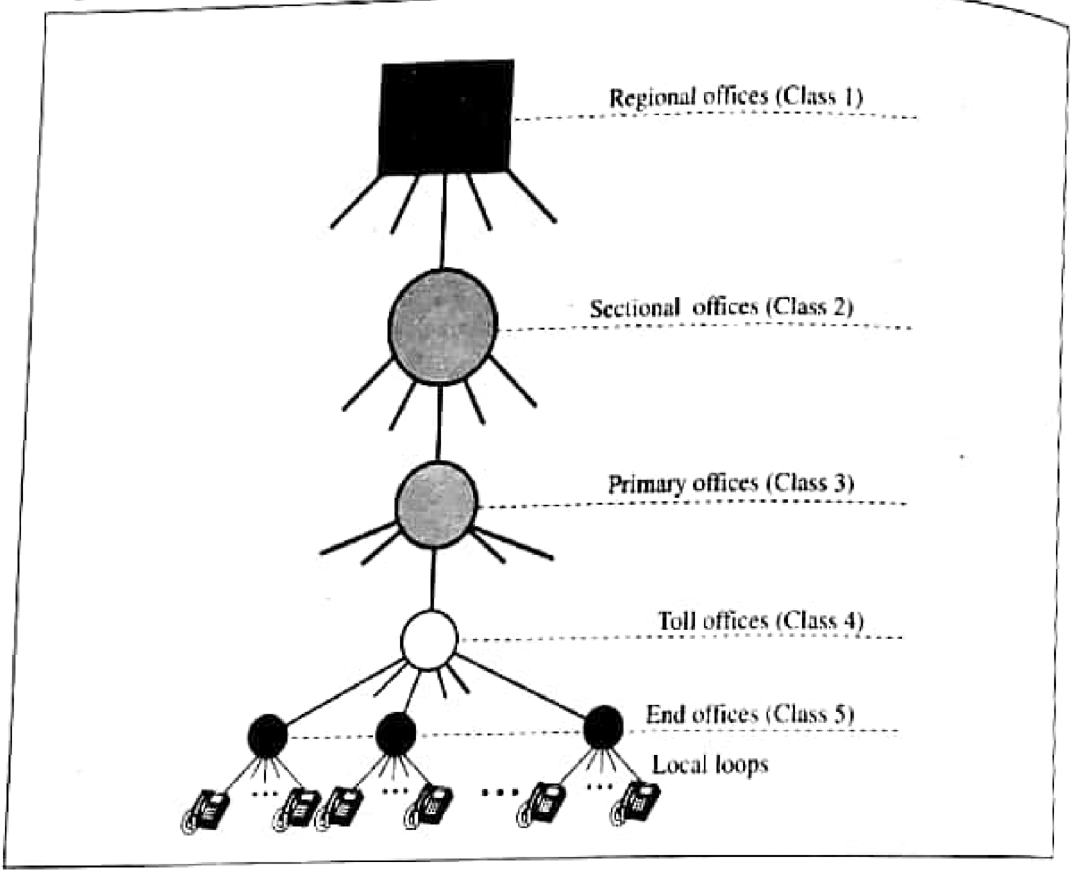
Public Switched Telephone Network (PSTN)

An example of a circuit-switched telephone network is the **Public Switched Telephone Network (PSTN)** in North America. The switching centers are organized into five classes: *regional offices* (class 1), *sectional offices* (class 2), *primary offices* (class 3), *toll offices* (class 4), and *end offices* (class 5). Figure 14.14 shows the hierarchical relationship between these offices.

Figure 14.14 *PSTN hierarchy*



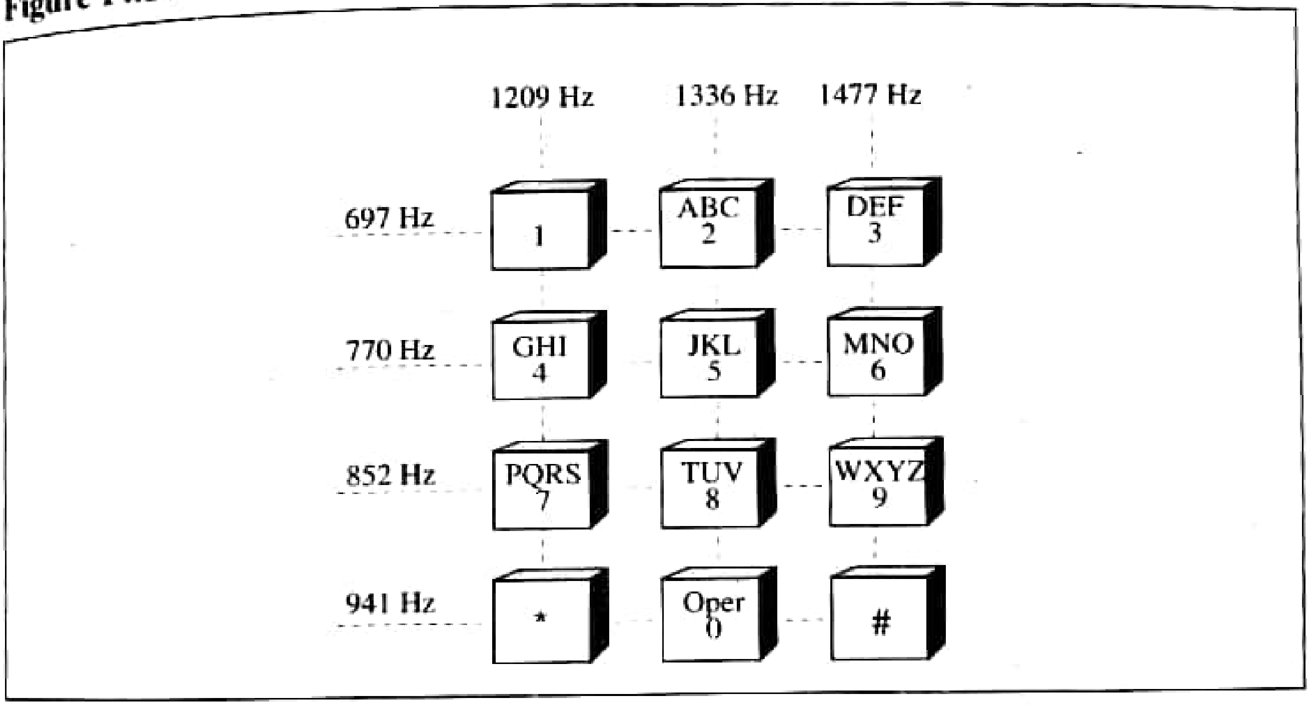
Subscriber telephones are connected, through **local loops,** to end offices (or central offices). A small town may have only one end office, but a large city will have several end offices. Many end offices are connected to one toll office. Several toll offices are connected to a primary office. Several primary offices are connected to a sectional office, which normally serves more than one state. And finally several sectional offices are connected to one regional office. All the regional offices are connected using mesh topology.

Accessing the switching station at the end offices is accomplished through dialing. In the past, telephones featured rotary or pulse dialing, in which a digital signal was sent to the end office for each number dialed. This type of dialing was prone to errors due to the inconsistency of humans during the dialing process.

Today, dialing is accomplished through the Touch-Tone technique. In this method, instead of sending a digital signal, the user sends two small bursts of analog signals, called *dual tone*. The frequency of the signals sent depends on the row and column of the pressed pad.

Figure 14.15 shows a 12-pad **Touch-Tone dialing** system. Note that there is also a variation with an extra column (16-pad Touch-Tone), which is used for special purposes.

Figure 14.15 *Touch-Tone dialing*



In Figure 14.15, when a user dials, for example, the number 8, two bursts of analog signals with frequencies 852 and 1336 Hz are sent to the end office.

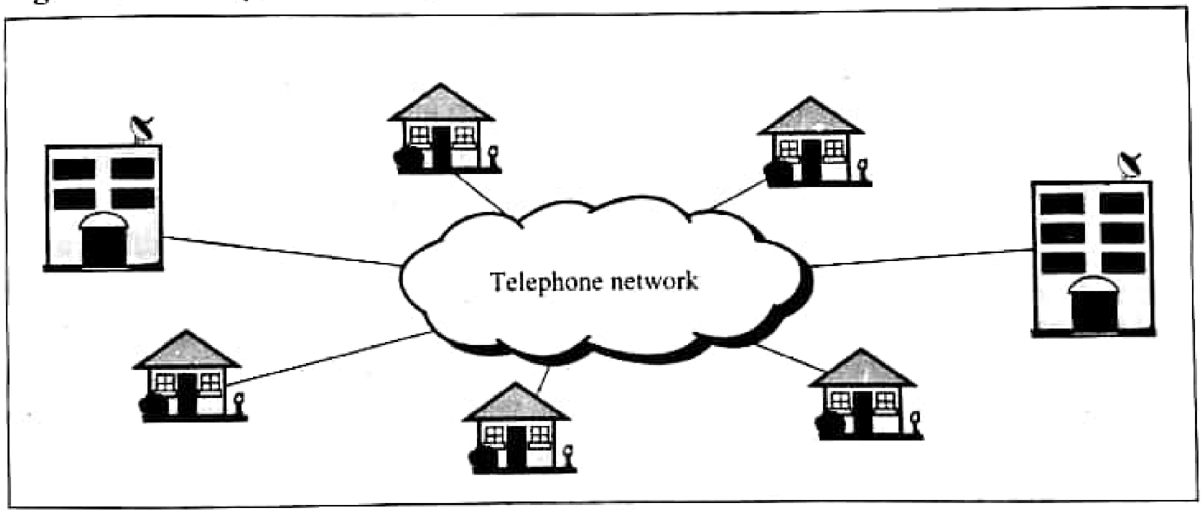
8.5 MULTIPLEXING APPLICATION: THE TELEPHONE SYSTEM

Multiplexing has long been an essential tool of the telephone industry. A look at some telephone company basics can help us understand the application of both FDM and TDM in the field. Of course, different parts of the world use different systems. We will concentrate only on the system used in North America.

The North American telephone system includes many **common carriers** that offer local and long-distance services to subscribers. These carriers include local companies such as Pacific Bell and long-distance providers such as AT&T, MCI, and Sprint.

For the purposes of this discussion, we will think of these various carriers as a single entity called the telephone network, and the line connecting a subscriber to that network as a *service line* (see Figure 8.19).

