement for the example in step 1 would indeed be 7,864,320 bits/second or 7.864 Mbps.
  3. Of course, data is sent in packets and packets have added bits for control of the packet. These extra bits must be considered when determining the total bandwidth requirement. Therefore, the total bandwidth requirement is represented by the data bits per second divided by the percent of data bits per total packet bits.

### The Case Study

The Red Rock Unified School District is comprised of four high schools. Each high school has a single video conferencing PC station capable of running the video conferencing software CUSeeMe and Timbuktu Pro 32.

The video specifications are as follows.

<b>CUSeeMe Video Specifications</b>	
Video Window Size	160 x 125 pixels
Compression Rate	64 %
Color Levels	16 levels of gray scale
Refresh Rate	10 frames per second
Data to packet ratio	0.80 data bits per total packet bits
<b>Timbuktu Pro 32 Video Specifications</b>	
Video Window Size	640 x 480 pixels
Compression Rate	64 %
Color Levels	256 colors
Refresh Rate	10 frames per second
Data to packet ratio	0.80 data bits per total packet bits

1. What are the bandwidth requirements for all four stations combined, without compression, using both CUSeeMe and Timbuktu Pro 32? Show your calculations.
2. What are the bandwidth requirements for all four stations with compression? Show your calculations.
3. What bandwidth solutions would you recommend to the school district to accommodate the requirements of #2? Justify your choice. Remember to be thorough, making sure to balance all the network design considerations.
4. After your teacher has graded your work, correct any problems and include this activity in your portfolio.

**Rubric: Suggested evaluation criteria and weightings:**

<b>Criteria</b>	<b>%</b>	<b>Your Score</b>
Correct answer to question 1	20	
Correct answer to question 2	20	
Valid recommendation demonstrating application of the network design considerations of alternative bandwidth solutions	50	
Inclusion in portfolio	10	
<b>TOTAL</b>	<b>100</b>	

## Stretch Yourself: Track Download Time

### Materials Needed:

- Windows 95 PC
- Any Word Processor (e.g., MS Word)
- Stop watch or wrist watch with a second hand
- Sniffer Basic
- Internet Connection

In the lesson, there is an estimate that it takes 14 minutes to download a 3.5 MB file using a 33.6 Kbps modem. Using a faster connection should result in a faster download. In this activity, you will download a file from the Internet and track how long the download takes. Additionally, you will use Sniffer Basic to analyze the network during the progress of the download.



### Materials:

- Stop watch or wrist watch with a second hand
  - Sniffer Basic
  - Internet Connection
1. Work in pairs, so that one person can record results while the other performs other tasks.
  2. Load Sniffer Basic.
    - a. Click Start.
    - b. Click Programs.
    - c. Click Sniffer Basic.
  3. There are four tools in Sniffer Basic used in this activity: the Network Probe/Adapter selector, the Dashboard, Global Statistics, and the Host Table.
    - a. Display the Dashboard, Global Statistics, and the Host Table by clicking on the Tools menu and selecting each tool.
    - b. Click on the Tools menu and choose Network Probe/Adapter.
    - c. Set the Network Probe/Adapter to the correct Internet connection. For example, if your Internet connection is through AOL, there will be a choice to set the probe to AOL.

4. Before you connect to the Internet, review the displays on Sniffer Basic. How many packets are being received or sent? How large are the packets that are being received or sent? Consider taking screen shots for your final evaluation.
5. Looking at the Global Statistics, record the size distribution of the packets and the utilization of your PC.
6. Establish an Internet connection with your web browser.
7. Navigate to Download.com (<http://www.download.com>).
8. Choose a free software program to download, such as Apple's Quicktime for Windows.
9. If the expected download time is displayed, record this time for comparison to how long the program actually takes to download.
10. Start downloading the program. When the PC prompts you whether to save the program to a disk or open the program after downloading, choose to save the program to disk.
11. Start timing the download using a watch.
12. As soon as the program begins to download, a screen will appear displaying the download process, which includes the number of minutes expected to complete the download and the number of bytes that have successfully downloaded.
13. Record every minute the information in the download display and also the time on your watch.
14. While the program is downloading, observe the changes in the Sniffer Basic displays. What changes have you noticed? Have the packets increased in size? Have the Global Statistics changed?
15. Record every minute the changes you observe in Sniffer Basic until the program is finished downloading. What happened after the download was finished?
16. With the information you have gathered, make a spreadsheet to summarize the information. The spreadsheet should have the displayed time, the watch time, the bytes downloaded per each record you took, the packet size and distribution, and the utilization changes over time.
17. From this information, write an analysis of what you observed.

