UNIT-2

Bandwidth utilization Multiplexing: FDM, TDM, spread spectrum. Transmission Media- guided media and unguided media .Switching: message, Circuit and packet switched networks, datagram networks, virtual- circuit networks.

Bandwidth utilization

Sometimes we need to combine several low-bandwidth channels to make use of one channel with a larger bandwidth. Sometimes we need to expand the bandwidth of a channel to achieve goals such as privacy and antijamming.
Two broad categories of bandwidth utilization:

- multiplexing
- spreading.

In multiplexing, our goal is efficiency;we combine several channels into one. In spreading, our goals are privacy and antijamming; we expand the bandwidth of a channel to insert redundancy, which is necessary to achieve these goals.
Bandwidth utilization is the use of available bandwidth to achieve specific goals.Efficiency can be achieved by multiplexing;privacy and antijamming can be achieved by spreading.

MULTIPLEXING

Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, the link can be shared. **Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link**.

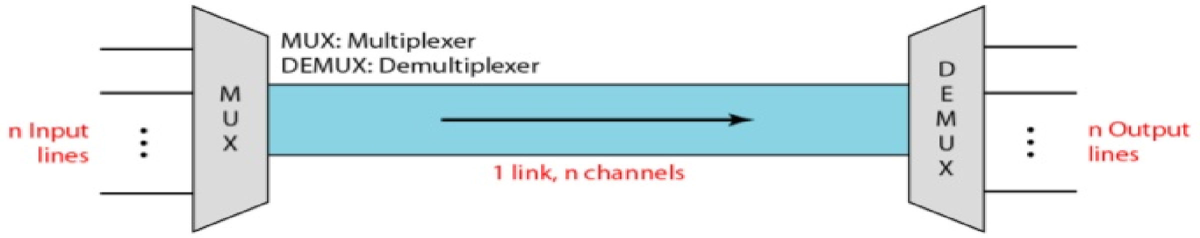
As data and telecommunications use increases, so does traffic. We can accommodate this increase by continuing to add individual links each time a new channel is needed; or we can install higher-bandwidth links and use each to carry multiple signals.

If the bandwidth of a link is greater than the bandwidth needs of the devices connected to it, the bandwidth is wasted. An efficient system maximizes the utilization of all resources; bandwidth is one of the most precious resources we have in data communications.

In a multiplexed system, *n* lines share the bandwidth of one link. Figure 6.1 shows the basic format of a multiplexed system. The lines on the left direct their transmission streams to a multiplexer (MUX), which combines them into a single stream (many-to-one).

At the receiving end, that stream is fed into a demultiplexer (DEMUX), which separates the stream back into its component transmissions (one-to-many) and directs them to their corresponding lines. In the figure, the word link refers to the physical path. The word channel refers to the portion of a link that carries a transmission between a given pair of lines. One link can have many *(n)* channels.

Figure 6.1 *Dividing a link into channels*

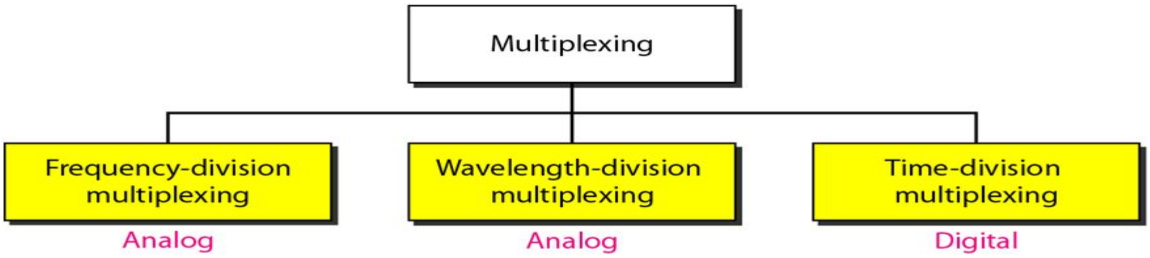


There are three basic multiplexing techniques:

- Frequency-division multiplexing,
- Wavelength-division multiplexing
- Time-division multiplexing.

The first two are techniques designed for analog signals, the third, for digital signals.

Figure 6.2 *Categories of multiplexing*



Frequency-Division Multiplexing

Frequency-division multiplexing (FDM) is an analog technique that can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted. In FDM, signals generated by each sending device modulate different carrier frequencies. These modulated signals are then combined into a single composite signal that can be transported by the link. Carrier frequencies are separated by sufficient bandwidth to accommodate the modulated signal. These bandwidth ranges are the channels through which the various signals travel. Channels can be separated by strips of unused bandwidth-guard bands-to prevent signals from overlapping. In addition, carrier frequencies must not interfere with the original data frequencies.

Figure 6.3 gives a conceptual view of FDM. In this illustration, the transmission path is divided into three parts, each representing a channel that carries one transmission.

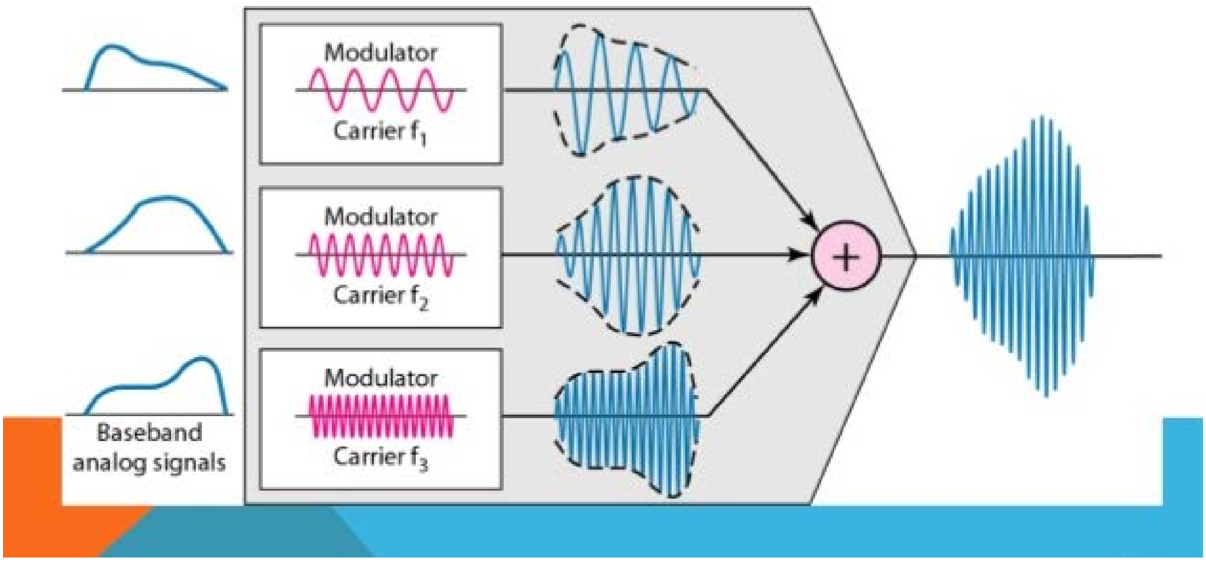
Figure 6.3 *Frequency-division multiplexing*

FDM is an analog multiplexing technique that combines analog signals.If a source sends digital signal it will be converted to analog signal before FDM is used to multiplex them.

Multiplexing Process

Figure 6.4 is a conceptual illustration of the multiplexing process. Each source generates a signal of a similar frequency range. Inside the multiplexer, these similar signals modulates different carrier frequencies *(f1,f2,* and *f3).* The resulting modulated signals are then combined into a single composite signal that is sent out over a media link that has enough bandwidth to accommodate it.

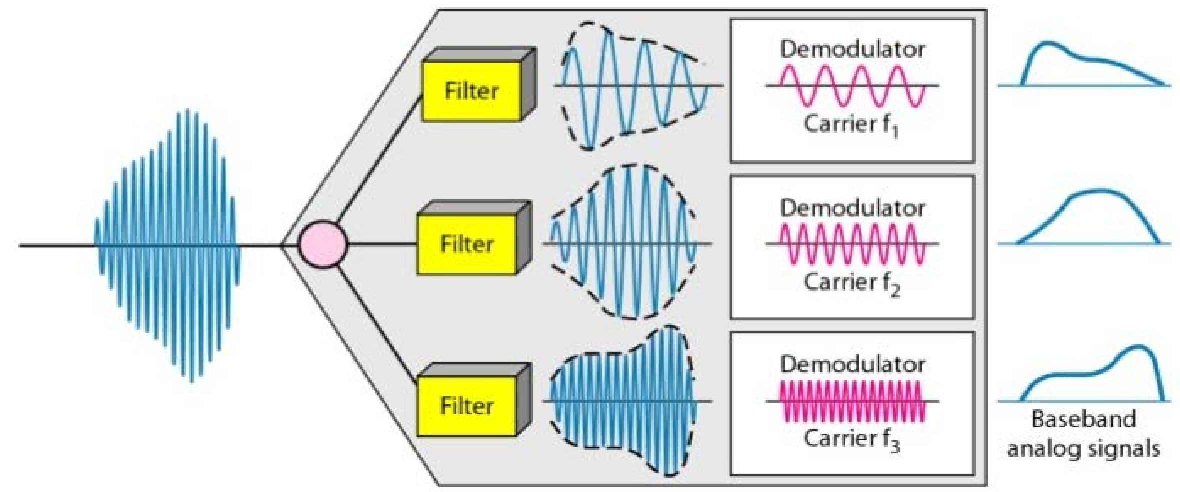
Figure 6.4 ***FDM process***



Demultiplexing Process

The demultiplexer uses a series of filters to decompose the multiplexed signal into its constituent component signals. The individual signals are then passed to a demodulator that separates them from their carriers and passes them to the output lines. Figure 6.5 is a conceptual illustration of demultiplexing process.

Figure 6.5 ***FDM demultiplexing example***



Time-Division Multiplexing

Time-division multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a line. Instead of sharing a portion of the bandwidth as in FDM, time is shared. Each connection occupies a portion of time in the link. Figure 6.12 gives a conceptual view of TDM. The same link is used as in FDM; here, however, the link is shown sectioned by time rather than by frequency. In the figure, portions of signals 1,2,3, and 4 occupy the link sequentially.

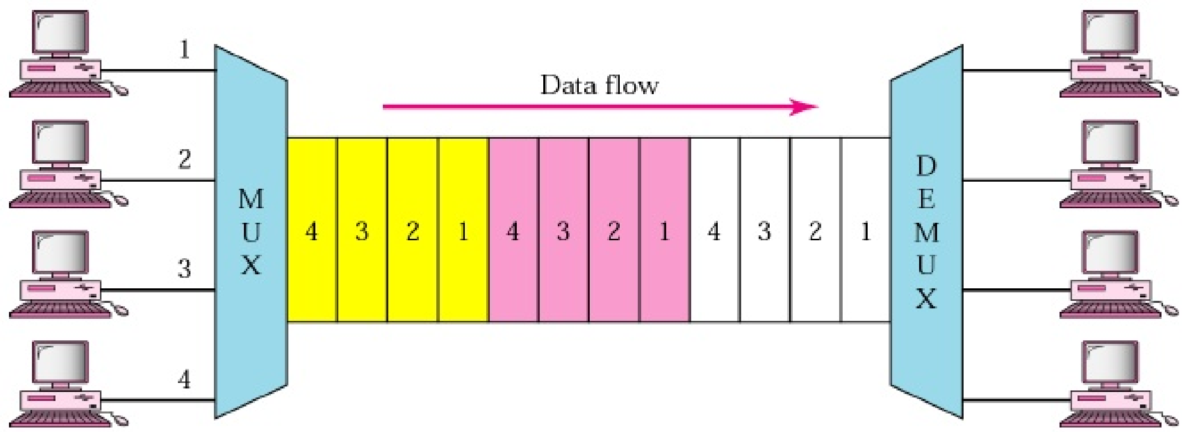


Figure 6.12 *TDM*

Note that in Figure 6.12 we are concerned with only multiplexing, not switching. This means that all the data in a message from source 1 always go to one specific destination, be it 1, 2, 3, or 4. The delivery is fixed and unvarying, unlike switching.

TDM is a digital multiplexing technique. Digital data from different sources are combined into one timeshared link. However, this does not mean that the sources cannot produce analog data; analog data can be sampled, changed to digital data, and then multiplexed by using TDM.

We can divide TDM into two different schemes:

- Synchronous
- Statistical.

