UNIT - II

BANDWIDTH UTILIZATION: MULTIPLEXING AND SPREADING

Bandwidth utilization is the wise use of available bandwidth to achieve specific goals.

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 anti jamming.

Bandwidth utilization has two broad categories :

- ❑ Multiplexing
- ❑ Spreading

- ❖ Efficiency can be achieved by multiplexing.
- ❖ Privacy and antijamming can be achieved by spreading.
- ❖ In multiplexing, we combine several channels into one.
- ❖ In spreading, we expand the bandwidth of a channel to insert redundancy.

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.

Figure : Dividing a link into channels

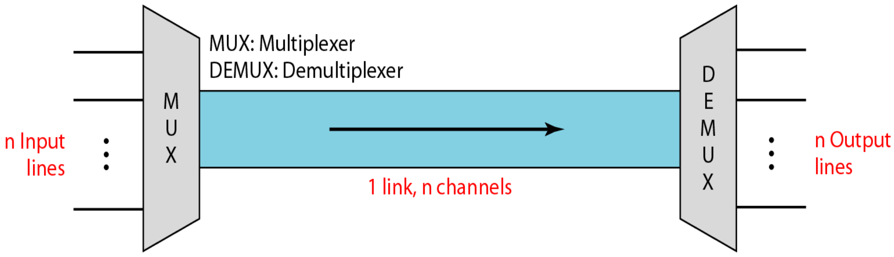


Figure shows the basic format of a multiplexed system.

In a multiplexed system, *n lines share the bandwidth of one link.* 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.

Link refers to the physical path.

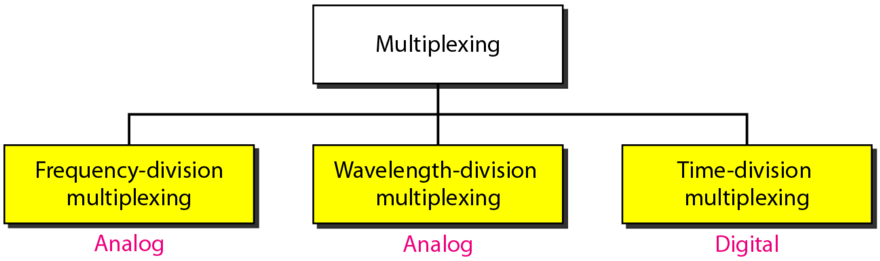
Channel refers to the portion of a link that carries a transmission between a given pair of lines. One link can have many *(n) channels*.

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 : 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.

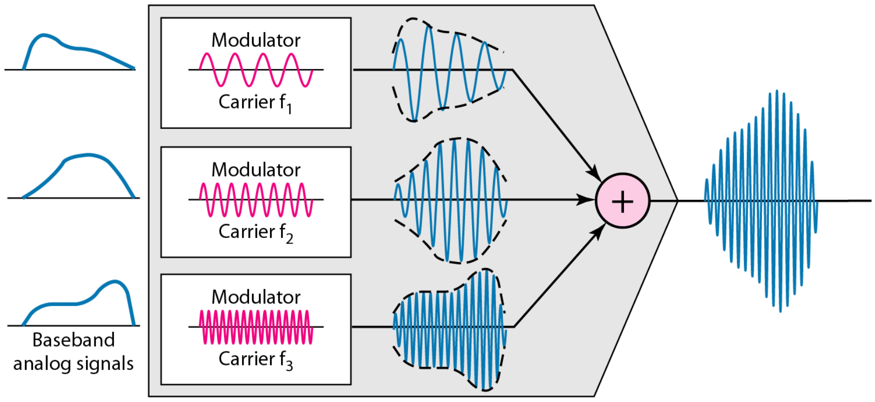
Figure : Frequency-division multiplexing

FDM is an analog multiplexing technique that combines analog signals.

Multiplexing Process

In figure, 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.