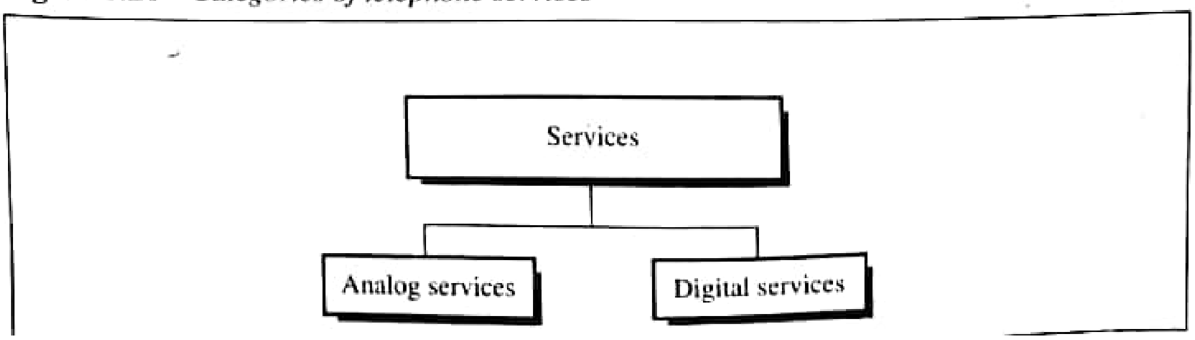
Figure 8.19 *Telephone network*



Common Carrier Services and Hierarchies

Telephone companies began by providing their subscribers with **analog services** that used analog networks. Later technology allowed the introduction of digital services and networks. Today, North American providers are in the process of changing even their service lines from analog to digital. It is anticipated that soon the entire network will be digital. For now, however, both types of services are available and both FDM and TDM are in use (see Figure 8.20).

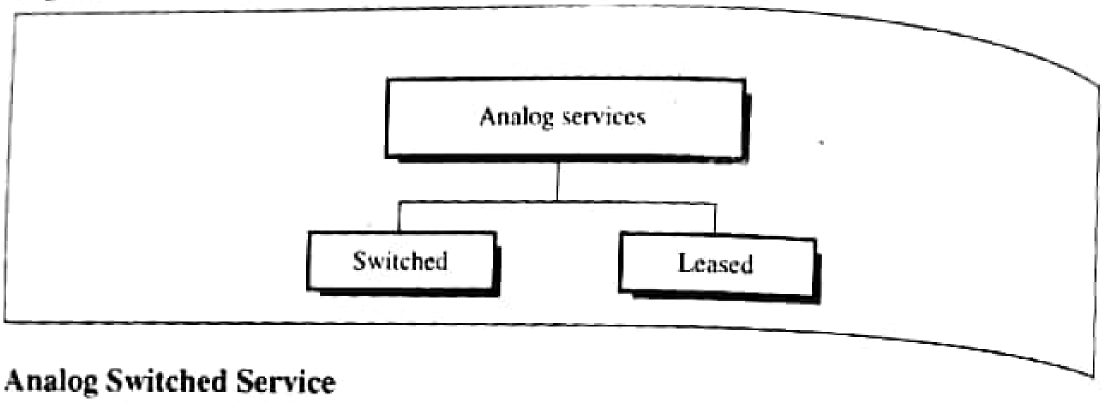
Figure 8.20 *Categories of telephone services*



Analog Services

Of the many analog services available to subscribers, two are particularly relevant to our discussion here: switched services and leased services (see Figure 8.21).

Figure 8.21 *Categories of analog services*



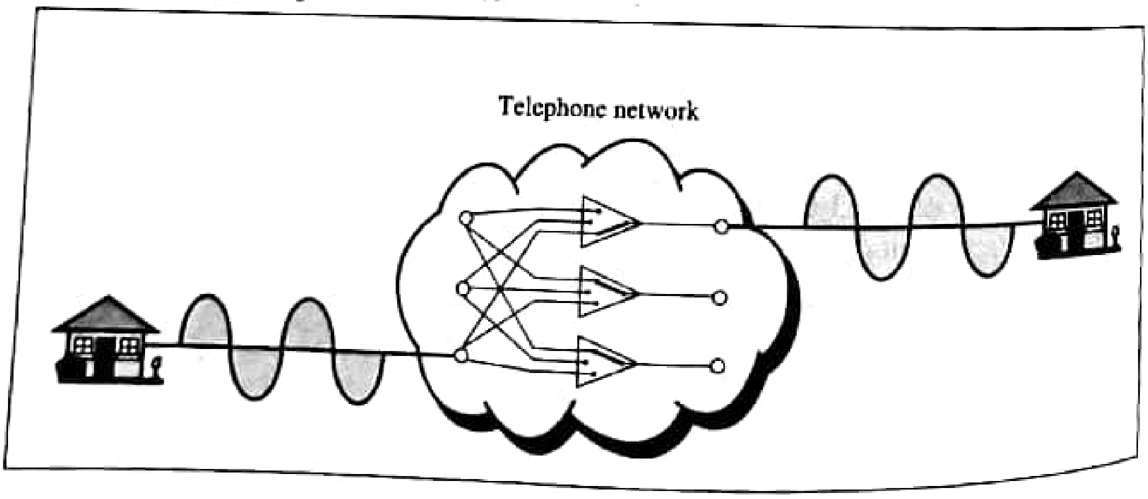
Analog Switched Service

Analog switched service is the familiar dial-up service most often encountered when using a home telephone. It uses two-wire (or, for specialized uses, four-wire) twisted-pair cable to connect the subscriber's handset to the network via an exchange. This connection is called the **local loop.** The network it joins is sometimes referred to as a public switched telephone network (PSTN).

The signal on a local loop is analog, and the bandwidth is usually between 0 and 4000 Hz. (For more information on telephone bandwidth, refer back to Chapter 7.)

With switched lines, when the caller dials a number, the call is conveyed to a switch, or series of switches, at the exchange. The appropriate switches are then activated to link the caller's line to that of the person being called. The switch connects the two lines for the duration of the call (see Figure 8.22).

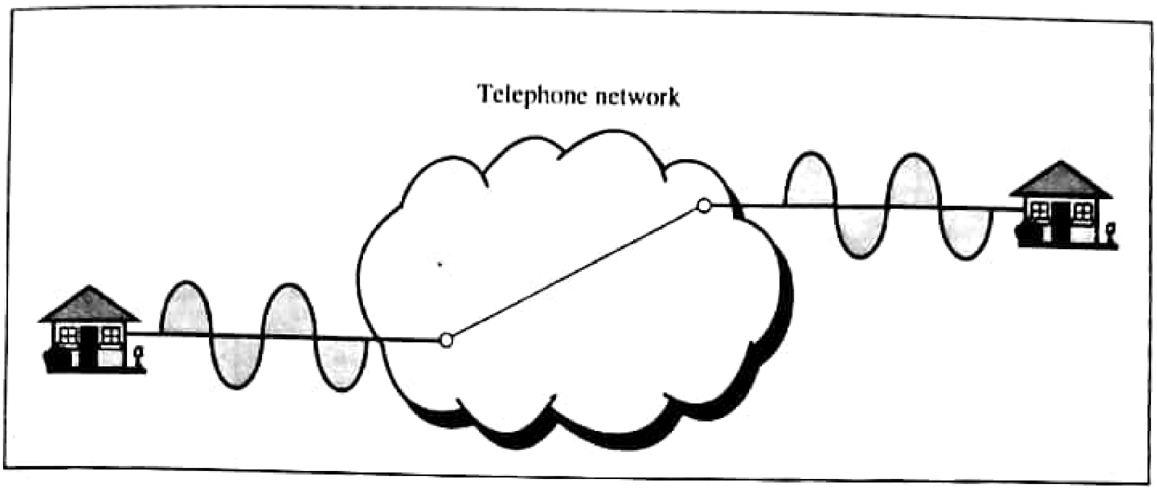
Figure 8.22 *Analog switched service*



Analog Leased Service

An **analog leased service** offers customers the opportunity to lease a line, sometimes called a dedicated line, that is permanently connected to another customer. Although the connection still passes through the switches in the telephone network, subscribers experience it as a single line because the switch is always closed; no dialing is needed (see Figure 8.23).

Figure 8.23 *Analog leased service*



Conditioned Lines Telephone carriers also offer a service called conditioning. **Conditioning** means improving the quality of a line by lessening attenuation, signal distortion, or delay distortion. Conditioned lines are analog, but their quality makes them usable for digital data communication if they are connected to modems.

The Analog Hierarchy

To maximize the efficiency of their infrastructure, telephone companies have traditionally multiplexed signals from lower bandwidth lines onto higher bandwidth lines. In this way, many switched or leased lines can be combined into fewer but bigger channels. For analog lines, FDM is used.

One of these hierarchical systems used by AT&T is made up of groups, supergroups, master groups, and jumbo groups (see Figure 8.24).

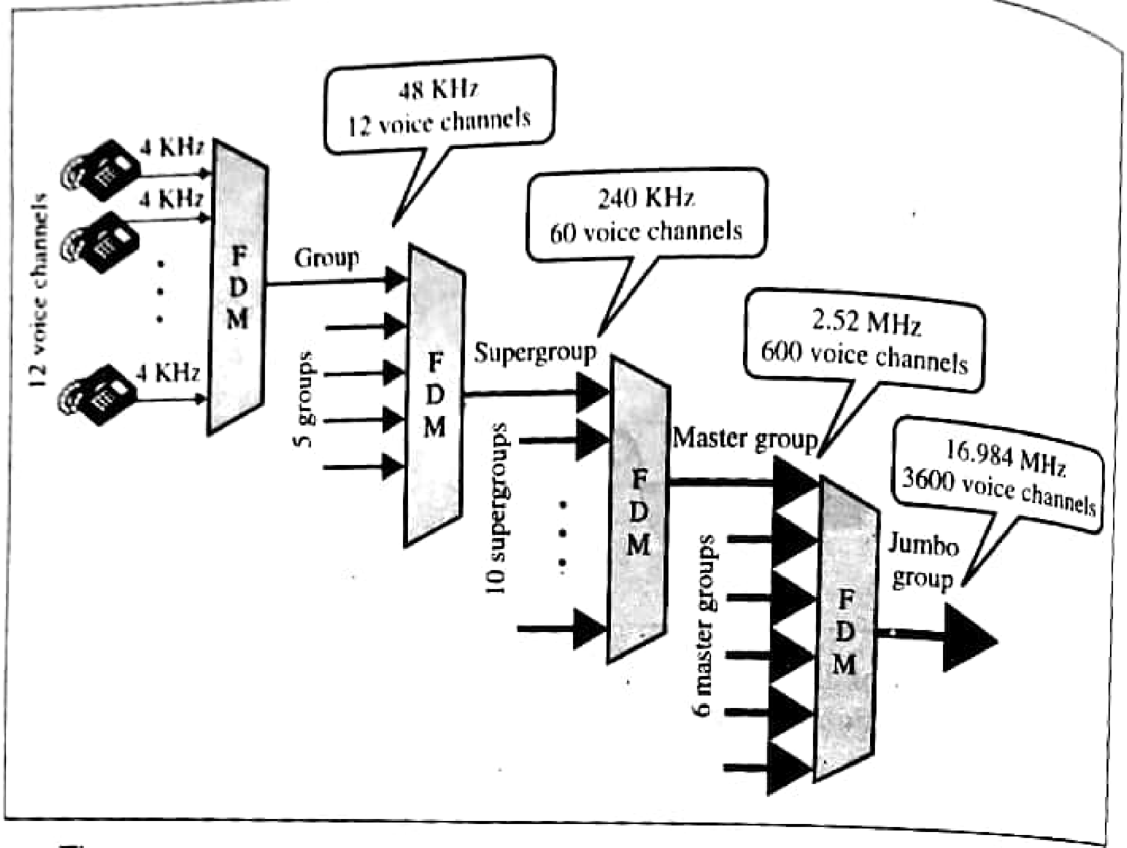
In this **analog hierarchy,** 12 voice channels are multiplexed onto a higher bandwidth line to create a **group.** (To conserve bandwidth, AT&T uses modulation techniques that suppress the carrier and the lower sidebands of each signal, and recover them upon demultiplexing.) A group has 48 KHz of bandwidth and supports 12 voice channels.