Synchronous TDM

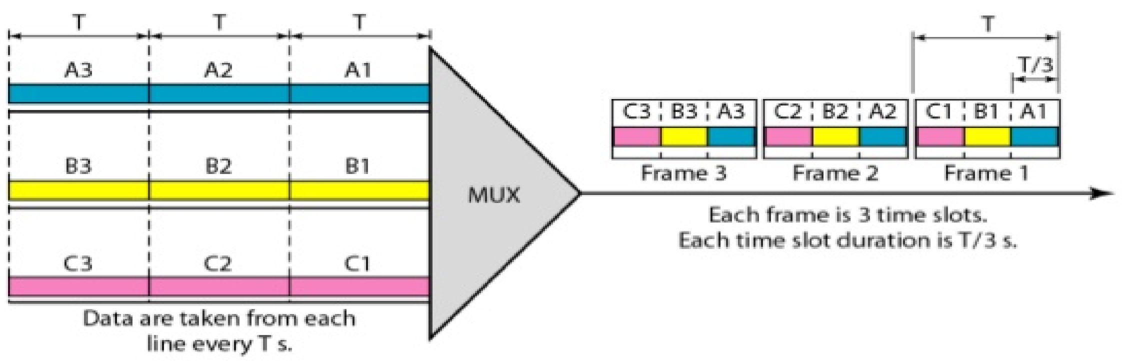
In synchronous TDM, each input connection has an allotment in the output even if it is not sending data.

Time Slots and Frames

In synchronous TDM, the data flow of each input connection is divided into units, where each input occupies one input time slot. A unit can be 1 bit, one character, or one block of data. Each input unit becomes one output unit and occupies one output time slot. However, the duration of an output time slot is *n* times shorter than the duration of an input time slot. If an input time slot is *T* s, the output time slot is *Tin* s, where *n* is the number of connections. In other words, a unit in the output connection has a shorter duration; it travels faster. Figure 6.13 shows an example of synchronous TDM where *n* is 3.

TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.

Figure 6.13 ***Synchronous time-division multiplexing***



In synchronous TDM, a round of data units from each input connection is collected into frame. If we have n connections, a frame is divided into n time slots and one time slot is allocated for each unit, one for each input line. If the duration of each input unit is T,the duration of each slots is T/n and the duration of each frame is T.

The data rate of the output link must be n times the data rate of a connection to guarantee the flow of data.

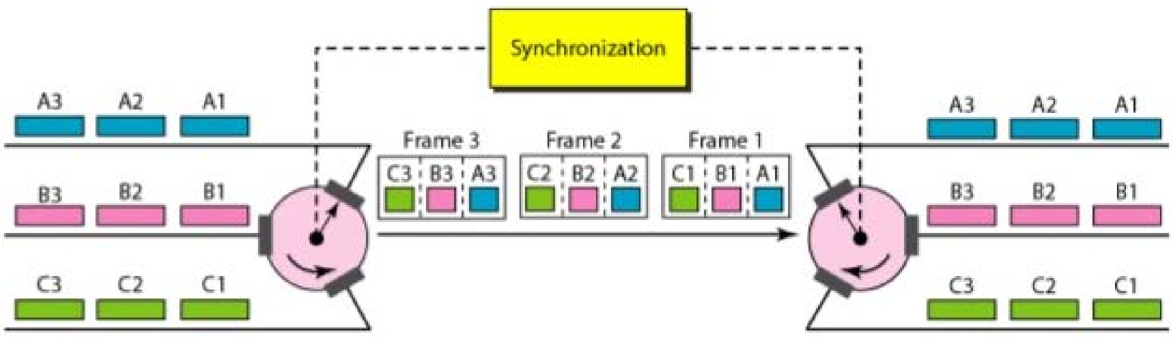
In synchronous TDM, the data rate of the link is *n* times faster, and the unit duration is *n* times shorter.

Interleaving

TDM can be visualized as two fast-rotating switches, one on the multiplexing side and the other on the demultiplexing side. The switches are synchronized and rotate at the same speed, but in opposite directions. On the multiplexing side, as the switch opens in front of a connection, that connection has the opportunity to send a unit onto the path. This process is called **interleaving.** On the demultiplexing side, as the switch opens in front of a connection, that connection has the opportunity to receive a unit from the path.

Figure 6.15 shows the interleaving process for the connection shown in Figure 6.13. In this fig: we assume no switching is involved and that the data from the first connection at the multiplexer site go to the first connection at the demultiplexer.

Figure 6.15 ***Interleaving***



Empty Slots

Synchronous TDM is not as efficient as it could be. If a source does not have data to send, the corresponding slot in the output frame is empty. Figure 6.18 shows a case in which one of the input lines has no data to send and one slot in another input line has discontinuous data.

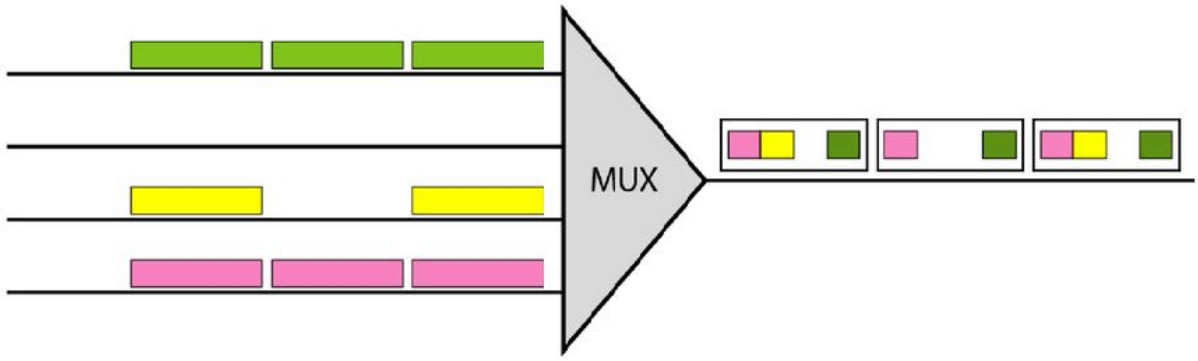


Figure 6.18 Empty slots

The first output frame has 3 slots filled, the second frame has 2 slots filled and the third frame has 3 slots filled. No frame is full. Statistical TDM can improve efficiency by removing the empty slots from the frame.

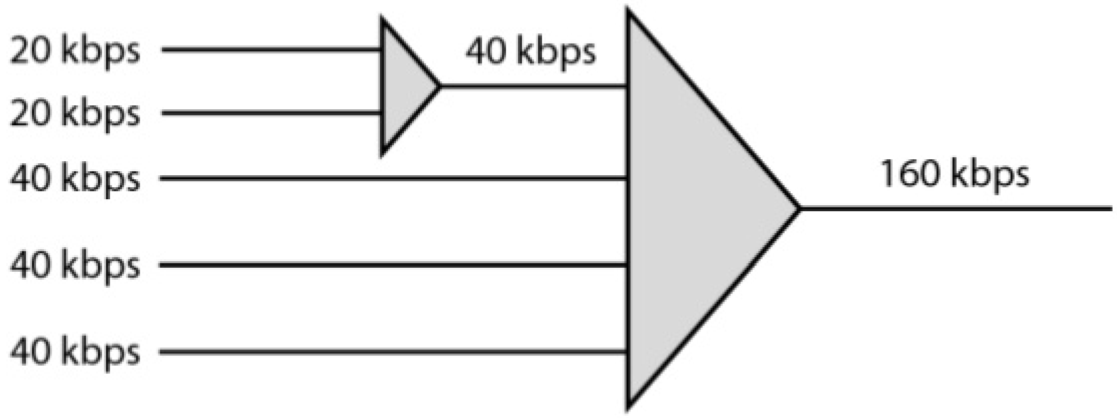
Data Rate management

If data rates are not same,3 strategies or a combination of them can be used.

1. Multilevel multiplexing
2. multiple slot allocation
3. pulse stuffing

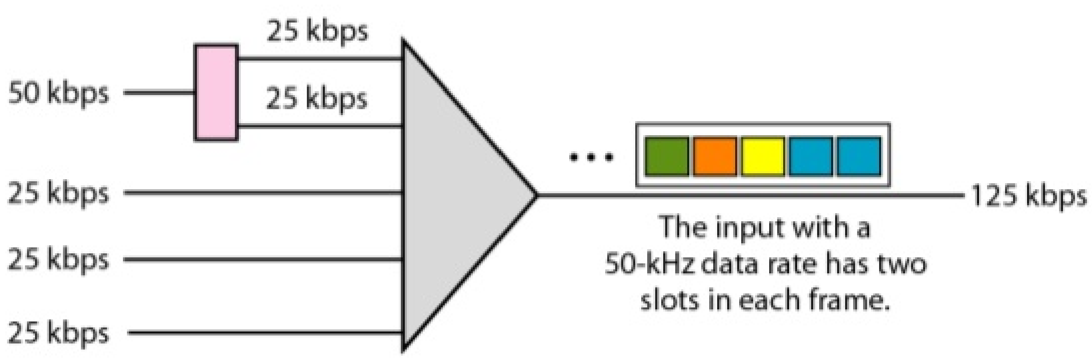
Multilevel Multiplexing Multilevel multiplexing is a technique used when the data rate of an input line is a multiple of others. For example, in Figure 6.19, we have two inputs of 20 kbps and three inputs of 40 kbps. The first two input lines can be multiplexed together to provide a data rate equal to the last three. A second level of multiplexing can create an output of 160 kbps.

Figure 6.19 *Multilevel multiplexing*



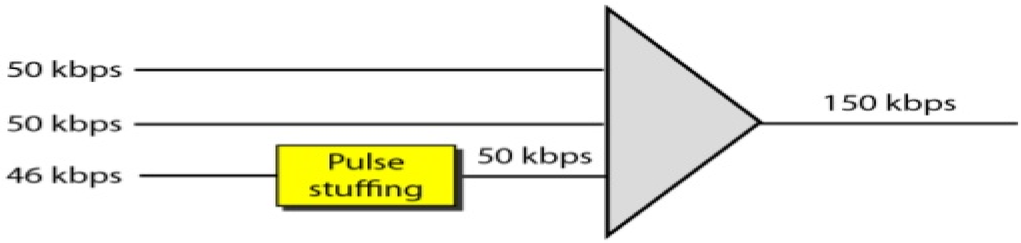
Multiple-Slot Allocation Sometimes it is more efficient to allot more than one slot in a frame to a single input line. For example, we might have an input line that has a data rate that is a multiple of another input. In Figure 6.20, the input line with a 50-kbps data rate can be given two slots in the output. We insert a serial-to-parallel converter in the line to make two inputs out of one.

Figure 6.20 *Multiple-slot multiplexing*



Pulse Stuffing Sometimes the bit rates of sources are not multiple integers of each other. Therefore, neither of the above two techniques can be applied. One solution is to make the highest input data rate the dominant data rate and then add dummy bits to the input lines with lower rates. This will increase their rates. This technique is called pulse stuffing, bit padding, or bit stuffing. The idea is shown in Figure 6.21. The input with a data rate of 46 is pulse-stuffed to increase the rate to 50 kbps. Now multiplexing can take place.

Figure 6.21 ***Pulse stuffing***



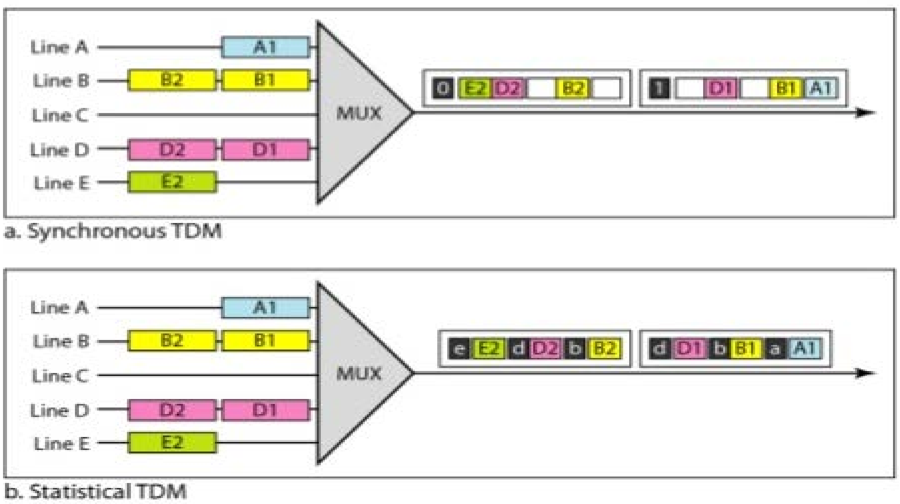
Statistical Time-Division Multiplexing

In synchronous TDM, each input has a reserved slot in the output frame. This can be inefficient if some input lines have no data to send.

In statistical time-division multiplexing, slots are dynamically allocated to improve bandwidth efficiency. Only when an input line has a slot's worth of data to send is it given a slot in the output frame. In statistical multiplexing, the number of slots in each frame is less than the number of input lines. The multiplexer checks each input line in roundrobin fashion; it allocates a slot for an input line if the line has data to send; otherwise, it skips the line and checks the next line.

Figure 6.26 shows a synchronous and a statistical TDM example. In the former, some slots are empty because the corresponding line does not have data to send. In the latter, however, no slot is left empty as long as there are data to be sent by any input line.