- a. Was there a difference between the actual download time, the displayed download time, and the expected download time suggested by the web site? If so, speculate why?
  - b. What was the download rate (bytes per minute)?
  - c. What might influence the download time?
  - d. What were the changes in packet size and distribution? Why?
  - e. What changes occurred in your PC's utilization? Why?
  - f. What steps would you recommend to improve download time?
18. After you have completed this activity, delete the downloaded file from your PC.

**Rubric: Suggested evaluation criteria and weightings:**

<b>Criteria</b>	<b>%</b>	<b>Your Score</b>
Cooperative team work	20	
Informative and accurate spreadsheet of data	40	
Thorough analysis of activity	40	
<b>TOTAL</b>	<b>100</b>	

## Network Wizards: Who Designs Networks?

### Materials Needed:

- Windows 95 PC
- Any Word Processor (e.g., MS Word)
- Pen/Pencil and Paper
- Internet Connection (optional)
- Newspaper Want-Ad Classifieds



There are many people who design networks. Not all people involved in designing a network have formal training. Particularly in the past, many designers learned the art of network architecture on the job as they progressed through their careers. It could be said that this is one reason that many networks are built in a somewhat haphazard manner. The overall picture is often overlooked, for the quick and easy solution for a specific issue at hand. Later, another issue presents itself, and another patch solution is implemented.

Today there are training programs in place. However, within these training programs, the students are networking professionals who have fulfilled many prerequisites. These individuals have reached the highest level of technical expertise in the networking field. Typically, a network designer or architect works for a networking company and provides his/her services on a consulting basis for other companies that need help developing a well-planned network.

1. After you have made your initial contact with the company, you will work with to create your network design proposal, make an appointment with the key personnel that will be working with you.
2. As part of your initial visit, discuss what qualifications or other attributes they look for when hiring a network architect consultant. What are the deciding factors when choosing a consultant? Are they interested only in the technical expertise or are they also interested in other attributes, such as listening, organizational, and people skills?
3. Keep a record of your visit. Include in your record the time, place, the staff interviewed and a list of the qualifications required by the company.
4. After you have collected their thoughts and opinions, compare their list to at least five job descriptions for network architects. You may find job listings on the Internet and in the classified section of the paper. Many networking companies, such as Nortel Networks, list their jobs and descriptions on their web site.

5. Share your findings and comparisons in a class discussion about the qualities and training required to become a network architect.

**Rubric: Suggested evaluation criteria and weightings:**

<b>Criteria</b>	<b>%</b>	<b>Your Score</b>
Participation in class discussion with quality contributions.	25	
Record of company visit: time, place, staff interviewed, key points.	25	
Minimum of 5 job listings used as sources.	25	
Qualifications list.	25	
<b>TOTAL</b>	<b>100</b>	

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## Summary

### Broadband Technologies

In this lesson, you learned how to do the following:

- Identify the network design considerations of POTS, xDSL, ISDN, and Cable, as last-mile solutions
- Identify the network design considerations of T-carriers, SONET, ATM, Frame Relay, SMDS, DWDM, and ISDN, as WAN solutions
- Describe the basics of DWDM as a solution for exhausted SONET lines
- Determine bandwidth requirements and possible solutions as part of a network design

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## Review Questions

### Broadband Technologies

#### Part A:

1. POTS bandwidth is classified as
  - a. broadband
  - b. narrowband
  - c. wideband
  - d. a WAN solution
  - e. none of the above
2. The bandwidth offered by ADSL is 8 Mbps downstream and 1 Mbps upstream.
  - a. True
  - b. False
3. The bandwidth offered by G.Lite is
  - a. 52 Mbps downstream and 2.3 Mbps upstream
  - b. 155 Mbps downstream and 42 Mbps upstream
  - c. 1.5 Mbps downstream and upstream
  - d. 1.5 Mbps downstream and 384 Kbps upstream
  - e. None of the above
4. POTS supports voice and data transmissions simultaneously.
  - a. True
  - b. False