At the next level, up to five groups can be multiplexed to create a composite signal called a **supergroup.** A supergroup has a bandwidth of 240 KHz and supports up to 60 voice channels. Supergroups can be made up of either five groups or 60 independent voice channels.

At the next level, 10 supergroups are multiplexed to create a **master group.** A master group must have 2.40 MHz of bandwidth, but the need for guard bands between the channels increases the necessary bandwidth to 2.52 MHz. Master groups support up to 600 voice channels.

Finally, six master groups can be combined into a **jumbo group.** A jumbo group must have 15.12 MHz (6×2.52 MHz) but is augmented to 16.984 MHz to allow for guard bands between the master groups.

Figure 8.24 *Analog hierarchy*



There are many variations of this hierarchy in the telecommunications industry (the ITU-T has approved a different system for use in Europe). However, because this analog hierarchy will be replaced by digital services in the near future, we will limit our discussion to the system above.

Digital Services

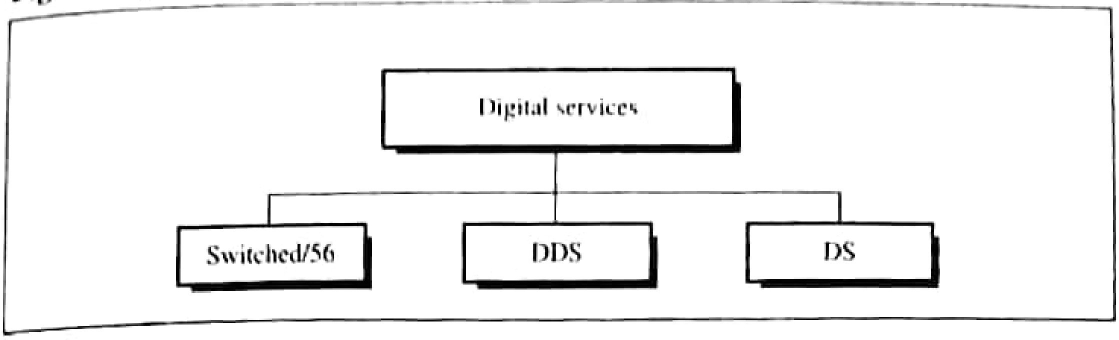
Recently telephone companies began offering digital services to their subscribers. One advantage is that digital services are less sensitive than analog services to noise and other forms of interference. A telephone line acts like an antenna and will pick up noise during both analog and digital transmission. In analog transmissions, both signal and noise are analog and cannot be easily separated. In digital transmission, on the other hand, the signal is digital but the interference is still analog. The signal therefore can be distinguished and separated easily. Another advantage to digital transmission is its lower cost. Because it needs to differentiate between only two or three levels of voltage instead of a continuous range of values, digital transmission equipment uses less expensive electronics than does the corresponding analog equipment.

We will examine three different types of digital services: switched/56, DDS, and DS (see Figure 8.25).

Switched/56 Service

Switched/56 is the digital version of an analog switched line. It is a switched digital service that allows data rates of up to 56 Kbps. To communicate through this service, both parties must subscribe. A caller with normal telephone service cannot connect to a telephone or computer with switched/56 even if using a modem. On the whole,

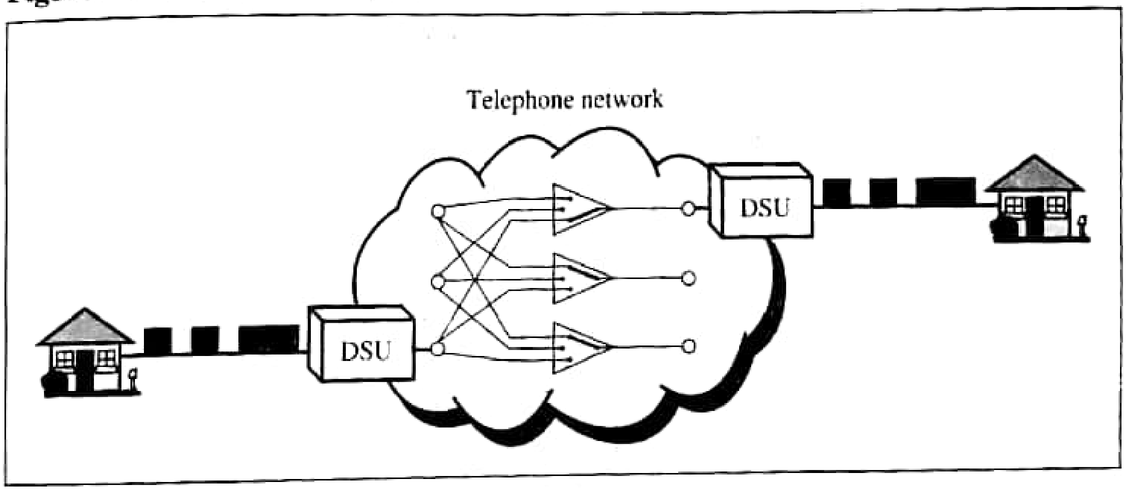
Figure 8.25 *Categories of digital services*



digital and analog services represent two completely different domains for the telephone companies.

Because the line in a switched/56 service is already digital, subscribers do not need modems to transmit digital data. However, they do need another device called a **digital service unit (DSU)**. This device changes the rate of the digital data created by the subscriber's device to 56 Kbps and encodes it in the format used by the service provider (see Figure 8.26). The DSU is often included in the dialing process (DSU with dial pad).

Figure 8.26 *Switched/56 service*



Ironically, a DSU is more expensive than a modem. So why would a subscriber elect to pay for the switched/56 service and DSU? Because the digital line has better speed, better quality, and less susceptibility to noise than an equivalent analog line.

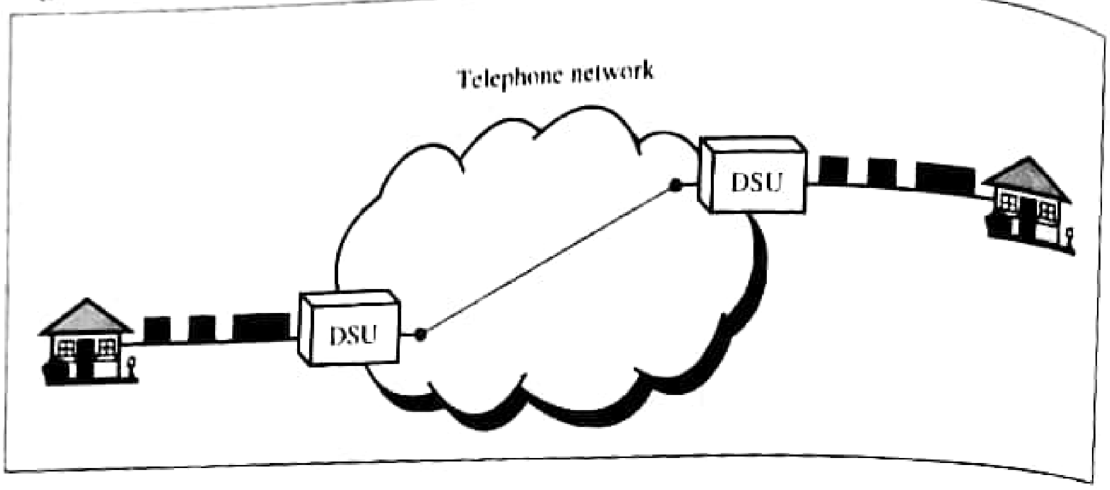
Bandwidth on Demand Switched/56 supports bandwidth on demand, allowing subscribers to obtain higher speeds by using more than one line (see the section on inverse multiplexing, above). This option allows switched/56 to support video conferencing, fast facsimile, multimedia, and fast data transfer, among other features.

Digital Data Service (DDS)

Digital data service (DDS) is the digital version of an analog leased line; it is a digital leased line with a maximum data rate of 64 Kbps.

Like switched/56, DDS requires the use of a DSU. The DSU for this service is cheaper than that required for switched/56, however, because it does not need a dial pad (see Figure 8.27).