Figure 6.26 ***TDM slot comparison***



Addressing

Figure 6.26 also shows a major difference between slots in synchronous TDM and statistical TDM. An output slot in synchronous TDM is totally occupied by data; in statistical TDM, a slot needs to carry data as well as the address of the destination.

In synchronous TDM, there is no need for addressing; synchronization and preassigned relationships between the inputs and outputs serve as an address.

SPREAD SPECTRUM

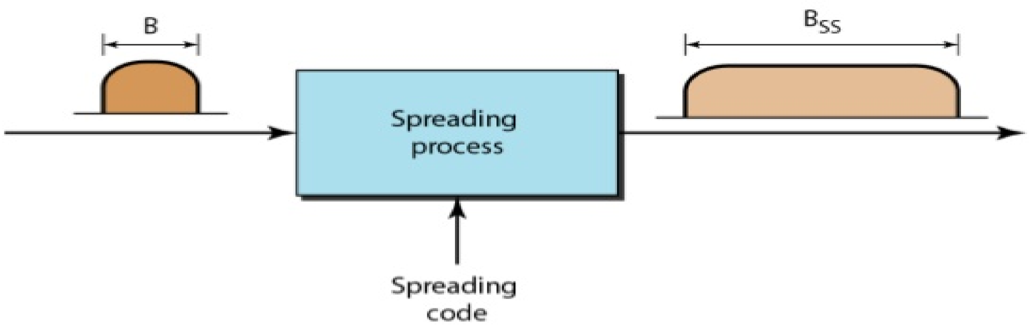
Multiplexing combines signals from several sources to achieve bandwidth efficiency; the available bandwidth of a link is divided between the sources. In spread spectrum signals from different sources are combined to fit into a larger bandwidth. Spread spectrum is designed to be used in wireless applications (LANs and WANs). In wireless applications, all stations use air (or a vacuum) as the medium for communication. Stations must be able to share this medium without interception by an eavesdropper and without being subject to jamming from a malicious intruder.

Spread spectrum is a form of wireless communications in which the frequency of the transmitted signal is deliberately varied.

Spread spectrum techniques add redundancy; they spread the original spectrum needed for each station. If the required bandwidth for each station is *B*, spread spectrum expands it to Bss such that Bss » *B*. The expanded bandwidth allows the source to wrap its message in a protective envelope for a more secure transmission.

Spread spectrum achieves its goals through two principles:
1. The bandwidth allocated to each station needs to be larger than what is needed. This allows redundancy.
2. The expanding of the original bandwidth *B* to the bandwidth Bss must be done by a process that is independent of the original signal. In other words, the spreading process occurs after the signal is created by the source.

Figure 6.27 ***Spread spectrum***



After the signal is created by the source, the spreading process uses a spreading code and spreads the bandwidth. The figure shows the original bandwidth *B* and the spreaded bandwidth *BSS*. The spreading code is a series of numbers that look random, but are actually a pattern.
There are two techniques to spread the bandwidth:

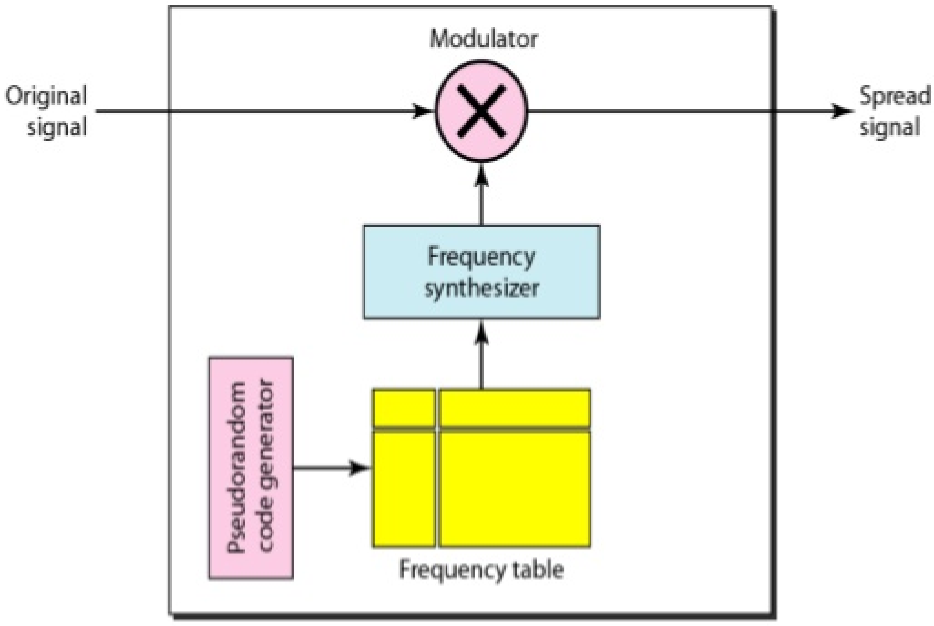
- Frequency hopping spread spectrum(FHSS)
- Direct sequence spread spectrum (DSSS).

Frequency Hopping Spread Spectrum (FHSS)

The frequency hopping spread spectrum (FHSS) technique uses *M* different carrier frequencies that are modulated by the source signal. At one moment, the signal modulates one carrier frequency; at the next moment, the signal modulates another carrier frequency. Although the modulation is done using one carrier frequency at a time, *M* frequencies are used in the long run. The bandwidth occupied by a source after spreading is *BpHSS »B.*

Figure 6.28 shows the general layout for FHSS. A pseudorandom code generator, called pseudorandom noise (PN), creates a k-bit pattern for every hopping period *Th.* The frequency table uses the pattern to find the frequency to be used for this hopping period and passes it to the frequency synthesizer. The frequency synthesizer creates a carrier signal of that frequency, and the source signal modulates the carrier signal.

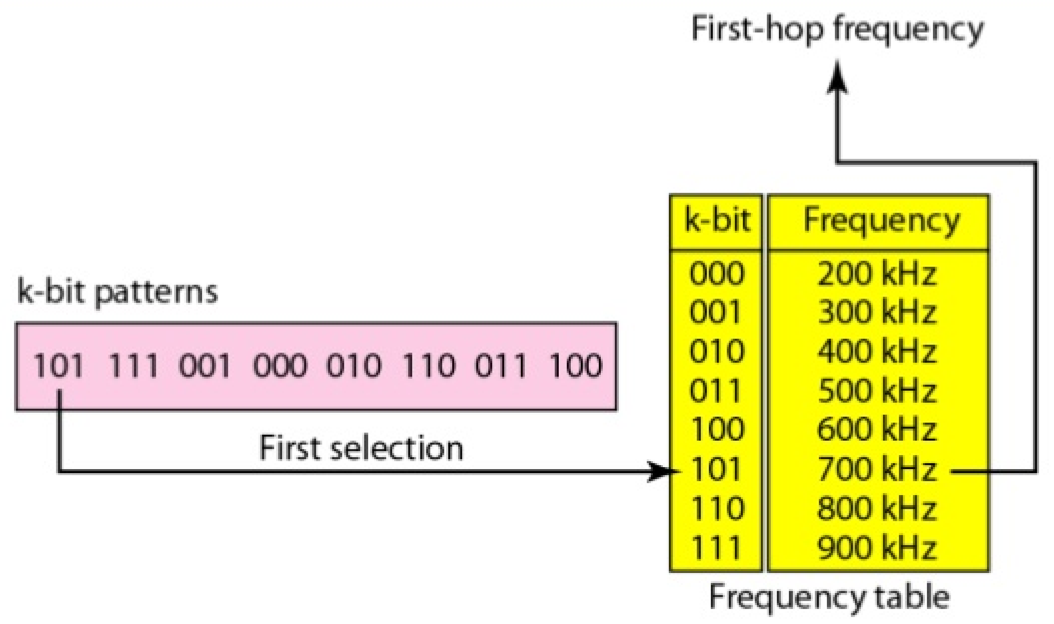
Figure 6.28 ***Frequency hopping spread spectrum (FHSS)***



We have eight hopping frequencies. In this case, *Mis* 8 and *k* is 3. The pseudorandom code generator will create eight different 3-bit patterns. These are mapped to eight different frequencies in the frequency table. The pattern for this station is 101, 111, 001, 000, 010, all, 100.The pattern is pseudorandom it is repeated after eight hoppings.This means that at hopping period 1, the pattern is 101. The frequency selected is 700 kHz; the source signal modulates this carrier frequency. The second k-bit pattern selected is 111, which selects the

900-kHz carrier; the eighth pattern is 100, the frequency is 600 kHz. After eight hoppings, the pattern repeats, starting from 101 again.

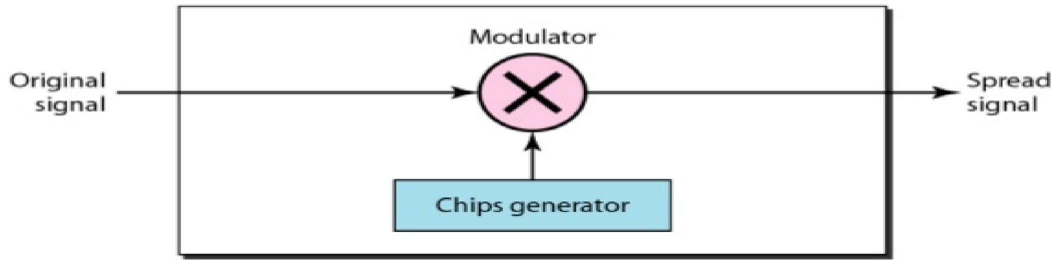
Figure 6.29 ***Frequency selection in FHSS***



Direct Sequence Spread Spectrum

Direct sequence spread spectrum (**DSSS**) is a transmission technology used in local area wireless network transmissions. In this technology, a data signal at the sending station is combined with a high data rate bit **sequence**, which divides user data based on a spreading ratio. In DSSS, we replace each data bit with n bits using a spreading code. In other words, each bit is assigned a code of n bits, called chips, where the chip rate is n times that of the data bit. Figure 6.32 shows the concept of DSSS.

Figure 6.32 ***DSSS***



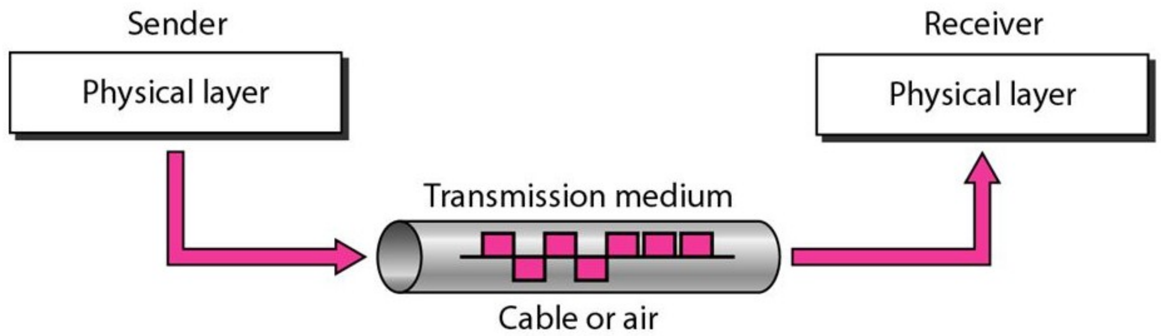
UNIT 2

Transmission Media- guided media and unguided media.

Transmission Media

Transmission media are located below the physical layer and are directly controlled by the physical layer. Figure 7.1 shows the position of transmission media in relation to the physical layer.

Figure 7.1 *Transmission medium and physical layer*



A transmission **medium** can be broadly defined as anything that can carry information from a source to a destination. The transmission medium is usually free space, metallic cable, or fiber-optic cable.
In telecommunications, transmission media can be divided into two broad categories:

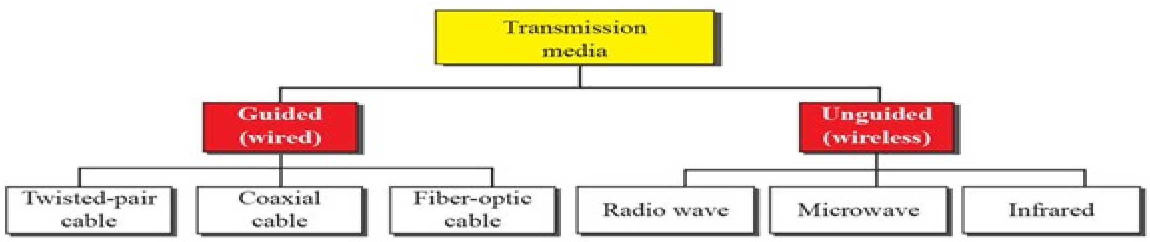
- Guided
- Unguided.

Guided media include

1. Twisted-pair cable,
2. Coaxial cable
3. Fiber-optic cable.

Unguided medium is free space.