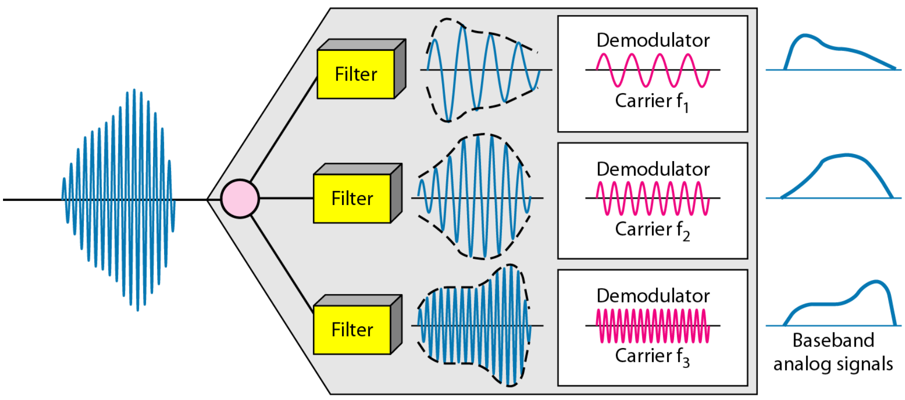
Figure : FDM process



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 : FDM demultiplexing

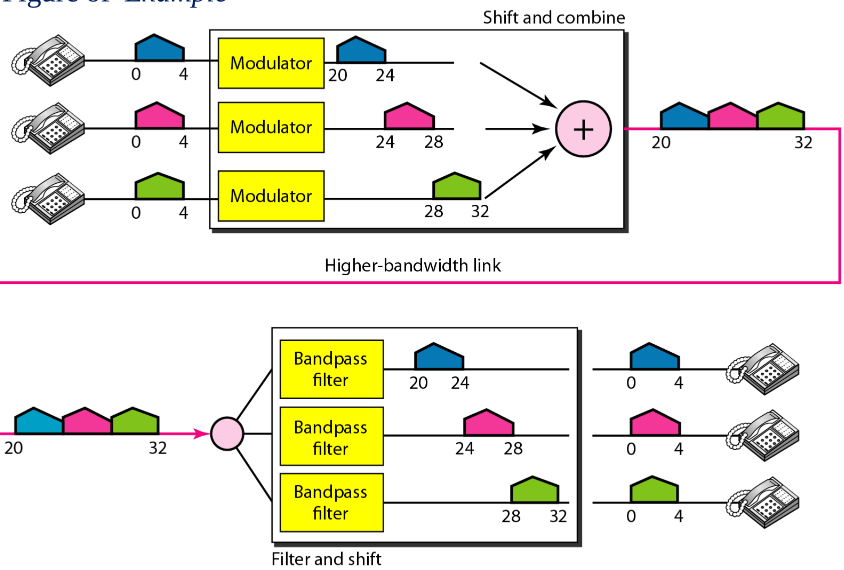


Example

Assume that a voice channel occupies a bandwidth of 4 kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32 kHz.

We shift (modulate) each of the three voice channels to a different bandwidth, as shown in Figure. We use the 20- to 24-kHz bandwidth for the first channel, the 24- to 28-kHz bandwidth for the second channel, and the 28- to 32-kHz bandwidth for the third one. Then we combine them as shown in Figure.

Figure of *Example*



Applications of FDM

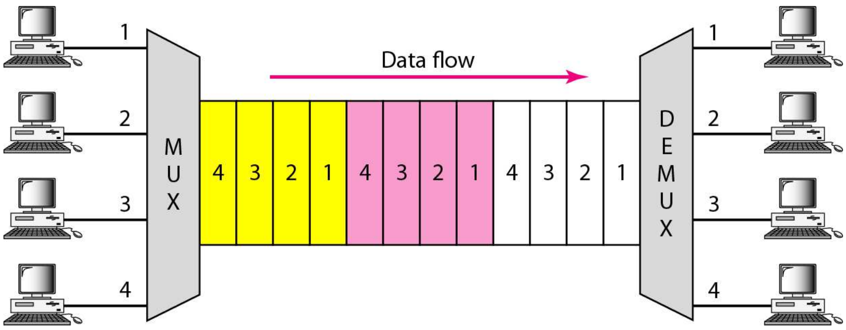
- ✓ FDM is very important in the context of the analog telephone system.
- ✓ A very common application of FDM is AM and FM radio broadcasting. Radio uses the air as the transmission medium.
- ✓ Another common use of FDM is in television broadcasting. Each TV channel has its own bandwidth of 6 MHz.
- ✓ The first generation of cellular telephones also uses FDM.