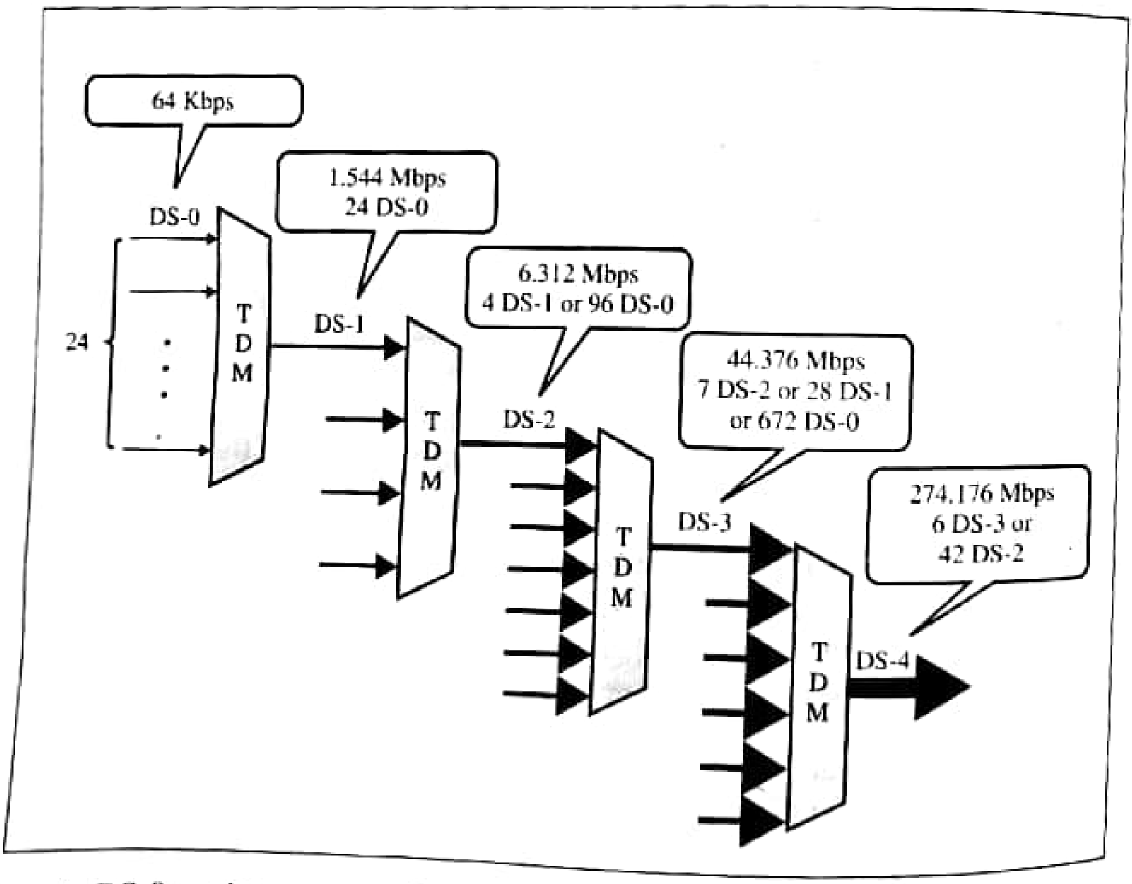
Figure 8.27 *DDS service*



Digital Signal (DS) Service

After offering switched/56 and DDS services, the telephone companies saw a need to develop a hierarchy of digital services much like that used for analog services. The next step was **digital signal (DS) service.** DS is a hierarchy of digital signals. Figure 8.28 shows the data rates supported by each level.

Figure 8.28 *DS hierarchy*



- A DS-0 service resembles DDS. It is a single digital channel of 64 Kbps.
- *DS-1* is a 1.544-Mbps service; 1.544 Mbps is 24 times 64 Kbps plus 8 Kbps of overhead. It can be used as a single service for 1.544-Mbps transmissions, or it can

be used to multiplex 24 DS-0 channels or to carry any other combination desired by the user that can fit within its 1.544-Mbps capacity.

- DS-2 is a 6.312-Mbps service; 6.312 Mbps is 96 times 64 Kbps plus 168 Kbps of overhead. It can be used as a single service for 6.312-Mbps transmissions, or it can be used to multiplex 4 DS-1 channels, 96 DS-0 channels, or a combination of these service types.
- DS-3 is a 44.376-Mbps service; 44.376 Mbps is 672 times 64 Kbps plus 1.368 Mbps of overhead. It can be used as a single service for 44.376-Mbps transmissions, or it can be used to multiplex 7 DS-2 channels, 28 DS-1 channels, 672 DS-0 channels, or a combination of these service types.
- DS-4 is a 274.176-Mbps service; 274.176 is 4032 times 64 Kbps plus 16.128 Mbps of overhead. It can be used to multiplex 6 DS-3 channels, 42 DS-2 channels, 168 DS-1 channels, 4032 DS-0 channels, or a combination of these service types.

T Lines

DS-0, DS-1, and so on are the names of services. To implement those services, the telephone companies use **T lines** (T-1 to T-4). These are lines with capacities precisely matched to the data rates of the DS-1 to DS-4 services (see Table 8.1).

Table 8.1 *DS and T line rates*

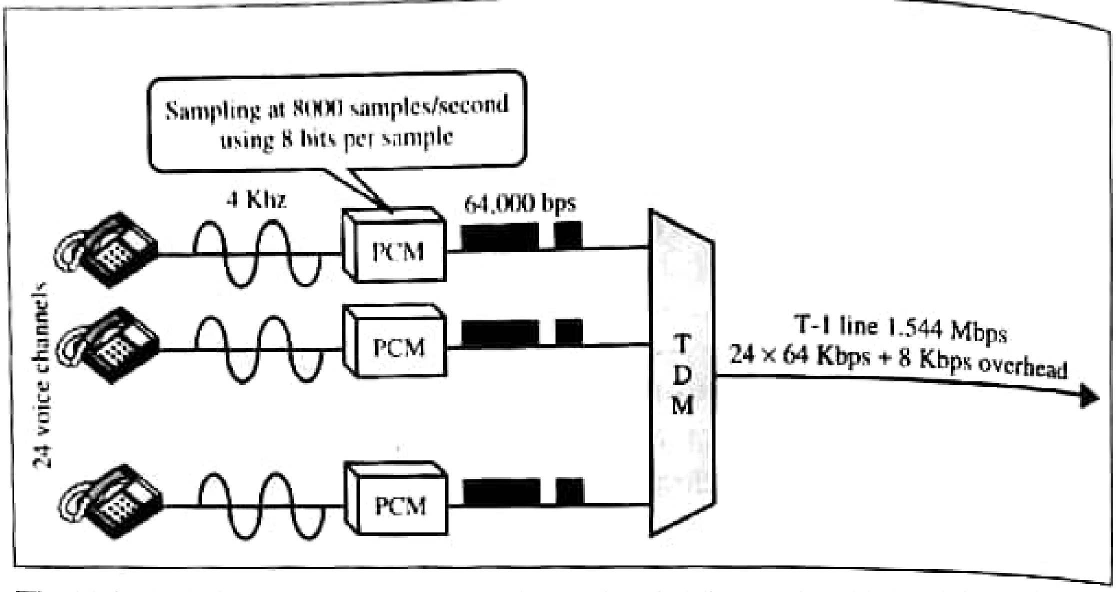
Service	*Line*	*Rate (Mbps)*	*Voice Channels*
DS-1	**T-1**	1.544	24
DS-2	**T-2**	6.312	96
DS-3	**T-3**	44.736	672
DS-4	**T-4**	274.176	4032

T-1 is used to implement DS-1, T-2 is used to implement DS-2, and so on. As you can see from Table 8.1, DS-0 is not actually offered as a service, but it has been defined as a basis for reference purposes. Telephone companies believe that customers needing the level of service that would be found in DS-0 can substitute DDS.

T Lines for Analog Transmission T lines are digital lines designed for the transmission of digital data, voice, or audio signals. However, they also can be used for analog transmission (regular telephone connections), provided the analog signals are sampled first, then time-division multiplexed.

The possibility of using T lines as analog carriers opened up a new generation of services for the telephone companies. Earlier, when an organization wanted 24 separate telephone lines, it needed to run 24 twisted-pair cables from the company to the central exchange. (Remember those old movies showing a busy executive with 10 telephones lined up on his desk? Or the old office telephones with a big fat cable running from them? Those cables contained a bundle of separate lines.) Today, that same organization can combine the 24 lines into one T-1 line and run only the T-1 line to the exchange. Figure 8.29 shows how 24 voice channels can be multiplexed onto one T-1 line. (Refer back to Chapter 5 for PCM encoding.)

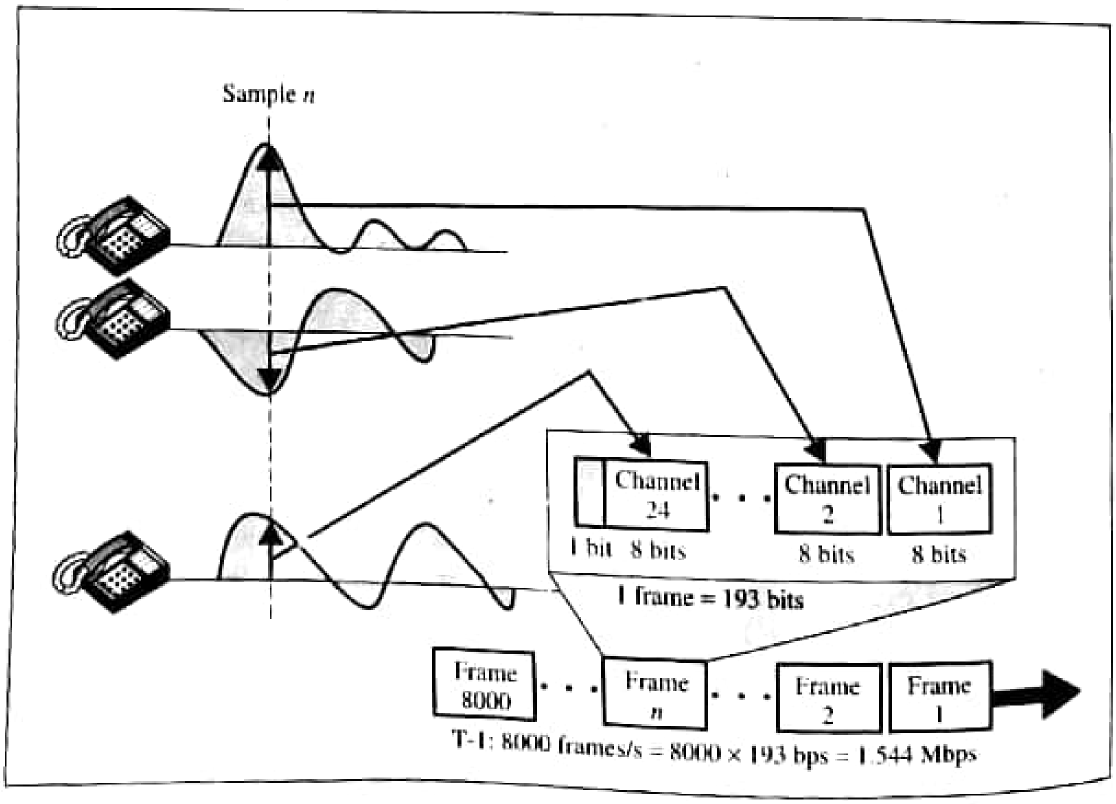
Figure 8.29 *T-1 line for multiplexing telephone lines*



The T-1 Frame As noted above, DS-1 requires 8 Kbps of overhead. To understand how this overhead is calculated, we must examine the format of a 24-voice-channel frame.