Figure 7.2: Classes of transmission media

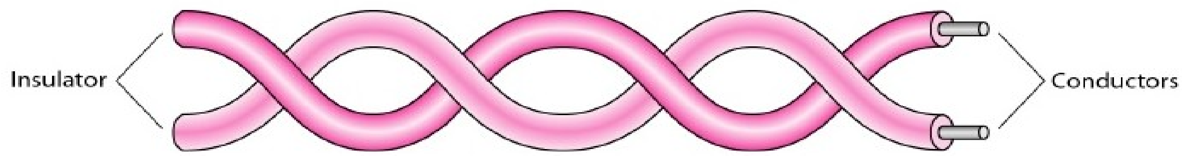


GUIDED MEDIA

This is the type of communication in which communication devices are directly linked with each other via cables or physical media. Examples include twisted pair cable, coaxial cable and optical fiber.
Twisted-pair and coaxial cable use metallic (copper) conductors that accept and transport signals in the form of electric current. Optical fiber is a cable that accepts and transports signals in the form of light.

Twisted-Pair Cable
A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together, as shown in Figure 7.3.

Figure 7.3 ***Twisted-pair cable***



One of the wires is used to **carry signals to the receiver**, and the other is used only as a **ground reference**. The receiver uses the difference between the two. In addition to the signal sent by the sender on one of the wires, interference (noise) and crosstalk may affect both wires and create unwanted signals.

If the two wires are parallel, the effect of these unwanted signals is not the same in both wires because they are at different locations relative to the noise or crosstalk sources (e,g., one is closer and the other is farther). This results in a difference at the receiver. By twisting the pairs, a balance is maintained.
For example, suppose in one twist, one wire is closer to the noise source and the other is farther; in the next twist, the reverse is true. Twisting makes it probable that both wires are equally affected by external influences (noise or crosstalk). This means that the receiver, which calculates the difference between the two, receives no unwanted signals. The unwanted signals are mostly cancelled out. The number of twists per unit of length (e.g., inch) has some effect on the quality of the cable.

Unshielded Versus Shielded Twisted-Pair Cable

The most common twisted-pair cable used in communications is referred to as unshielded twisted-pair (UTP). Shielded twisted-pair (STP) cable has a metal foil or braided mesh covering that encases each pair of insulated conductors. Although metal casing improves the quality of cable by preventing the penetration of noise or crosstalk, it is bulkier and more expensive. Figure 7.4 shows the difference between UTP and STP.

Figure 7.4 *UTP and STP cables*

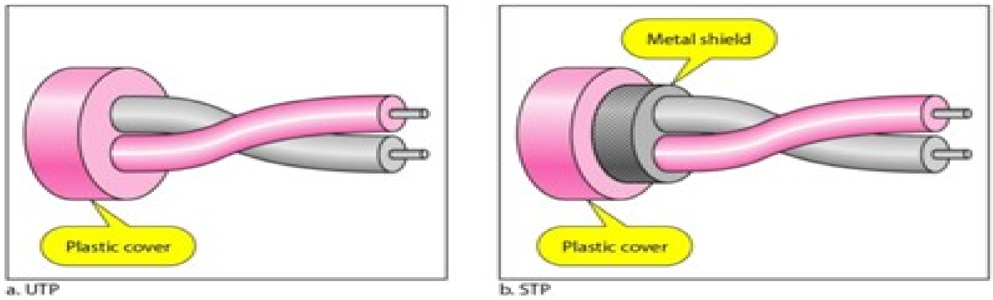


Table 7.1 *Categories of unshielded twisted-pair cables*

Category	*Specification*	*Data Rate (Mbps)*	*Use*
1	Unshielded twisted-pair used in telephone	< 0.1	Telephone
2	Unshielded twisted-pair originally used in T-lines	2	T-1 lines
3	Improved CAT 2 used in LANs	10	LANs
4	Improved CAT 3 used in Token Ring networks	20	LANs
5	Cable wire is normally 24 AWG with a jacket and outside sheath	100	LANs
5E	An extension to category 5 that includes extra features to minimize the crosstalk and electromagnetic interference	125	LANs
6	A new category with matched components coming from the same manufacturer. The cable must be tested at a 200-Mbps data rate.	200	LANs
7	Sometimes called SSTP (shielded screen twisted-pair). Each pair is individually wrapped in a helical metallic foil followed by a metallic foil shield in addition to the outside sheath. The shield decreases the effect of crosstalk and increases the data rate.	600	LANs

Performance

One way to measure the performance of twisted-pair cable is to compare attenuation versus frequency and distance. A twisted-pair cable can pass a wide range of frequencies. *gauge* is a measure of the thickness of the wire.

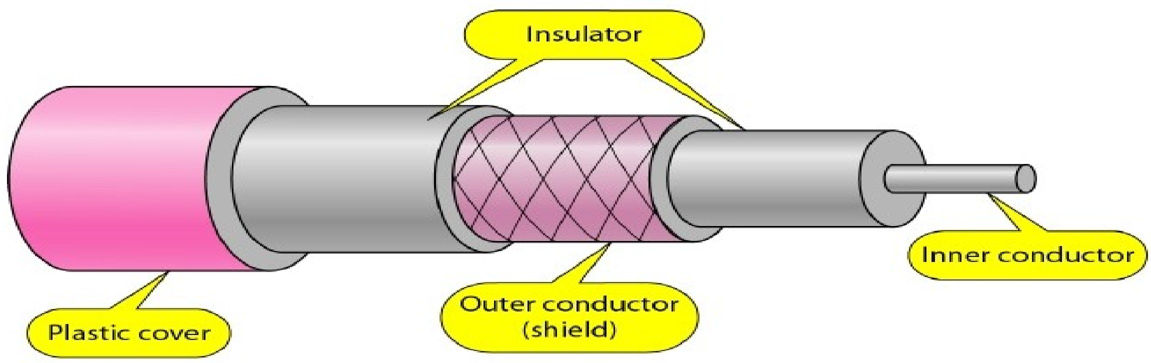
Applications

- Twisted-pair cables are used in **telephone lines** to provide voice and data channels. The local loop-the line that connects subscribers to the central telephone office---commonly consists of unshielded twisted-pair cables.
- The DSL lines that are used by the telephone companies to provide high-data-rate connections also use the high-bandwidth capability of unshielded twisted-pair cables.
- Local-area networks, such as l0Base-T and l00Base-T, also use twisted-pair cables.

Coaxial Cable

Coaxial cable (or *coax)* carries signals of higher frequency ranges than those in twisted pair cable. Instead of having two wires, coax has a central core conductor of solid or stranded wire (usually copper) enclosed in an insulating sheath, which is, in turn, encased in an outer conductor of metal foil, braid, or a combination of the two. The outer metallic wrapping serves both as a shield against noise and as the second conductor, which completes the circuit. This outer conductor is also enclosed in an insulating sheath, and the whole cable is protected by a plastic cover.

Figure 7.7 ***Coaxial cable***



Coaxial Cable Standards

Coaxial cables are categorized by their radio government (RG) ratings. Each RG number denotes a unique set of physical specifications, including the wire gauge of the inner conductor, the thickness and type of the inner insulator, the construction of the shield, and the size and type of the outer casing. Each cable defined by an RG rating is adapted for a specialized function.

Table 7.2 ***Categories of coaxial cables***

Category	*Impedance*	*Use*
RG-59	75 Ω	Cable TV
RG-58	50 Ω	Thin Ethernet
RG-11	50 Ω	Thick Ethernet

Coaxial Cable Connectors

The most common type of connector used today is the Bayone-Neill-Concelman (BNe), connector.
Figure 7.8 shows three popular types of these connectors:

- The BNC connector
- The BNC T connector
- The BNC terminator.

The **BNC connector** is used to connect the end of the cable to a device, such as a TV set. **The BNC T connecto**r is used in Ethernet networks to branch out to a connection to a computer or other device.
The **BNC terminator** is used at theend of the cable to prevent the reflection of the signal.

Applications

Coaxial cable was widely used in **analog telephone networks** where a single coaxial network could carry 10,000 voice signals. Later it was used in digital telephone networks where a single coaxial cable could carry digital data up to 600 Mbps. However, coaxial cable in telephone networks has largely been replaced today with fiber-optic cable.

Cable TV networks also use coaxial cables. In the traditional cable TV network, the entire network used coaxial cable. Later cable TV providers replaced most of the media with fiber optic cable; hybrid networks use coaxial cable only at the network boundaries, near the consumer premises. Cable TV uses RG-59 coaxial cable.

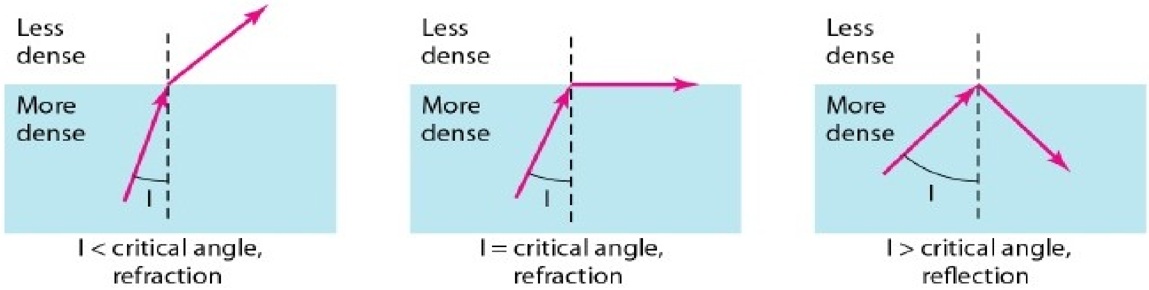
Another common application of coaxial cable is in **traditional Ethernet LANs**. Because of its high bandwidth, and consequently high data rate, coaxial cable was chosen for digital transmission in early Ethernet LANs. The 10Base-2, or Thin Ethernet, uses RG-58 coaxial cable with BNC connectors to transmit data at 10 Mbps with a range of 185 m. The l0 Base5, or Thick Ethernet, uses RG-11 (thick coaxial cable) to transmit 10 Mbps with a range of 5000 m. Thick Ethernet has specialized connectors.

Fiber-Optic Cable

A fiber-optic cable is made of glass or plastic and transmits signals in the form of light.

Nature of Light
Light travels in a straight line as long as it is moving through a single uniform substance. If a ray of light travelling through one substance suddenly enters another substance (of a different density), the ray changes its direction. Figure 7.10 shows how a ray of light changes direction when going from a more dense to a less dense substance.

Figure 7.10 ***Bending of light ray***

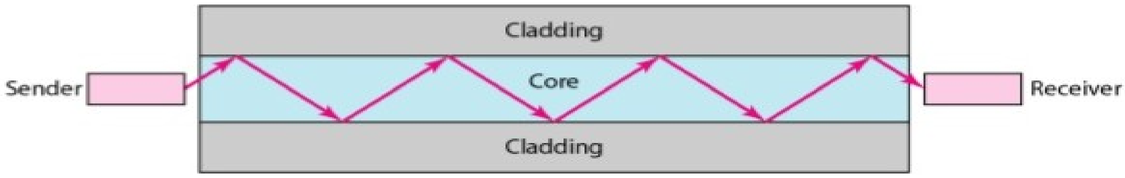


If the angle of incidence *I* (the angle the ray makes with the line perpendicular to the interface between the two substances) is less than the critical angle, the ray refracts and moves closer to the surface.

If the angle of incidence is equal to the critical angle, the light bends along the interface.
If the angle is greater than the critical angle, the ray reflects (makes a turn) and travels again in the denser substance.

Optical fibers use reflection to guide light through a channel. A glass or plastic core is surrounded by a cladding of less dense glass or plastic. The difference in density of the two materials must be such that a beam of light moving through the core is reflected off the cladding instead of being refracted into it. Figure 7.11.

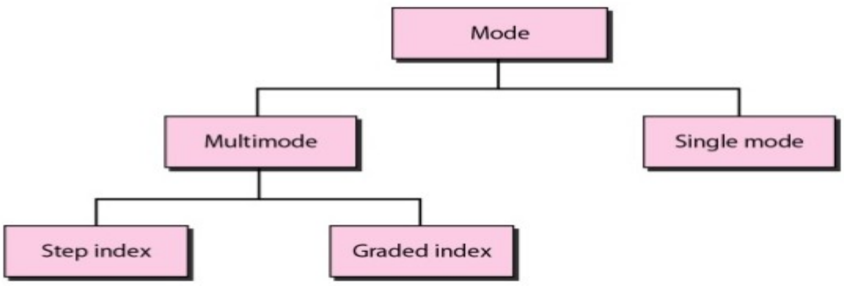
Figure 7.11 ***Optical fiber***



Propagation Modes
Two modes are used (multimode and single mode) for propagating light along optical channels, each requiring fiber with different physical characteristics. Multimode can be implemented in two forms:

- Step-index
- Graded-index (Figure 7.12).