5. Which of the following last-mile solutions require the installation of a modem?
  - a. POTS
  - b. ISDN
  - c. ADSL
  - d. Cable
  - e. All of the above
6. The maximum bandwidth offered by POTS is
  - a. 14.4 Kbps
  - b. 56 Kbps
  - c. 128 Kbps
  - d. 1.5 Mbps
  - e. None of the above
7. Using ADSL, the maximum distance the end user can be from the telephone central office is
  - a. 3 miles
  - b. 5 miles
  - c. 10 miles
  - d. 2 miles
  - e. 1 mile

8. ISDN-BRI supports a maximum bandwidth of
  - a. 64 Mbps
  - b. 128 Kbps
  - c. 64 Kbps
  - d. 1.52 Mbps
  - e. 56 Kbps
9. What last-mile solution is a WAN connection?
  - a. ADSL
  - b. POTS
  - c. ISDN-BRI
  - d. Cable
  - e. All of the above
10. There are security issues for xDSL and cable because these are...
  - a. "always on" technologies.
  - b. "always off" technologies
  - c. WAN technologies
  - d. B only
  - e. A and C

**Part B:**

1. DWDM splits an optical fiber into up to 80 wavelength channels.
  - a. True
  - b. False
2. SONET OC-4 bandwidth is
  - a. 51.84 Mbps
  - b. 192 Mbps
  - c. 207.36 Mbps
  - d. 155 Mbps
  - e. None of the above
3. Which ATM service is typically used for video conferencing?
  - a. CBR
  - b. UBR
  - c. VBR
  - d. ABR
  - e. Any one of the above.
4. ATM can be implemented all the way to the desktop without special equipment.
  - a. True
  - b. False

5. The maximum radius of SMDS is
  - a. 1 mile
  - b. 3 miles
  - c. 30 miles
  - d. 50 miles
  - e. 18,000 feet
6. The cost of Frame Relay is dependent on
  - a. the service type, CBR or ABR
  - b. the CIR
  - c. the distance from end to end of the leased line
  - d. B and C only
  - e. All of the above
7. The bandwidth range offered by B-ISDN is
  - a. 155-622 Mbps
  - b. 64-128 Kbps
  - c. 1.5-2.3 Mbps
  - d. 1.5-44.736 Mbps
  - e. 200-400 Gbps
8. SONET uses TDM to increase the capacity of the optical fiber.
  - a. True
  - b. False

9. The range of bandwidth for Frame Relay is
  - a. 155-622 Mbps
  - b. 64-128 Kbps
  - c. 56 Kbps-44.736 Mbps
  - d. 1.5-44.736 Mbps
  - e. 200-400 Gbps
10. The range of bandwidth for ATM is
  - a. 155-622 Mbps
  - b. 64-128 Kbps
  - c. 1.5-2.3 Mbps
  - d. 1.5-44.736 Mbps
  - e. 200-400 Gbps

**Part C:**

1. Briefly describe Dense Wavelength Division Multiplexing technology and how it is a solution for exhausted SONET networks. Include in your description a diagram of DWDM's operation.

## Scoring

Criteria	%	Your Score
Part A: Identify the network design considerations of POTS, xDSL, ISDN, and Cable, as last-mile solutions.	40	
Part B: Identify the network design considerations of T-carriers, SONET, ATM, Frame Relay, SMDS, DWDM, and ISDN, as WAN solutions.	40	
Part C: Describe the basics of DWDM as a solution for exhausted SONET lines.	20	
<b>TOTAL</b>	<b>100</b>	
<b>Try It Out:</b> Determine bandwidth requirements and possible solutions as part of a network design.	<b>100</b>	
<b>Stretch Yourself:</b>	<b>100</b>	
<b>Network Wizards:</b>	<b>100</b>	
<b>FINAL TOTAL</b>	<b>400</b>	

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