The frame used on a T-1 line is usually 193 bits divided into 24 slots of 8 bits each plus 1 extra bit for synchronization ($24 \times 8 + 1 = 193$); see Figure 8.30. In other words, each slot contains 1 signal segment from each channel; 24 segments are interleaved in one frame. If a T-1 line carries 8000 frames per second, the data rate is 1.544 Mbps ($193 \times 8000 = 1.544$ Mbps)—the capacity of the line.

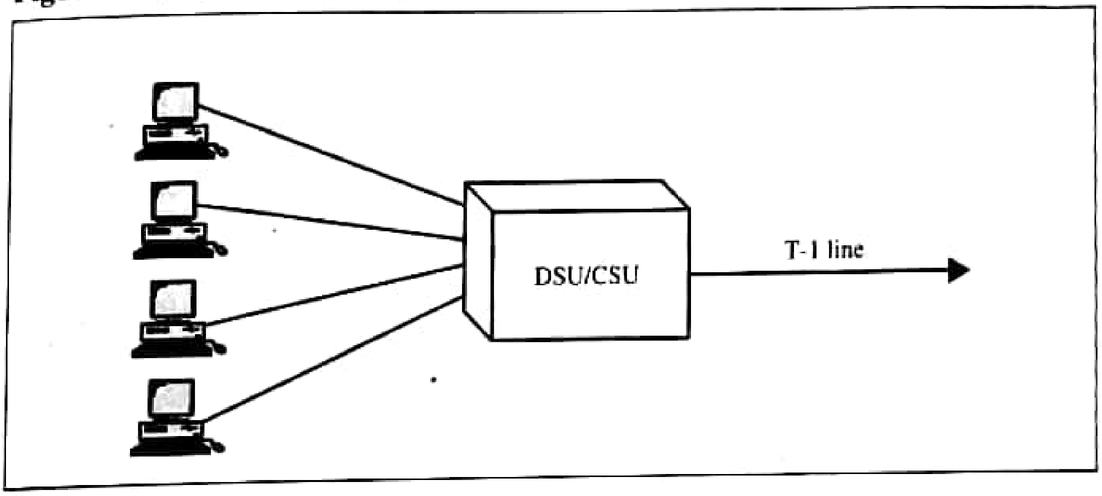
Figure 8.30 *T-1 frame structure*



Fractional T Lines Many subscribers may not need the entire capacity of a T line. To accommodate these customers, the telephone companies have developed **fractional T line** services, which allow several subscribers to share one line by multiplexing their transmissions.

For example, a small business may need only one-fourth of the capacity of a T-1 line. If four businesses that size have offices in the same building, they can share a T-1 line. To do so, they direct their transmissions through a device called a **digital service unit/channel service unit (DSU/CSU).** This device lets them divide the capacity of the line into four interleaved channels (see Figure 8.31).

Figure 8.31 *Fractional T-1 line*



E Lines

Europeans use a version of T lines called **E lines.** The two systems are conceptually identical, but their capacities differ. Table 8.2 shows the E lines and their capacities.

Table 8.2 *E line rates*

Line	*Rate (Mbps)*	*Voice Channels*
E-1	2.048	30
E-2	8.448	120
E-3	34.368	480
E-4	139.264	1920

Other Multiplexing Services

We have discussed multiplexing over physical cable, but multiplexing is equally vital to the efficient use of both terrestrial and satellite microwave transmission. Today telephone service providers are introducing other powerful services, such as ISDN, SONET, and ATM, which also depend on multiplexing. These services will be discussed in Chapters 16 through 20.

8.6 DIGITAL SUBSCRIBER LINE (DSL)

One example of multiplexing, demultiplexing, and modulation is a technology called the DSL family. The **digital subscriber line (DSL)** is a newer technology that uses the existing telecommunication networks such as the local loop telephone line to accomplish high-speed delivery of data, voice, video, and multimedia.

DSL is a family of technologies; five of them will be discussed here: ADSL, RADSL, HDSL, VDSL, and SDSL.

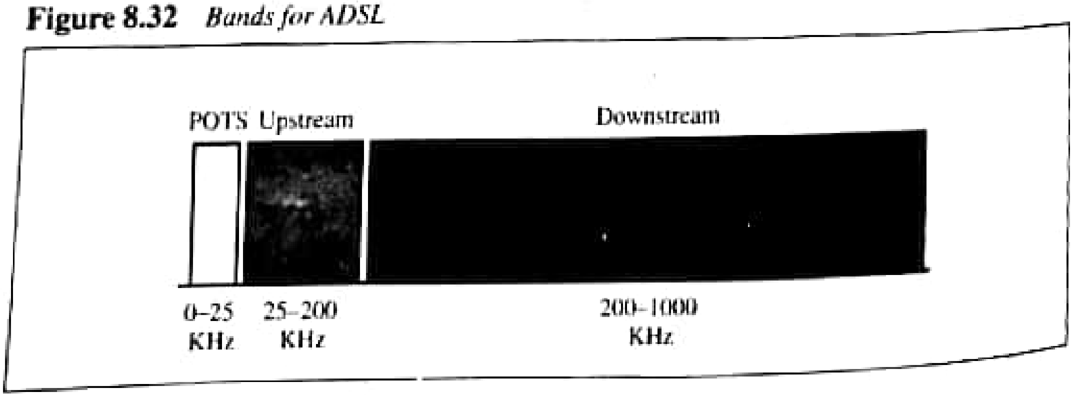
ADSL

Telephone companies have installed high-speed digital wide area networks to handle communication between their central offices. The link between the user (subscriber) and the network, however, is still an analog line (local loop). The challenge is to make these links digital—a digital subscriber line—without changing the existing local loops. The local loop is a twisted-pair cable with a potential bandwidth of 1 MHz or more.

Asymmetric digital subscriber line (ADSL) is asymmetrical, which means it provides higher bit rates in the downstream direction (from the telephone central office to the subscriber's site) than the upstream direction (from the subscriber site to the telephone central office). This is what subscribers usually want. They want to receive high-volume files quickly from the Internet, but they usually have small files, such as a short e-mail message, to send.

ADSL divides the bandwidth of a twisted-pair cable (one megahertz) into three bands. The first band, normally between 0 and 25 KHz, is used for regular telephone service (known as plain old telephone service or POTS). This service uses only 4 KHz of this band; the rest is used as the guard band to separate the voice channel from the data channels. The second band, usually between 25 and 200 KHz, is used for upstream communication. The third band, usually 200 KHz to 1 MHz, is used for downstream communication. Some implementations overlap the downstream and upstream band to provide more bandwidth in the downstream direction. Figure 8.32 shows the bands.

Figure 8.32 *Bands for ADSL*



Modulation Techniques

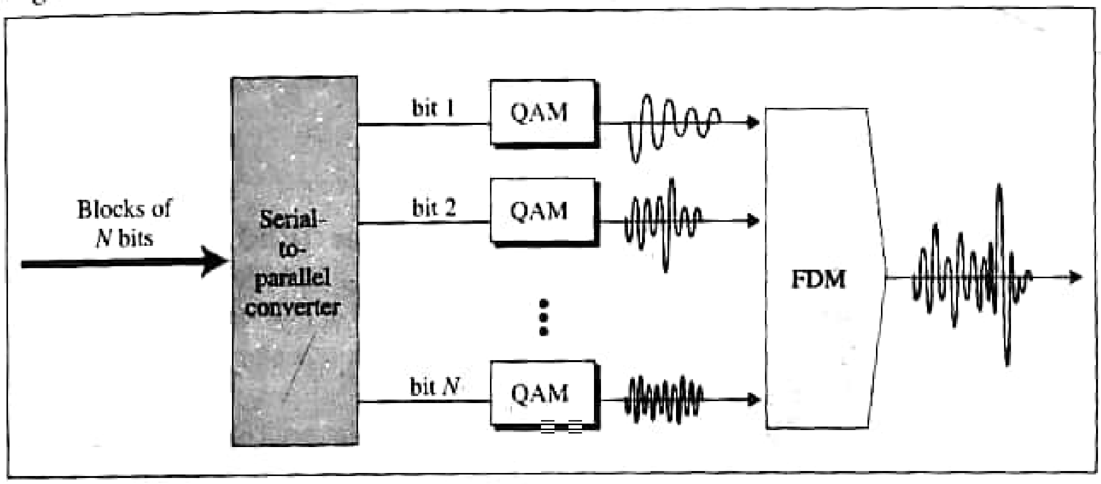
Most implementations of ADSL originally used a modulation technique called carrierless amplitude/phase (CAP). Later, another modulation technique, known as discrete multitone (DMT) was standardized by ANSI.

CAP **Carrierless amplitude/phase (CAP)** is a modulation technique that is similar to QAM, but with one important difference: the carrier signal is eliminated. The technique, however, is more complex than QAM and is not standardized.

DMT The **discrete multitone technique (DMT)** combines QAM and FDM. The available bandwidth for each direction is divided into 4-KHz channels, each having its own carrier frequency.

Figure 8.33 shows the concept of DMT with *N* channels. The bits created by the source are passed through a serial-to-parallel converter, where a block of *N* bits is divided into *N* parallel paths, each consisting of one bit. The QAM signals created from each path are frequency multiplexed together and the result is sent to the line.

Figure 8.33 *DMT*



The ANSI standard defines a rate of 60 Kbps for each 4-KHz channel, which means a QAM modulation with 15 bits per baud.