Figure 7.12 ***Propagation modes***

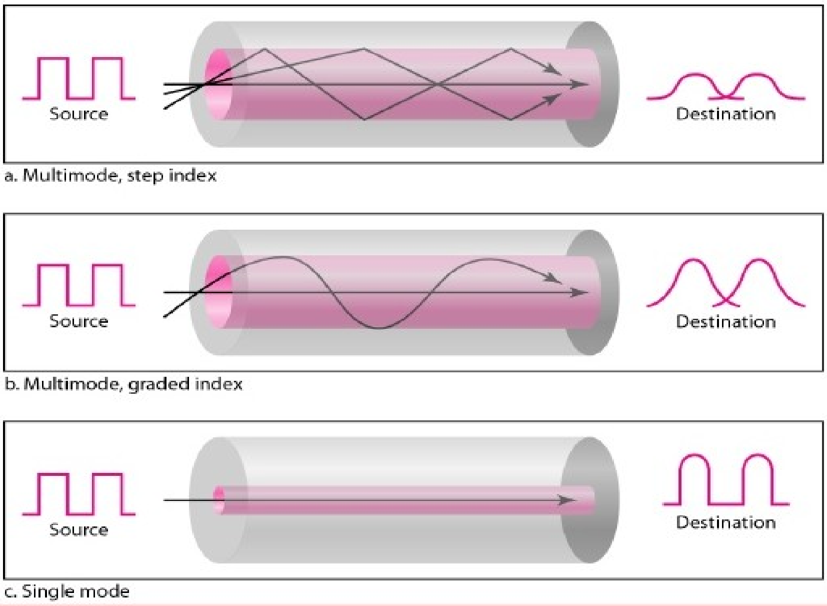


Multimode
In multimode multiple beams from a light source move through the core in different paths. The movement of beams within the cable depends on the structure of the core.

In **Multimode step-index** fiber, the density of the core remains constant from the center to the edges. A beam of light moves through this constant density in a straight line until it reaches the interface of the core and the cladding. At the interface, there is an abrupt change due to a lower density; this alters the angle of the beam's motion. The term *step index* refers to the suddenness of this change, which contributes to the distortion of the signal as it passes through the fiber.

Multimode graded-index fiber decreases distortion of the signal through the cable. The word *index* refers to the index of refraction. The index of refraction is related to density. A graded-index fiber, therefore, is one with varying densities. Density is highest at the center of the core and decreases gradually to its lowest at the edge. Figure 7.13 shows the impact of this variable density on the propagation of light beams.

Figure 7.13 ***Modes***



Single-Mode

Single-mode uses step-index fiber and a highly focused source of light that limits beams to a small range of angles, all close to the horizontal. The single mode fiber itself is manufactured with a much smaller diameter than that of multimode fiber, and with substantially lower density (index of refraction). The decrease in density results in a critical angle that is close enough to 90° to make the propagation of beams almost horizontal. In this case, propagation of different beams is almost identical, and delays are negligible. All the beams arrive at the destination "together" and can be recombined with little distortion to the signal.

Single mode fiber	Multi mode fiber
›Core radius is small. ›Supports one mode of propagation. ›Optical source- LASER. ›The launching of optical power into fiber is difficult Because the core radius is small. ›Supports larger bandwidth. ›Intermodal dispersion is absent. ›Used for long distance communication.	›Core radius is large. ›Supports hundreds of modes. ›Optical source- LED. ›The launching of optical power into fiber is easier Because the core radius is large. ›Supports lesser bandwidth. ›These fiber suffer from Intermodal dispersion. ›Used for short distance communication.

Fiber Sizes

Optical fibers are defined by the ratio of the diameter of their core to the diameter of their cladding, both expressed in micrometers. The common sizes are shown in Table 7.3.

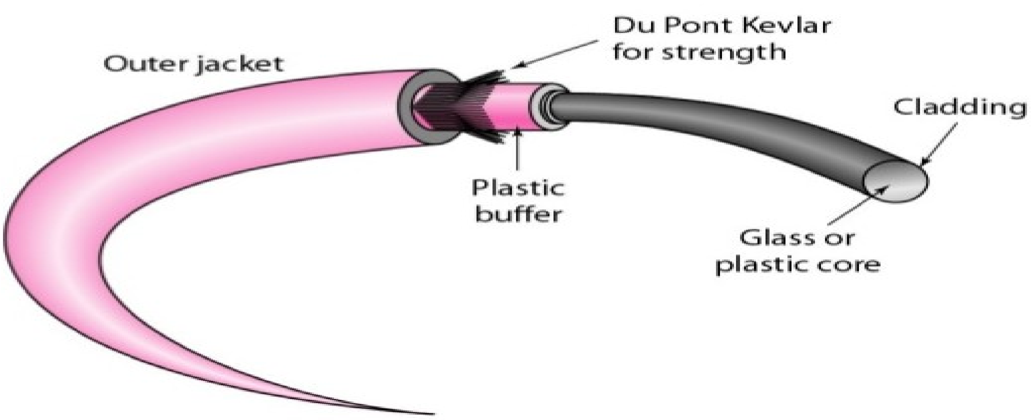
Table 7.3 ***Fiber types***

Type	*Core (µm)*	*Cladding (µm)*	*Mode*
50/125	50.0	125	Multimode, graded index
62.5/125	62.5	125	Multimode, graded index
100/125	100.0	125	Multimode, graded index
7/125	7.0	125	Single mode

Cable Composition

Figure 7.14 shows the composition of a typical fiber-optic cable. The outer jacket is made of either PVC or Teflon. Inside the jacket are Kevlar strands to strengthen the cable. Kevlar is a strong material used in the fabrication of bulletproof vests. Below the Kevlar is another plastic coating to cushion the fiber. The fiber is at the center of the cable, and it consists of cladding and core.

Figure 7.14 ***Fiber construction***



Fiber-Optic Cable Connectors

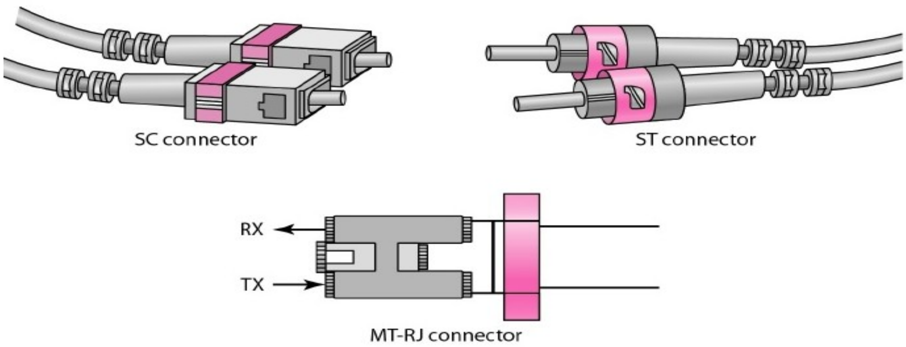
There are 3 types of connectors for fiber-optic cables as shown in Figure 7.15.

1) The **subscriber channel** (SC) **connector**
   used for cable TV. It uses a push/pull locking system.

2)The **straight-tip** (ST) **connector**
   used for connecting cable to networking devices. It uses a bayonet locking system and is more reliable than SC.

3)MT-RJ is a connector
   It has same size as RJ45.

Figure 7.15 *Fiber-optic cable connectors*



Applications

Some cable TV companies use a combination of optical fiber and coaxial cable, thus creating a hybrid network. Optical fiber provides the backbone structure while coaxial cable provides the connection to the user premises. This is a cost-effective configuration since the narrow bandwidth requirement at the user end does not justify the use of optical fiber.

Local-area networks such as 100Base-FX network (Fast Ethernet) and 1000Base-X also use fiber-optic cable.

Advantages and Disadvantages of Optical Fiber

Advantages

- **Higher bandwidth**. Fiber-optic cable can support dramatically higher bandwidths than either twisted-pair or coaxial cable. Currently, data rates and bandwidth utilization over fiber-optic cable are limited not by the medium but by the signal generation and reception technology available.
- **Less signal attenuation**. Fiber-optic transmission distance is significantly greater than that of other guided media. A signal can run for 50 km without requiring regeneration. We need repeaters every 5 km for coaxial or twisted-pair cable.
- **Immunity to electromagnetic interference.** Electromagnetic noise cannot affect fiber-optic cables.
- **Resistance to corrosive materials**. Glass is more resistant to corrosive materials than copper.
- **Light weight.** Fiber-optic cables are much lighter than copper cables.
- **Greater immunity to tapping**. Fiber-optic cables are more immune to tapping than copper cables. Copper cables create antenna effects that can easily be tapped.

Disadvantages

- **Installation and maintenance.** Fiber-optic cable is a relatively new technology. Its installation and maintenance require expertise that is not yet available everywhere.
- **Unidirectional light propagation.** Propagation of light is unidirectional. If we need bidirectional communication, two fibers are needed.
- **Cost**. The cable and the interfaces are relatively more expensive than those of other guided media. If the demand for bandwidth is not high, often the use of optical fiber cannot be justified.

UNGUIDED MEDIA: WIRELESS

Unguided media transport electromagnetic waves without using a physical conductor. This type of communication is referred to as wireless communication. Signals are normally broadcast through free space and are available to anyone who has a device capable of receiving them.
Figure 7.17 shows the part of the electromagnetic spectrum, ranging from 3 kHz to 900 THz, used for wireless communication.

Figure 7.17 *Electromagnetic spectrum for wireless communication*

Unguided signals can travel from the source to destination in several ways:

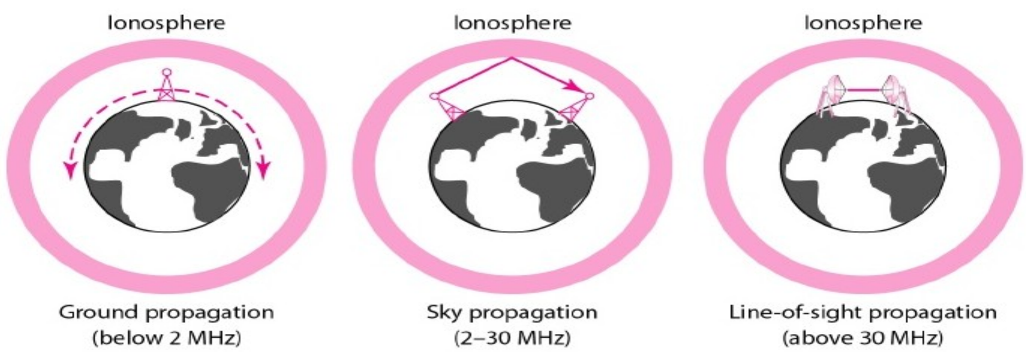
- Ground propagation
- Sky propagation
- Line-of-sight propagation

Ground propagation
In ground propagation, radio waves travel through the lowest portion of the atmosphere, hugging the earth. These low-frequency signals emanate in all directions from the transmitting antenna and follow the curvature of the planet. Distance depends on the amount of power in the signal: The greater the power, the greater the distance.

Sky propagation
In sky propagation, higher-frequency radio waves radiate upward into the ionosphere (the layer of atmosphere where particles exist as ions) where they are reflected back to earth. This type of transmission allows for greater distances with lower output power.

Line-of-sight propagation
In line-or-sight propagation, very high-frequency signals are transmitted in straight lines directly from antenna to antenna. Antennas must be directional, facing each other and either tall enough or close enough together not to be affected by the curvature of the earth. Line-of-sight propagation is tricky because radio transmissions cannot be completely focused.

Figure 7.18 *Propagation methods*



The section of the electromagnetic spectrum defined as radio waves and microwaves is divided into eight ranges, called *bands,* each regulated by government authorities. These bands are rated from *very low frequency* (VLF) to *extremely high frequency* (EHF).

Table 7.4 lists these bands, their ranges, propagation methods, and some applications.

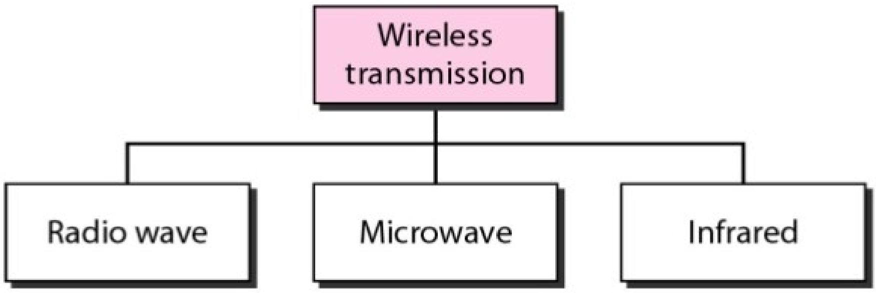
Table 7.4 ***Bands***

Band	*Range*	*Propagation*	*Application*
VLF (very low frequency)	3–30 kHz	Ground	Long-range radio navigation
LF (low frequency)	30–300 kHz	Ground	Radio beacons and navigational locators
MF (middle frequency)	300 kHz–3 MHz	Sky	AM radio
HF (high frequency)	3–30 MHz	Sky	Citizens band (CB), ship/aircraft communication
VHF (very high frequency)	30–300 MHz	Sky and line-of-sight	VHF TV, FM radio
UHF (ultrahigh frequency)	300 MHz–3 GHz	Line-of-sight	UHF TV, cellular phones, paging, satellite
SHF (superhigh frequency)	3–30 GHz	Line-of-sight	Satellite communication
EHF (extremely high frequency)	30–300 GHz	Line-of-sight	Radar, satellite

We divide wireless transmission into three broad groups:

- Radiowaves
- Microwaves
- Infrared Waves

Figure 7.19 ***Wireless transmission waves***



Radio Waves

- Electromagnetic waves ranging in frequencies between 3 khz and 1 ghz
- Are omnidirectional
- Used for long-distance broadcasting such as AM radio.
- Radio waves can penetrate walls.