Time-Division Multiplexing

Time-division multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a link. 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 gives a conceptual view of TDM.

Figure : TDM



Note that the same link is used as in FDM; here, 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.

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.

Note

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

We can divide TDM into two different schemes:

- Synchronous TDM
- Statistical TDM

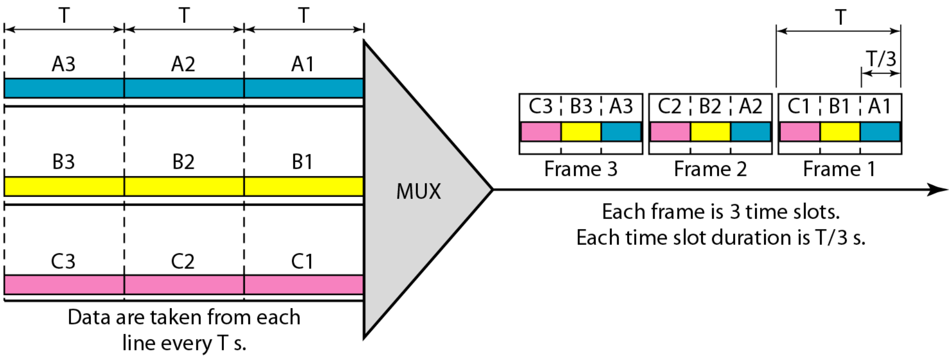
Synchronous TDM

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.

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 T/n s, where n is the number* of connections.

Figure shows an example of synchronous TDM where *n is 3*.

Figure : Synchronous time-division multiplexing



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

Time slots are grouped into frames. A frame consists of one complete cycle of time slots, with one slot dedicated to each sending device.

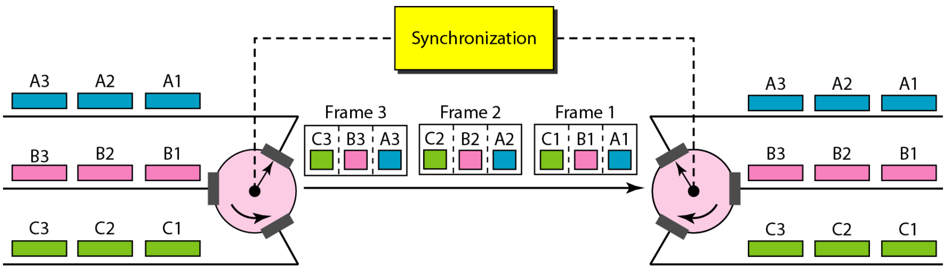
Note

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

Interleaving

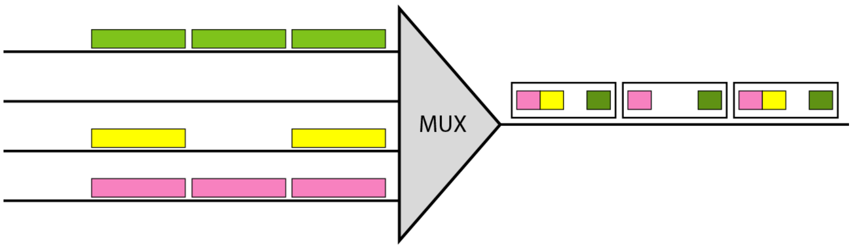
TDM can be visualized as two fast-rotating switches, one on the multiplexing side and the other on the demultiplexing side. The switches are synchronized and rotate at the same speed, but in opposite directions. On the multiplexing side, as the switch opens in front of a connection, that connection has 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 : *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 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.