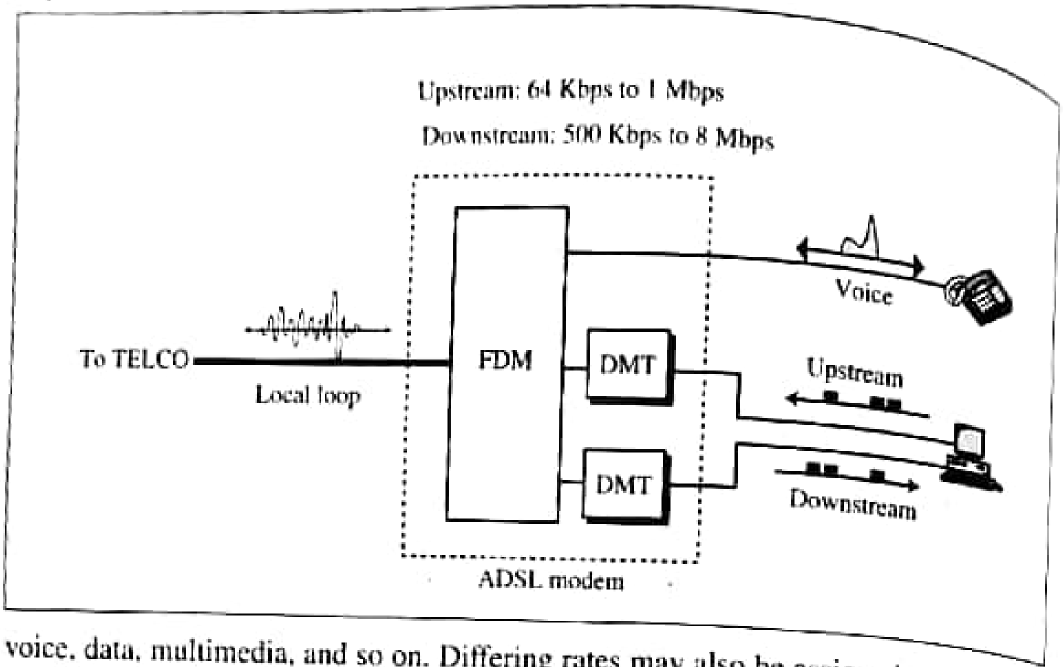
- The upstream channel usually occupies 25 channels, which means a bit rate of 25 × 60 Kbps, or 1.5 Mbps. Normally, however, the bit rate in this direction ranges from 64 Kbps to 1 Mbps due to noise.
- The downstream channel usually occupies 200 channels, which means a bit rate of 200 × 60 Kbps, or 12 Mbps. Normally, however, the bit rate in this direction ranges from 500 Kbps to 8 Mbps due to noise.

Figure 8.34 shows the ADSL and the bit rates in each direction.

RADSL

The **rate adaptive asymmetrical digital subscriber line (RADSL)** is a technology based on ADSL. It allows different data rates depending on the type of communication:

Figure 8.34 *ADSL modem*



voice, data, multimedia, and so on. Differing rates may also be assigned to subscribers based on their demand of the bandwidth. RADSL is beneficial to the customer because the cost is based on the data rate needed.

HDSL

The **high bit rate digital subscriber line (HDSL)** was designed by Bellcore (now Telcordia) as an alternative to the T-1 line (1.544 Mbps). The T-1 line uses AMI encoding, which is very susceptible to attenuation at high frequencies. This limits the length of a T-1 line to 1 Km. For longer distances, a repeater (amplifier) is necessary, which means increased costs.

HDSL uses 2B1Q encoding (see Chapter 16), which is less susceptible to attenuation. A data rate of almost 2 Mbps can be achieved without repeaters up to a distance of 3.6 Km. HDSL uses two twisted-pair wires to achieve full-duplex transmission.

SDSL

The **symmetric** (or single-line) **digital subscriber line (SDSL)** is the same as HDSL but uses one single twisted-pair cable, available to most residential subscribers, to achieve the same data rate as HDSL. A technique called *echo cancellation* is employed to create a full-duplex transmission.

VDSL

The **very high bit rate digital subscriber line (VDSL),** an alternative approach that is similar to ADSL, uses coaxial, fiber-optic, or twisted-pair cable for short distances (300 to 1800 meters). The modulating technique is DMT with a bit rate of 50 to 55 Mbps downstream and 1.5 to 2.5 Mbps upstream.

Before examining the specifics of how data are transmitted from one device to another, it is important to understand the relationship between the communicating devices. Five general concepts provide the basis for this relationship:

- Line configuration.
- Topology.
- Transmission mode.
- Categories of networks.
- Internetworks.

2.1 LINE CONFIGURATION

Line configuration refers to the way two or more communication devices attach to a *link*. A **link** is the physical communication pathway that transfers data from one device to another. For the purposes of visualization, it is simplest to imagine any link as a line drawn between two points. For communication to occur, two devices must be connected in some way to the same link at the same time. There are two possible line configurations: point-to-point and multipoint (see Figure 2.1).

Line configuration defines the attachment of communication devices to a link.

Point-to-Point

A **point-to-point line configuration** provides a dedicated link between two devices. The entire capacity of the channel is reserved for transmission between those two devices. Most point-to-point line configurations use an actual length of wire or cable to connect the two ends, but other options, such as microwave or satellite links, are also possible (see Figure 2.2). When you change television channels by infrared remote control, you are establishing a point-to-point line configuration between the remote control and the television's control system.

Figure 2.1 *Two categories of line configuration*

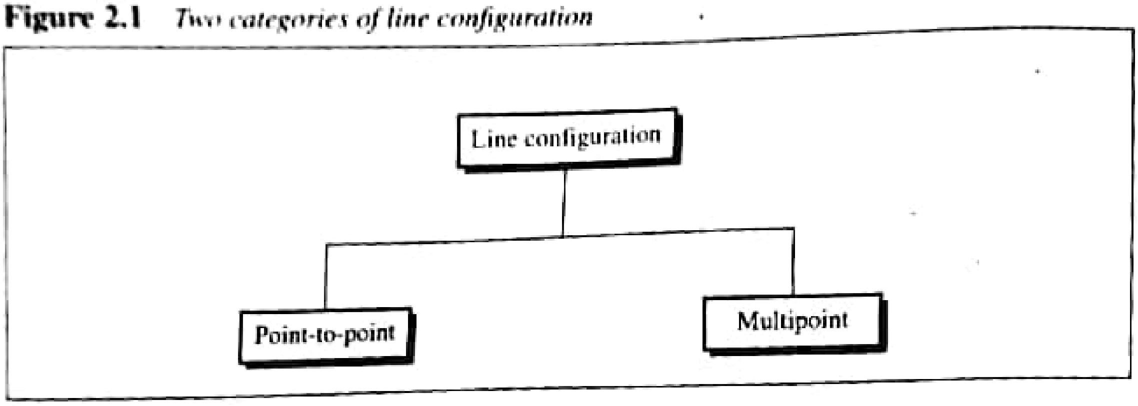
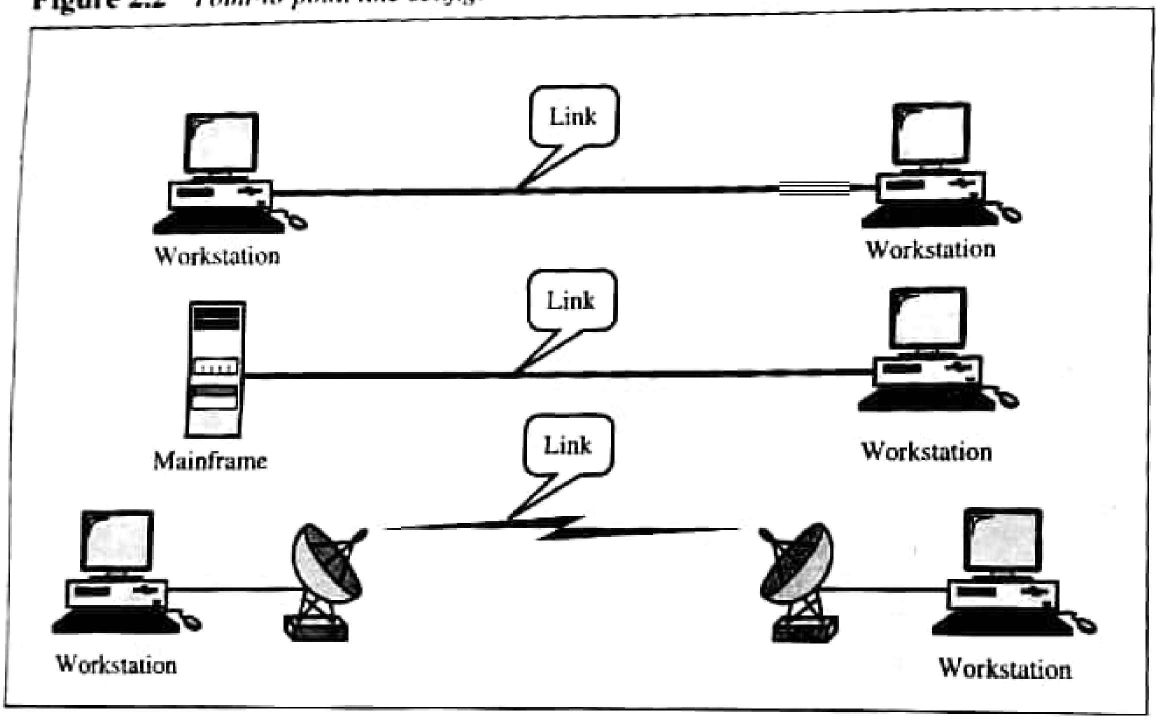


Figure 2.2 *Point-to-point line configuration*



Multipoint

A **multipoint** (also called **multidrop) line configuration** is one in which more than two specific devices share a single link (see Figure 2.3).

In a multipoint environment, the capacity of the channel is shared, either spatially or temporally. If several devices can use the link simultaneously, it is a *spatially shared* line configuration. If users must take turns, it is a *time-shared* line configuration.

2.2 TOPOLOGY

The term **topology** refers to the way a network is laid out, either physically or logically. Two or more devices connect to a link; two or more links form a topology. The topology of a network is the geometric representation of the relationship of all the links and linking devices (usually called **nodes**) to each other. There are five basic topologies possible: mesh, star, tree, bus, and ring (see Figure 2.4).