- Uses omnidirectional antennas
- Useful for multicasting
- Using any part of the band requires permission from the authorities.

1) Radio waves are ***omnidirectional***

When an antenna transmits radio waves, they are propagated in all directions. This means that the sending and receiving antennas do not have to be aligned. A sending antenna sends waves that can be received by any receiving antenna.

Disadvantage

The radio waves transmitted by one antenna are susceptible to interference by another antenna that may send signals using the same frequency or band.

2) Used for ***long-distance broadcasting*** *such as AM radio.*

Radio waves, particularly those waves that propagate in the sky mode, can travel long distances. This makes radio waves a good candidate for long-distance broadcasting such as AM radio.

3)Radio waves can ***penetrate walls****.*

Radio waves of low and medium frequencies, can penetrate walls.

Advantage

AM radio can receive signals inside a building.

Disadvantage

We cannot isolate a communication to just inside or outside a building. The radio wave band is relatively narrow, just under 1 GHz, compared to the microwave band. When this band is divided into subbands, the subbands are also narrow, leading to a low data rate for digital communications.

4) Omnidirectional Antenna

Radio waves use omnidirectional antennas that send out signals in all directions. Based on the wavelength, strength, and the purpose of transmission, we can have several types of antennas.

Figure 7.20 ***Omnidirectional antenna***

5) Useful for multicasting

The omnidirectional characteristics of radio waves make them useful for multicasting, in which there is one sender but many receivers. AM and FM radio, television, maritime radio, cordless phones, and paging are examples of multicasting.

Microwaves

- Electromagnetic waves having frequencies between 1 and 300 GHz
- are unidirectional
- Microwave propagation is line-of-sight
- Very high-frequency microwaves cannot penetrate walls.
- The microwave band is relatively wide almost 299 GHz.
- Use of certain portions of the band requires permission from authorities.

1) *Microwaves are unidirectional*
   When an antenna transmits microwave waves, they can be narrowly focused. This means that the sending and receiving antennas need to be aligned.
   Advantage
   A pair of antennas can be aligned without interfering with another pair of aligned antennas

characteristics of microwave propagation

- Microwave propagation is line-of-sight.

Since the towers with the mounted antennas need to be in direct sight of each other, towers that are far apart need to be very tall. The curvatures of the earth as well as other blocking obstacles do not allow two short towers to communicate by using microwaves. Repeaters are often needed for long distance communication.

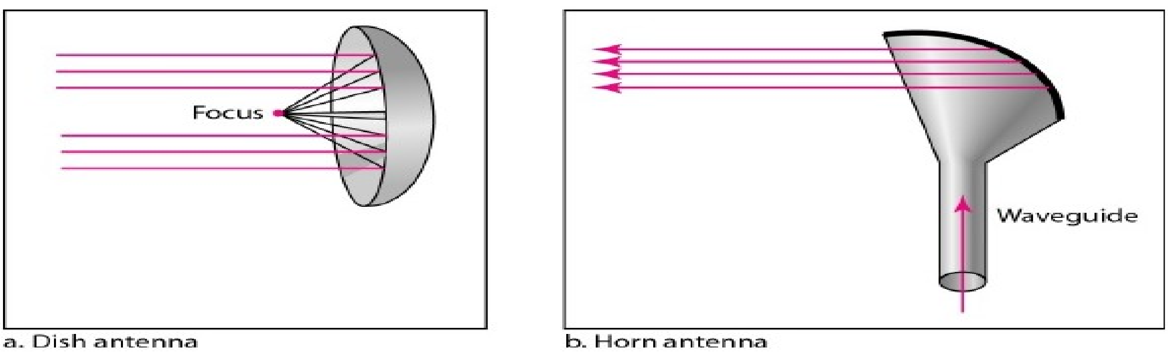
- Very high-frequency microwaves cannot penetrate walls. This characteristic can be a disadvantage if receivers are inside buildings.
- The microwave band is relatively wide, almost 299 GHz. Therefore wider subbands can be assigned, and a high data rate is possible
- Use of certain portions of the band requires permission from authorities.

Unidirectional Antenna

Microwaves need unidirectional antennas that send out signals in one direction. Two types of antennas are used for microwave communications:

- The parabolic dish
- The horn antenna

Figure 7.21 *Unidirectional antennas*



Parabolic dish antenna

A parabolic dish antenna is based on the geometry of a parabola: Every line parallel to the line of symmetry (line of sight) reflects off the curve at angles such that all the lines intersect in a common point called the **focus**. The parabolic dish works as a funnel, catching a wide range of waves and directing them to a common point. In this way, more of the signal is recovered than would be possible with a single-point receiver.

Horn antenna

Outgoing transmissions are broadcast through a horn aimed at the dish. The microwaves hit the dish and are deflected outward in a reversal of the receipt path. A horn antenna looks like a gigantic scoop. Outgoing transmissions are broadcast up a stem (resembling a handle) and deflected outward in a series of narrow parallel beams by the curved head. Received transmissions are collected by the scooped shape of the horn, in a manner similar to the parabolic dish, and are deflected down into the stem.

Applications

Microwaves, due to their unidirectional properties, are very useful when unicast (one-to-one) communication is needed between the sender and the receiver. They are used in cellular phones ,satellite networks and wireless LANs.

Infrared

- Frequencies from 300 GHz to 400 THz can be used for short-range communication.
- Infrared waves, having high frequencies, cannot penetrate walls.
- Cannot use infrared waves outside a building

Infrared waves, having high frequencies, cannot penetrate walls. This advantageous characteristic prevents interference between one system and another; a short-range communication system in one room cannot be affected by another system in the next room. When we use our infrared remote control, we do not interfere with the use of the remote by our neighbors. However, this same characteristic makes infrared signals useless for long-range communication. In addition, we cannot use infrared waves outside a building because the sun's rays contain infrared waves that can interfere with the communication.

Applications

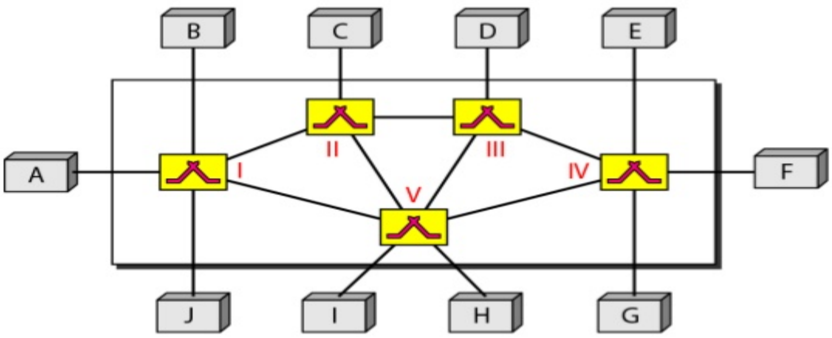
The infrared band, almost 400 THz, has an excellent potential for data transmission.Such a wide bandwidth can be used to transmit digital data with a very high data rate. The *Infrared Data Association* (IrDA), an association for sponsoring the use of infrared waves, has established standards for using these signals for communication between devices such as keyboards, mouse, PCs, and printers. Infrared signals defined by IrDA transmit through line of sight; the IrDA port on the keyboard needs to point to the PC for transmission to occur.

Switching: message, Circuit and packet switched networks, datagram networks, virtual-circuit networks.

Switching

A network is a set of connected devices. A switched network consists of a series of interlinked nodes, called **switches**. Switches are devices capable of creating temporary connections between two or more devices linked to the switch. In a switched network, some of these nodes are connected to the end systems (computers or telephones).Others are used only for routing. Figure 8.1 shows a switched network.

Figure 8.1 *Switched network*



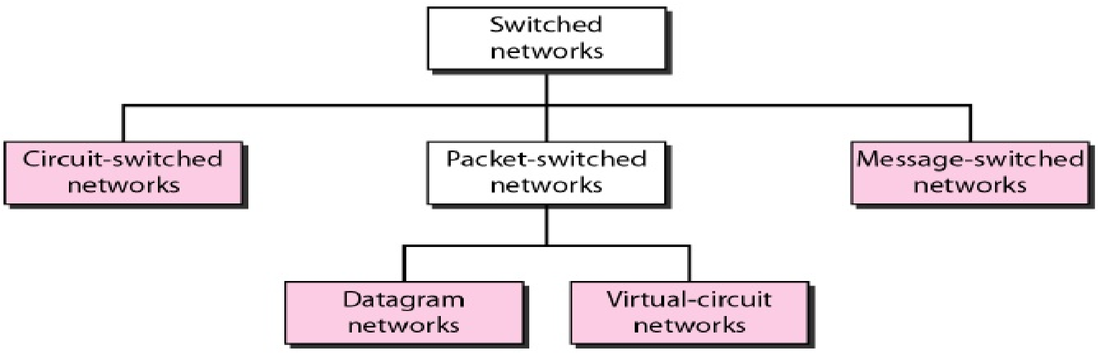
The end systems (communicating devices) are labeled A, B, C, D, and so on, and the switches are labeled I, II, III, IV, and V. Each switch is connected to multiple links.
Three methods of switching

- Circuit switching
- Packet switching
- Message switching.

Packet-switched networks can be divided into two subcategories-

- virtual-circuit networks
- datagram networks

Figure 8.2 *Taxonomy of switched networks*

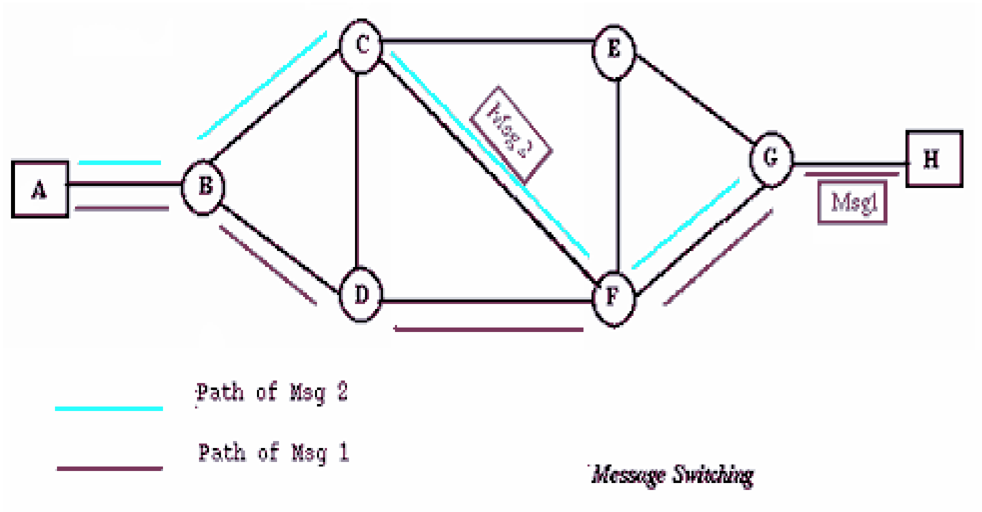


Message switching

In message switching, each switch stores the whole message and forwards it to the next switch. Although, we don't see message switching at lower layers, it is still used in some applications like electronic mail (e-mail).

A message is a logical unit of information and can be of any length. In message switching, if a station wishes to send a message to another station, it first adds the destination address to the message. Message switching does not establish a dedicated path between the two communicating devices *i.e.* no direct link is established between sender and receiver. Each message is treated as an independent unit.

In message switching, each complete message is then transmitted from device to device through the internetwork *i.e.* message is transmitted from the source node to intermediate node. The intermediate node stores the complete message temporarily, inspects it for errors and transmits the message to the next node based on an available free channel and its routing information. Because of this reason message switched networks are called **store and forward network** as shown in fig. The actual path taken by the message to its destination is dynamic as the path is established as it travels along. When the message reaches a node, the channel on which it came is released for use by another message. As shown in Figure message Ml is transmitted from A to D and M2 is transmitted C to B. Message Ml follows the route A --> I --> II --> III --> D and M2 follows the route C --> IV --> II --> B depending upon the availability of free path at that particular moment.



Advantages of Message Switching

1. It provides efficient traffic management by assigning priorities to the messages to be switched.

2. No physical connection is required between the source & destination as it is in circuit switching.

3. It reduces the traffic congestion on network because of store & forward facility. Each node can store the message until communication channel becomes available.

4. Channels are used effectively and network devices share the data channels.

5. It supports the message length of unlimited size.

Disadvantages of Message Switching

The various disadvantages of message switching are

1. As message length is unlimited, each switching node must have sufficient storage to buffer message.

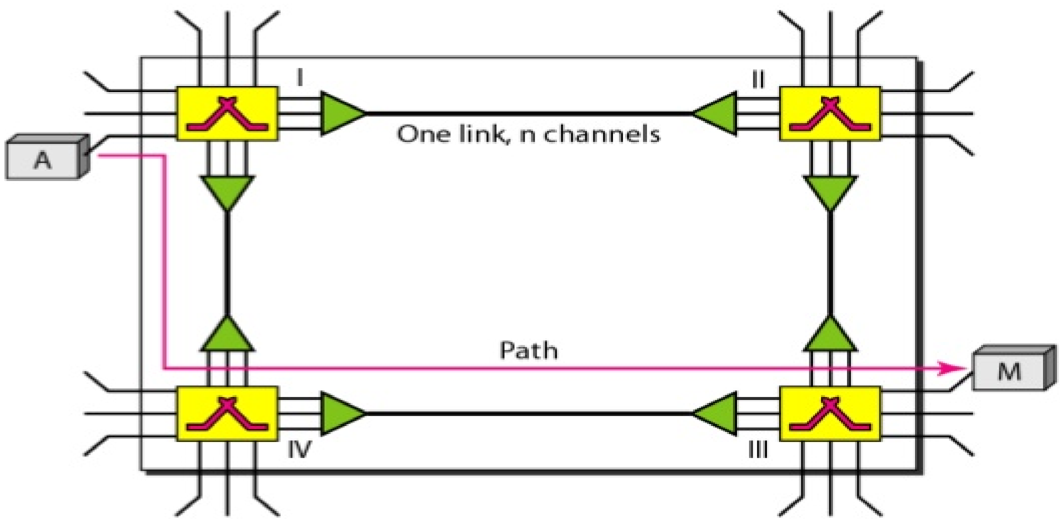
2. Storing & forwarding facility introduces delay thus making message switching unsuitable for real time applications like voice and video.

Circuit-Switched Networks

A circuit-switched network consists of a set of switches connected by physical links. A connection between two stations is a dedicated path made of one or more links. However, each connection uses only one dedicated channel on each link. Each link is normally divided into *n* channels by using FDM or TDM.
A circuit-switched network is made of a set of switches connected by physical links, in which each link is divided into *n* channels.

Figure 8.3 shows a trivial circuit-switched network with four switches and four links. Each link is divided into *n (n* is 3 in the figure) channels by using FDM or TDM.

Figure 8.3 ***A trivial circuit-switched network***



The end systems, such as computers or telephones, are directly connected to a switch. When end system A needs to communicate with end system M, system A needs to request a connection to M that must be accepted by all switches as well as by M itself. This is called the **setup phase**; a circuit (channel) is reserved on each link, and the combination of circuits or channels defines the dedicated path. After the dedicated path made of connected circuits (channels) is established, data transfer can take place. After all data have been transferred, the circuits are **tear down.**

Main points

- Circuit switching takes place at the **physical layer.**

- Before starting communication, the stations must **make a reservation for the resources** to be used during the communication. These resources, such as channels (bandwidth in FDM and time slots in TDM), switch buffers, switch processing time, and switch input/output ports, must remain dedicated during the entire duration of data transfer until the teardown phase.
- Data transferred between the two stations are not packetized (physical layer transfer of the signal). The data are a continuous flow sent by the source station and received by the destination station, although there may be periods of silence.
- There is no addressing involved during data transfer. The switches route the data based on their occupied band (FDM) or time slot (TDM). Of course, there is end-to-end addressing used during the setup phase.

In circuit switching, the resources need to be reserved during the setup phase; the resources remain dedicated for the entire duration of data transfer until the teardown phase.

Three Phases

The actual communication in a circuit-switched network requires three phases:

- Connection setup
- Data transfer
- Connection teardown

Setup Phase

Before the two parties (or multiple parties in a conference call) can communicate, a dedicated circuit (combination of channels in links) needs to be established. The end systems are normally connected through dedicated lines to the switches, so connection setup means creating dedicated channels between the switches.

For eg, in Figure 8.3, when system A needs to connect to system M, it sends a **setup request** that includes the address of system M, to switch I. Switch I finds a channel between itself and switch IV that can be dedicated for this purpose. Switch I then sends the request to switch IV, which finds a dedicated channel between itself and switch III. Switch III informs system M of system A's intention at this time.

In the next step to making a connection, an acknowledgment from system M needs to be sent in the opposite direction to system A. Only after system A receives this acknowledgment is the connection established.

End-to-end addressing is required for creating a connection between the two end systems. These can be, for example, the addresses of the computers assigned by the administrator in a TDM network, or telephone numbers in an FDM network.

Data Transfer Phase

After the establishment of the dedicated circuit (channels), the two parties can transfer data.

Teardown Phase

When one of the parties needs to disconnect, a signal is sent to each switch to release the resources.

Efficiency

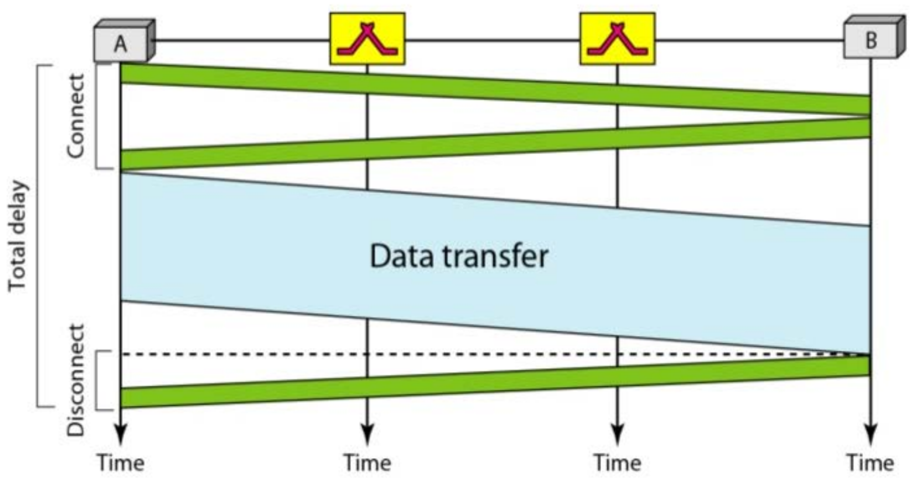
Circuit-switched networks are not as efficient as the other 2 types of networks because resources are allocated during the entire duration of the connection. These resources are unavailable to other connections. In a telephone network, people normally terminate the communication when they have finished their conversation.

However, in computer networks, a computer can be connected to another computer even if there is no activity for a long time. In this case, allowing resources to be dedicated means that other connections are deprived.

Delay

Although a circuit-switched network normally has low efficiency, the delay in this type of network is minimal. During data transfer the data are not delayed at each switch; the resources are allocated for the duration of the connection. Figure 8.6 shows the idea of delay in a circuit-switched network when only two switches are involved.

Figure 8.6 ***Delay in a circuit-switched network***



As Figure 8.6 shows, there is no waiting time at each switch. The total delay is due to the time needed to create the connection, transfer data, and disconnect the circuit.
The **delay caused by the setup** is the sum of four parts:

- The propagation time of the source computer request (slope of the first gray box)
- The request signal transfer time (height of the first gray box)
- The propagation time of the acknowledgment from the destination computer (slope of the second gray box)
- The signal transfer time of the acknowledgment (height of the second gray box).

The **delay due to data transfer** is the sum of two parts:

- The propagation time (slope of the colored box)
- The data transfer time (height of the colored box), which can be very long.
- The third box shows the time needed to tear down the circuit.

We have shown the case in which the receiver requests disconnection, which creates the maximum delay.

DATAGRAM NETWORKS

In data communications, we need to send messages from one end system to another. If the message is going to pass through a packet-switched network, it needs to be divided into packets of fixed or variable size. The size of the packet is determined by the network and the governing protocol.

In packet switching, there is no resource allocation for a packet. This means that there is no reserved bandwidth on the links, and there is no scheduled processing time for each packet. Resources are allocated on demand. The allocation is done on a first come, first-served basis. When a switch receives a packet, no matter what is the source or destination, the packet must wait if there are other packets being processed.

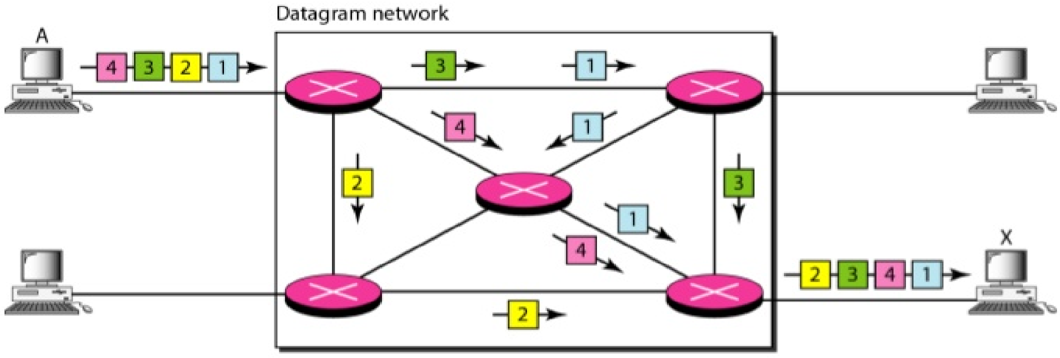
In a packet-switched network, there is no resource reservation; resources are allocated on demand.

In a datagram network, each packet is treated independently of all others. Even if a packet is part of a multipacket transmission, the network treats it as though it existed alone. Packets in this approach are referred to as datagrams.

Datagram switching is normally done at **the network layer.**

Figure 8.7 shows how the datagram approach is used to deliver four packets from station A to station X. The switches in a datagram network are traditionally referred to as routers. That is why we use a different symbol for the switches in the figure.

Figure 8.7 ***A datagram network with four switches (routers)***



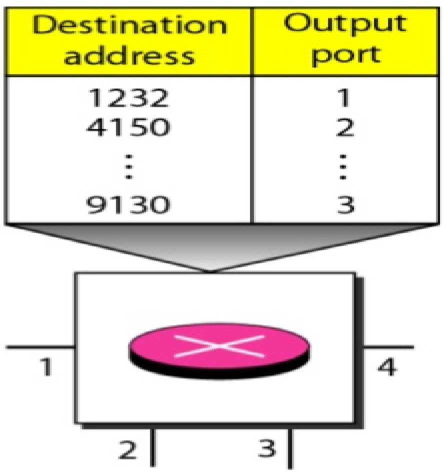
In this example, all four packets (or datagrams) belong to the same message, but may travel different paths to reach their destination. This is so because the links may be involved in carrying packets from other sources and do not have the necessary bandwidth available to carry all the packets from A to X. This approach can cause the datagrams of a transmission to arrive at their destination out of order with different delays between the packets. Packets may also be lost or dropped because of a lack of resources. In most protocols, it is the responsibility of an upper-layer protocol to reorder the datagrams or ask for lost datagrams before passing them on to the application.

The datagram networks are sometimes referred to as connectionless networks. The term *connectionless* here means that the switch (packet switch) does not keep information about the connection state. There **are no setup or teardown phases**. Each packet is treated the same by a switch regardless of its source or destination.

Routing Table

In this type of network, each switch (or packet switch) has a routing table which is based on the destination address. The routing tables are **dynamic and are updated periodically**. The destination addresses and the corresponding forwarding output ports are recorded in the tables. This is different from the table of a circuit switched network in which each entry is created when the setup phase is completed and deleted when the teardown phase is over. Figure 8.8 shows the routing table for a switch.

Figure 8.8 ***Routing table in a datagram network***



A switch in a datagram network uses a routing table that is based on the destination address.

Destination Address

Every packet in a datagram network carries a header that contains, among other information, the destination address of the packet. When the switch receives the packet, this destination address is examined; the routing table is consulted to find the corresponding port through which the packet should be forwarded. This address, unlike the address in a virtual-circuit-switched network, remains the same during the entire journey of the packet.

The destination address in the header of a packet in a datagram network remains the same during the entire journey of the packet.