Figure 2.3 *Multipoint line configuration*

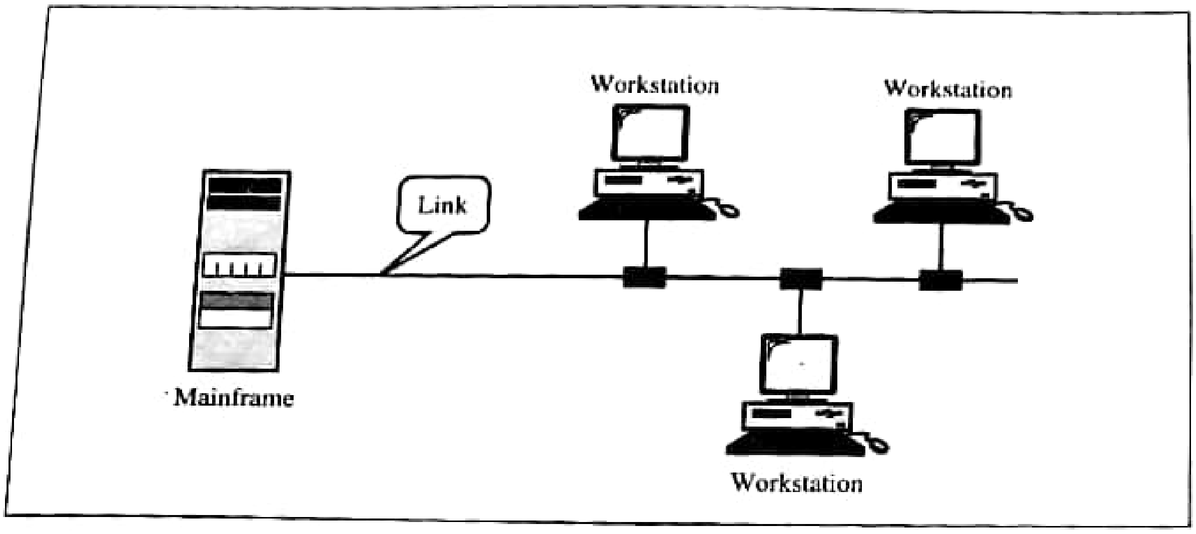
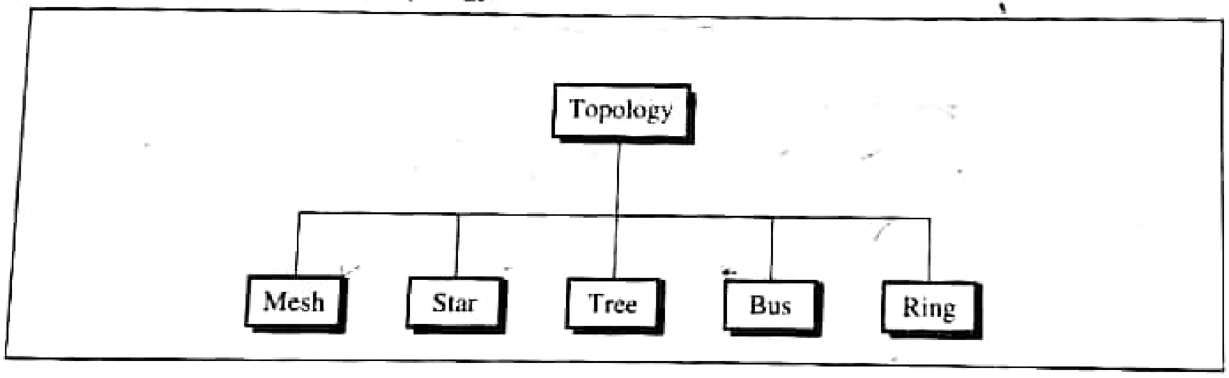


Figure 2.4 *Categories of topology*



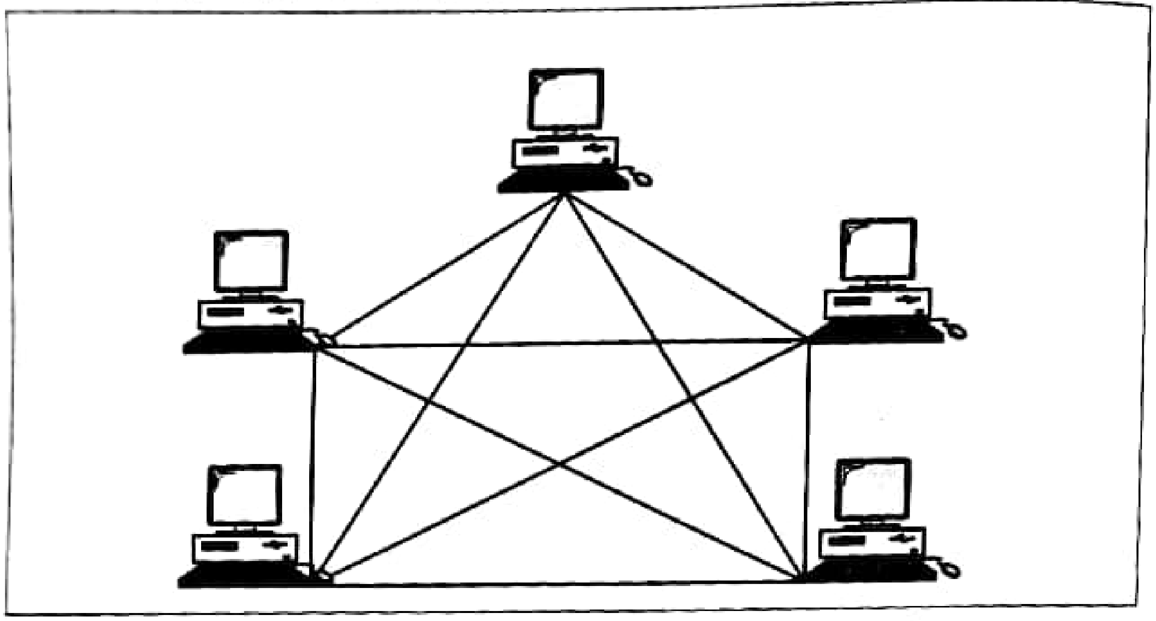
Topology defines the physical or logical arrangement of links in a network.

These five labels describe how the devices in a network are interconnected rather than their physical arrangement. For example, having a star topology does not mean that all of the computers in the network must be placed physically around a hub in a star shape. A consideration when choosing a topology is the relative status of the devices to be linked. Two relationships are possible: **peer-to-peer,** where the devices share the link equally, and **primary–secondary,** where one device controls traffic and the others must transmit through it. Ring and mesh topologies are more convenient for peer-to-peer transmission, while star and tree are more convenient for primary–secondary. A bus topology is equally convenient for either.

Mesh

In a **mesh topology,** every device has a dedicated point-to-point link to every other device. The term *dedicated* means that the link carries traffic only between the two devices it connects. A fully connected mesh network therefore has $n(n-1)/2$ physical channels to link n devices. To accommodate that many links, every device on the network must have $n - 1$ input/output (I/O) ports (see Figure 2.5).

Figure 2.5 *Fully connected mesh topology (for five devices)*



A mesh offers several advantages over other network topologies. First, the use of dedicated links guarantees that each connection can carry its own data load, thus eliminating the traffic problems that can occur when links must be shared by multiple devices.

Second, a mesh topology is robust. If one link becomes unusable, it does not incapacitate the entire system.

Another advantage is privacy or security. When every message sent travels along a dedicated line, only the intended recipient sees it. Physical boundaries prevent other users from gaining access to messages.

Finally, point-to-point links make fault identification and fault isolation easy. Traffic can be routed to avoid links with suspected problems. This facility enables the network manager to discover the precise location of the fault and aids in finding its cause and solution.

The main disadvantages of a mesh are related to the amount of cabling and the number of I/O ports required. First, because every device must be connected to every other device, installation and reconfiguration are difficult. Second, the sheer bulk of the wiring can be greater than the available space (in walls, ceilings, or floors) can accommodate. And, finally, the hardware required to connect each link (I/O ports and cable) can be prohibitively expensive. For these reasons a mesh topology is usually implemented in a limited fashion—for example, as a backbone connecting the main computers of a hybrid network that can include several other topologies.

Example 2.1

The Lucky Ducky Corporation has a fully connected mesh network consisting of eight devices. Calculate the total number of cable links needed and the number of ports for each device.

Solution

The formula for the number of links for a fully connected mesh is $n(n-1)/2$, where n is the number of devices.

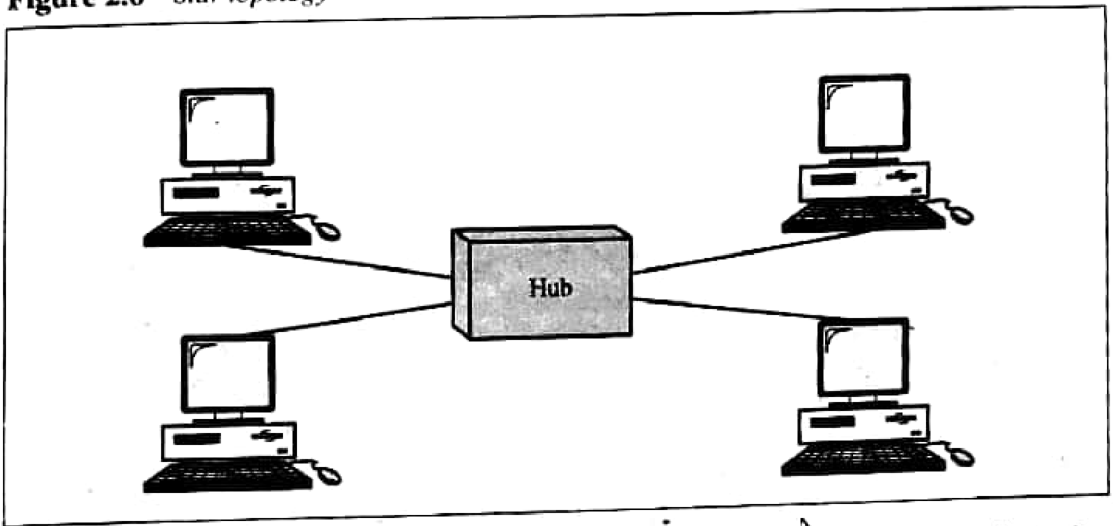
$$\text{Number of links} = n(n-1)/2 = 8(8-1)/2 = 28$$

$$\text{Number of ports per device} = n - 1 = 8 - 1 = 7$$

Star

In a **star topology**, each device has a dedicated point-to-point link only to a central controller, usually called a **hub**. The devices are not directly linked to each other. Unlike a mesh topology, a star topology does not allow direct traffic between devices. The controller acts as an exchange. If one device wants to send data to another, it sends the data to the controller, which then relays the data to the other connected device (see Figure 2.6).

Figure 2.6 *Star topology*



A star topology is less expensive than a mesh topology. In a star, each device needs only one link and one I/O port to connect it to any number of others. This factor also makes it easy to install and reconfigure. Far less cabling needs to be housed, and additions, moves, and deletions involve only one connection: between that device and the hub.

Other advantages include robustness. If one link fails, only that link is affected. All other links remain active. This factor also lends itself to easy fault identification and fault isolation. As long as the hub is working, it can be used to monitor link problems and bypass defective links.