Efficiency

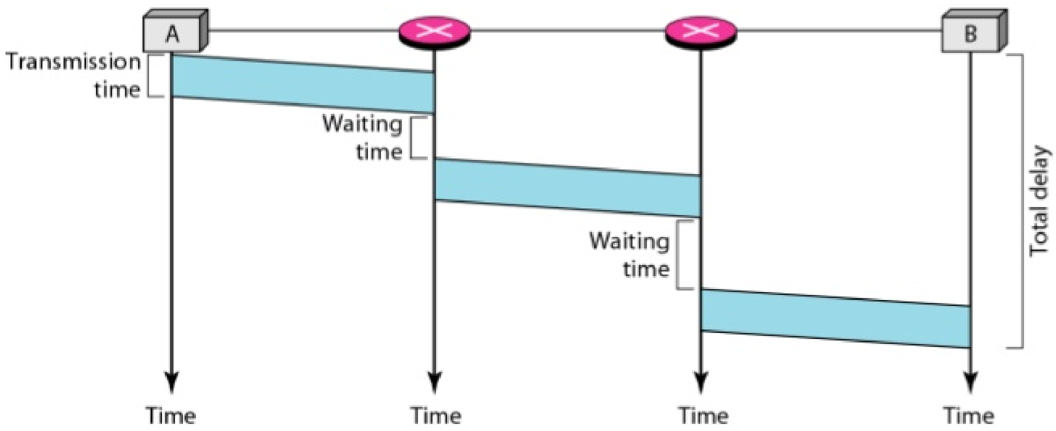
The efficiency of a datagram network is better than that of a circuit-switched network; resources are allocated only when there are packets to be transferred. If a source sends a packet and there is a delay of a few minutes before another packet can be sent, the resources can be reallocated during these minutes for other packets from other sources.

Delay

There may be greater delay in a datagram network than in a virtual-circuit network. Although there are no setup and teardown phases, each packet may experience a wait at a switch before it is forwarded. In addition, since not all packets in a message necessarily travel through the same switches, the delay is not uniform for the packets of a message.

Figure 8.9 gives an example of delay in a datagram network for one single packet.

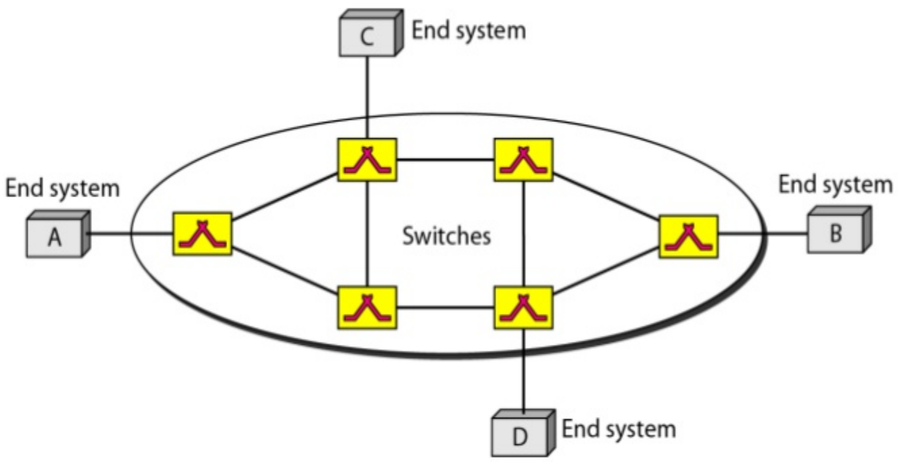
Figure 8.9 ***Delay in a datagram network***



Virtual-circuit networks

A virtual-circuit network is a cross between a circuit-switched network and a datagram network. It has some characteristics of both.
1.As in a circuit-switched network, there are setup and teardown phases in addition to the data transfer phase.
2. Resources can be allocated during the setup phase, as in a circuit-switched network, or on demand, as in a datagram network.
3. As in a datagram network, data are packetized and each packet carries an address in the header. However, the address in the header has local jurisdiction (it defines what should be the next switch and the channel on which the packet is being carried), not end-to-end jurisdiction.
4. As in a circuit-switched network, all packets follow the same path established during the connection.
5. A virtual-circuit network is normally implemented in the data link layer, while a circuit-switched network is implemented in the physical layer and a datagram network in the network layer. But this may change in the future.
Figure 8.10 is an example of a virtual-circuit network. The network has switches that allow traffic from sources to destinations. A source or destination can be a computer, packet switch, bridge, or any other device that connects other networks.

Figure 8.10 *Virtual-circuit network*



Addressing

In a virtual-circuit network, two types of addressing are involved: global and local (virtual-circuit identifier).

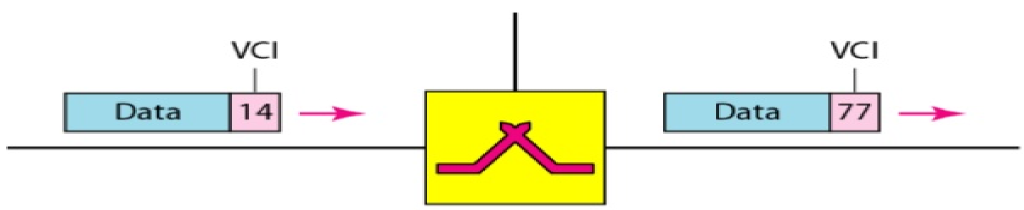
Global Addressing

A source or a destination needs to have a global address-an address that can be unique in the scope of the network or internationally if the network is part of an international network. A global address in virtual-circuit networks is used only to create a virtual-circuit identifier.

Virtual-Circuit Identifier

The identifier that is actually used for data transfer is called the virtual-circuit identifier (Vel). A vel, unlike a global address, is a small number that has only switch scope; it is used by a frame between two switches. When a frame arrives at a switch, it has a VCI; when it leaves, it has a different VCl. Figure 8.11 shows how the VCI in a data frame changes from one switch to another. Note that a VCI does not need to be a large number since each switch can use its own unique set of VCls.

Figure 8.11 *Virtual-circuit identifier*



Three Phases

As in a circuit-switched network, a source and destination need to go through 3 phases in a virtual-circuit network:

1)Setup
2) Data Transfer
3)Teardown.

In the **setup** phase, the source and destination use their global addresses to help switches make table entries for the connection.
In the **teardown** phase, the source and destination inform the switches to delete the corresponding entry.
Data transfer occurs between these two. phases.

Data Transfer Phase
To transfer a frame from a source to its destination, all switches need to have a table entry for this virtual circuit. The table, in its simplest form, has four columns. This means that the switch holds 4 pieces of information for each virtual circuit that is already set up.

Figure 8.12 shows such a switch and its corresponding table. Figure 8.12 shows a frame arriving at port 1 with a VCI of 14. When the frame arrives, the switch looks in its table to find port 1 and a VCI of 14. When it is found, the switch knows to change the VCI to 22 and send out the frame from port 3.
Figure 8.13 shows how a frame from source A reaches destination B and how its VCI changes during the trip. Each switch changes the VCI and routes the frame.

The data transfer phase is active until the source sends all its frames to the destination.
The procedure at the switch is the same for each frame of a message. The process creates a virtual circuit, not a real circuit, between the source and destination.

Setup Phase
In the setup phase, a switch creates an entry for a virtual circuit. For example, suppose source A needs to create a virtual circuit to B. Two steps are required:

- the setup request
- the acknowledgment.

Figure 8.12: Switch and table for a virtual-circuit network

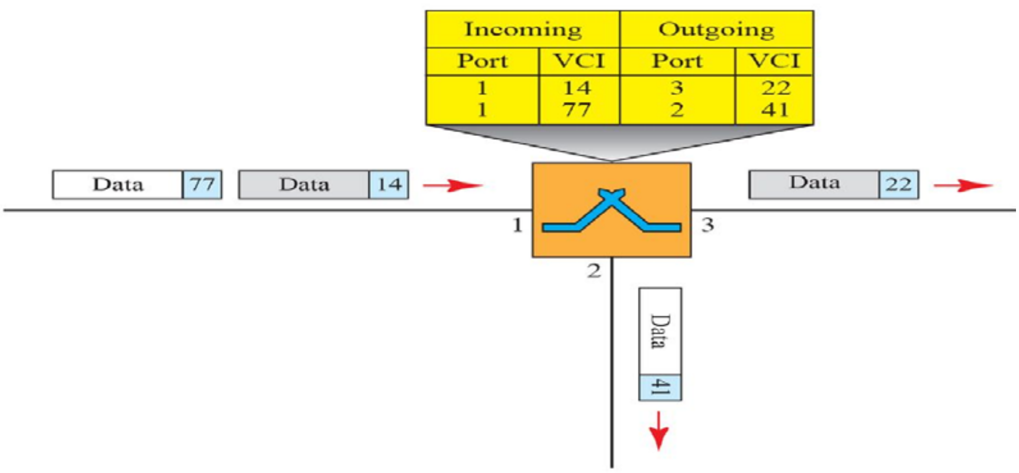
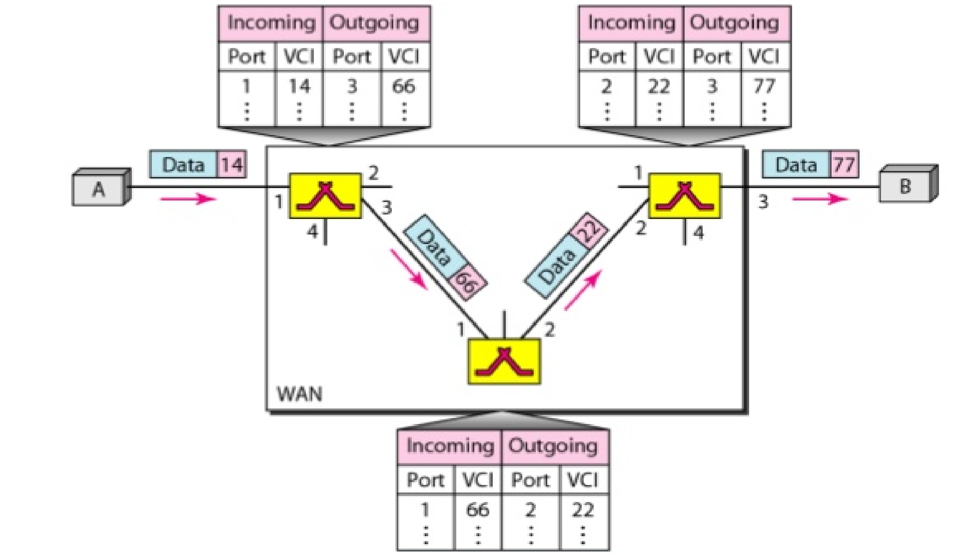


Figure 8.13 ***Source-to-destination data transfer in a virtual-circuit network***



Setup Request

A setup request frame is sent from the source to the destination. Figure 8.14 shows the process.

a. Source A sends a setup frame to switch 1.

b. Switch 1 receives the setup request frame. It knows that a frame going from A to B goes out through port 3. The switch, in the setup phase, acts as a packet switch; it has a routing table which is different from the switching table. The switch creates an entry in its table for this virtual circuit, but it is only able to fill three of the four columns. The switch assigns the incoming port (1) and chooses an available incoming VCI (14) and the outgoing port (3). It does not yet know the outgoing VCI, which will be found during the acknowledgment step. The switch then forwards the frame through port 3 to switch 2.

c. Switch 2 receives the setup request frame. The same events happen here as at switch 1; three columns of the table are completed: in this case, incoming port (l), incoming VCI (66), and outgoing port (2).

d. Switch 3 receives the setup request frame. Again, three columns are completed: incoming port (2), incoming VCI (22), and outgoing port (3).

e. Destination B receives the setup frame, and if it is ready to receive frames from A, it assigns a VCI to the incoming frames that come from A, in this case 77. This VCI lets the destination know that the frames come from A, and not other sources.

Acknowledgment A special frame, called the **acknowledgment frame**, completes the entries in the switching tables. Figure 8.15 shows the process.

a. The destination sends an acknowledgment to switch 3. The acknowledgment carries the global source and destination addresses so the switch knows which entry in the table is to be completed. The frame also carries VCI 77, chosen by the destination as the incoming VCI for frames from A. Switch 3 uses this VCI to complete the outgoing VCI column for this entry. Note that 77 is the incoming VCI for destination B, but the outgoing VCI for switch 3.

b. Switch 3 sends an acknowledgment to switch 2 that contains its incoming VCI in the table, chosen in the previous step. Switch 2 uses this as the outgoing VCI in the table.

c. Switch 2 sends an acknowledgment to switch 1 that contains its incoming VCI in the table, chosen in the previous step. Switch 1 uses this as the outgoing VCI in the table.

d. Finally switch 1 sends an acknowledgment to source A that contains its incoming VCI in the table, the table, chosen in the previous step.

e. The source uses this as the outgoing VCI for the data frames to be sent to destination B.

Teardown Phase

In this phase, source A, after sending all frames to B, sends a special frame called a *teardown request.* Destination B responds with a teardown confirmation frame. All switches delete the corresponding entry from their tables.

Efficiency

Resource reservation in a virtual-circuit network can be made during the setup or can be on demand during the data transfer phase. In the first case, the delay for each packet is the same; in the second case, each packet may encounter different delays. There is one big advantage in a virtual-circuit network even if resource allocation is on demand. The source can check the availability of the resources, without actually reserving it.

In virtual-circuit switching, all packets belonging to the same source and destination travel the same path; but the packets may arrive at the destination with different delays if resource allocation is on demand.