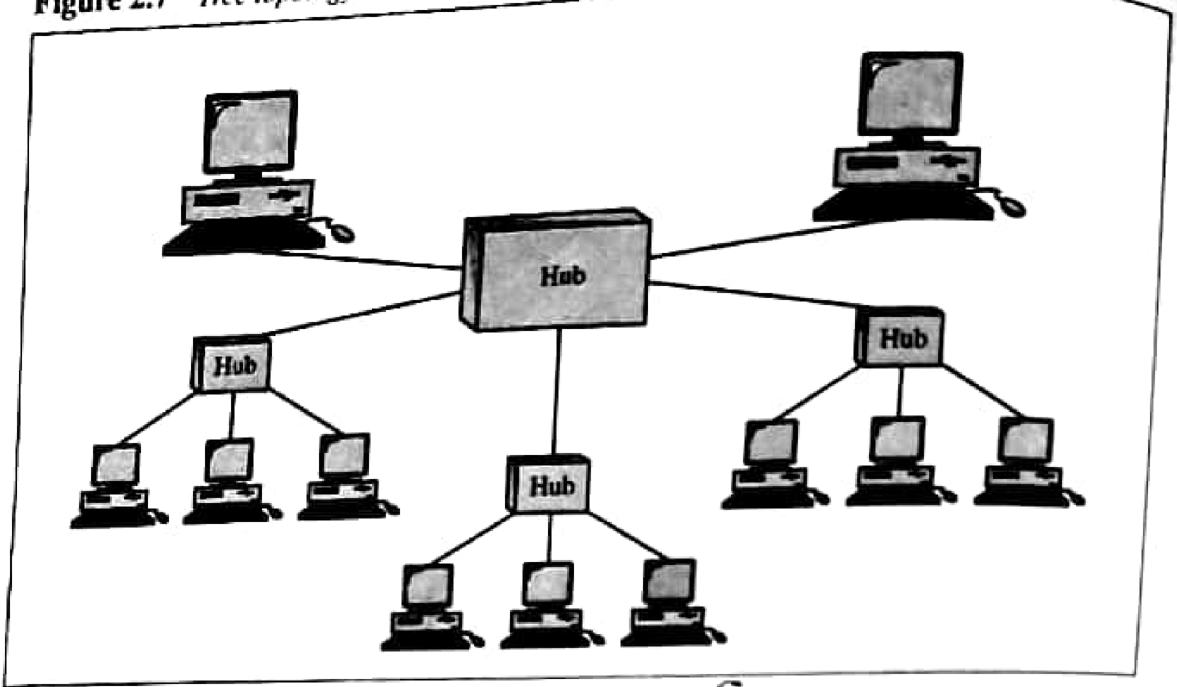
However, although a star requires far less cable than a mesh, each node must be linked to a central hub. For this reason more cabling is required in a star than in some other topologies (such as tree, ring, or bus).

Tree

A **tree topology** is a variation of a star. As in a star, nodes in a tree are linked to a central hub that controls the traffic to the network. However, not every device plugs directly into the central hub. The majority of devices connect to a secondary hub that in turn is connected to the central hub (see Figure 2.7).

The central hub in the tree is an active hub. An **active hub** contains a repeater, which is a hardware device that regenerates the received bit patterns before sending them out (repeaters are discussed at length in Chapter 21). Repeating strengthens transmissions and increases the distance a signal can travel.

Figure 2.7 *Tree topology*



The secondary hubs may be active or passive hubs. A **passive hub** provides a simple physical connection between the attached devices.

The advantages and disadvantages of a tree topology are generally the same as those of a star. The addition of secondary hubs, however, brings two further advantages. First, it allows more devices to be attached to a single central hub and can therefore increase the distance a signal can travel between devices. Second, it allows the network to isolate and prioritize communications from different computers. For example, the computers attached to one secondary hub can be given priority over computers attached to another secondary hub. In this way, the network designers and operator can guarantee that time-sensitive data will not have to wait for access to the network.

A good example of tree topology can be seen in cable TV technology where the main cable from the main office is divided into main branches and each branch is divided into smaller branches and so on. The hubs are used when a cable is divided.

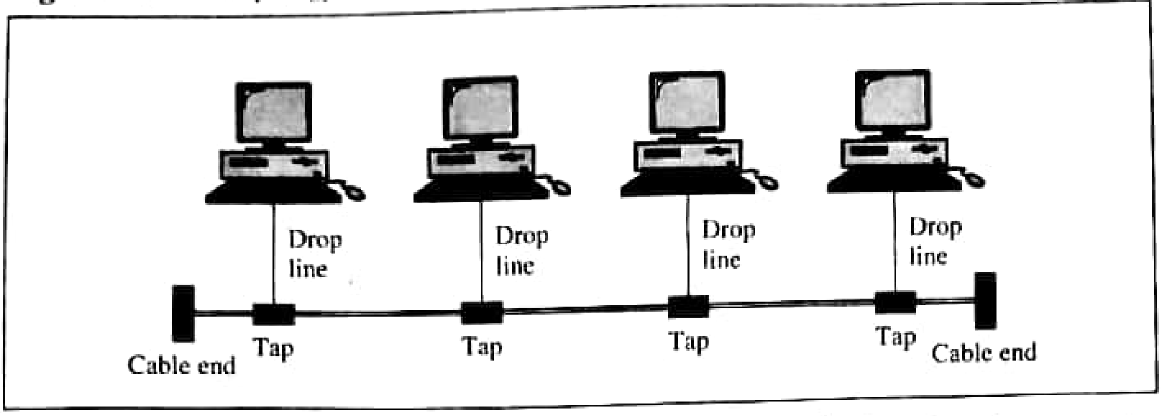
Bus

The preceding examples all describe point-to-point configurations. A **bus topology,** on the other hand, is multipoint. One long cable acts as a **backbone** to link all the devices in the network (see Figure 2.8).

Nodes are connected to the bus cable by drop lines and taps. A drop line is a connection running between the device and the main cable. A tap is a connector that either splices into the main cable or punctures the sheathing of a cable to create a contact with the metallic core. As a signal travels along the backbone, some of its energy is transformed into heat. Therefore, it becomes weaker and weaker the farther it has to travel. For this reason there is a limit on the number of taps a bus can support and on the distance between those taps.

Advantages of a bus topology include ease of installation. Backbone cable can be laid along the most efficient path, then connected to the nodes by drop lines of various lengths. In this way, a bus uses less cabling than mesh, star, or tree topologies. In a star,

Figure 2.8 *Bus topology*



for example, four network devices in the same room require four lengths of cable reaching all the way to the hub. In a bus, this redundancy is eliminated. Only the backbone cable stretches through the entire facility. Each drop line has to reach only as far as the nearest point on the backbone.

Disadvantages include difficult reconfiguration and fault isolation. A bus is usually designed to be optimally efficient at installation. It can therefore be difficult to add new devices. As mentioned above, signal reflection at the taps can cause degradation in quality. This degradation can be controlled by limiting the number and spacing of devices connected to a given length of cable. Adding new devices may therefore require modification or replacement of the backbone.

In addition, a fault or break in the bus cable stops all transmission, even between devices on the same side of the problem. The damaged area reflects signals back in the direction of origin, creating noise in both directions.

Ring

In a **ring topology,** each device has a dedicated point-to-point line configuration only with the two devices on either side of it. A signal is passed along the ring in one direction, from device to device, until it reaches its destination. Each device in the ring incorporates a repeater. When a device receives a signal intended for another device, its repeater regenerates the bits and passes them along (see Figure 2.9).

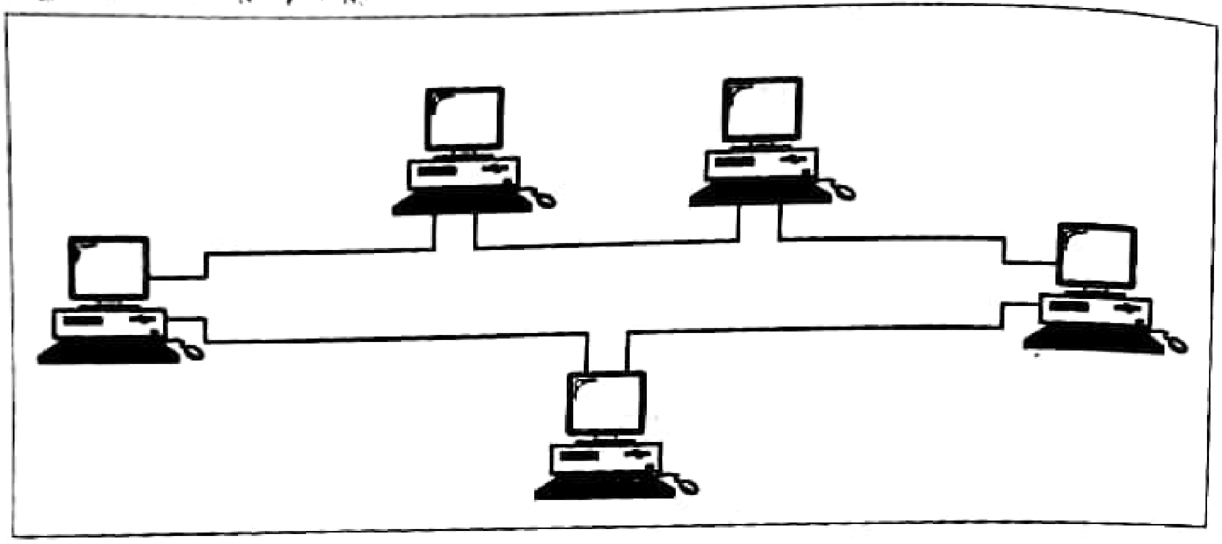
A ring is relatively easy to install and reconfigure. Each device is linked only to its immediate neighbors (either physically or logically). To add or delete a device requires moving only two connections. The only constraints are media and traffic considerations (maximum ring length and number of devices). In addition, fault isolation is simplified. Generally in a ring, a signal is circulating at all times. If one device does not receive a signal within a specified period, it can issue an alarm. The alarm alerts the network operator to the problem and its location.

However, unidirectional traffic can be a disadvantage. In a simple ring, a break in the ring (such as a disabled station) can disable the entire network. This weakness can be solved by using a dual ring or a switch capable of closing off the break.

Example 2.2

If the devices in Example 2.1 are configured as a ring instead of a mesh, how many cable links are required?

Figure 2.9 *Ring topology*



Solution

To connect n devices in a ring topology, we need n cable links. An eight-device ring needs eight cable links.

Hybrid Topologies

Often a network combines several topologies as subnetworks linked together in a larger topology. For instance, one department of a business may have decided to use a bus topology while another department has a ring. The two can be connected to each other via a central controller in a star topology (see Figure 2.10).

Figure 2.10 *Hybrid topology*