The first output frame has three slots filled, the second frame has two slots filled, and the third frame has three slots filled. No frame is full.

Synchronous TDM Applications

- Some second-generation cellular telephone companies use synchronous TDM.

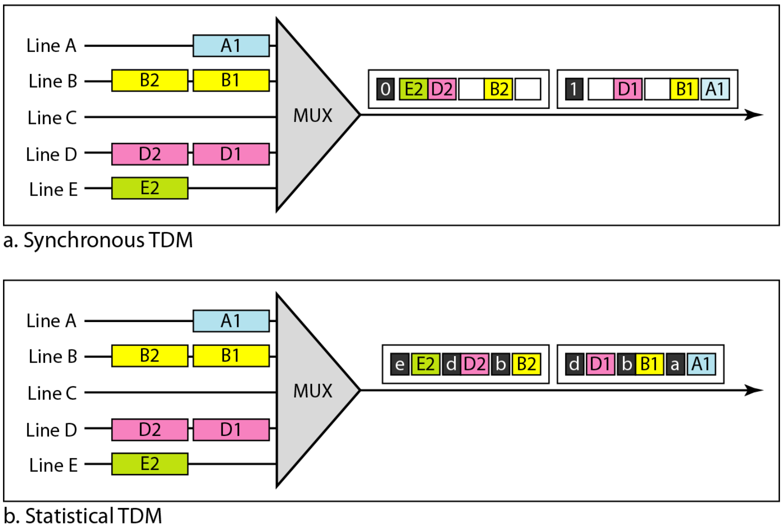
Statistical Time-Division Multiplexing

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.

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 round robin 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 shows a synchronous and a statistical TDM example.

Figure : *TDM slot comparison*



Differences Between Synchronous TDM and Statistical TDM

Figure 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. We know, for example, that input 1 always goes to input 2. If the multiplexer and the demultiplexer are synchronized, this is guaranteed.

In statistical multiplexing, there is no fixed relationship between the inputs and outputs because there are no preassigned or reserved slots. We need to include the address of the receiver inside each slot to show where it is to be delivered.

The frames in statistical TDM need not be synchronized, so we do not need synchronization bits.

In statistical TDM, the capacity of the link is normally less than the sum of the capacities of each channel.

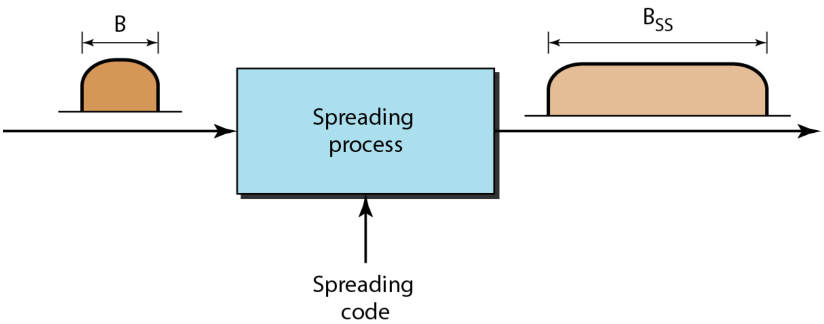
SPREAD SPECTRUM

In spread spectrum (SS), we also combine signals from different sources to fit into a larger bandwidth. Spread spectrum is designed to be used in wireless applications. In wireless applications, all stations use air 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.

To achieve these goals, 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* B_{ss} *such that* $B_{ss} \gg B$*. The expanded bandwidth* allows the source to wrap its message in a protective envelope for a more secure transmission.

Figure shows the idea of spread spectrum.

Figure : *Spread spectrum*



After the signal is created by the source, the spreading process uses a spreading code and spreads the bandwidth. *The spreading code is a series of numbers that look random,* but are actually a pattern.

There are two techniques to spread the bandwidth:

I. Frequency hopping spread spectrum (FHSS)

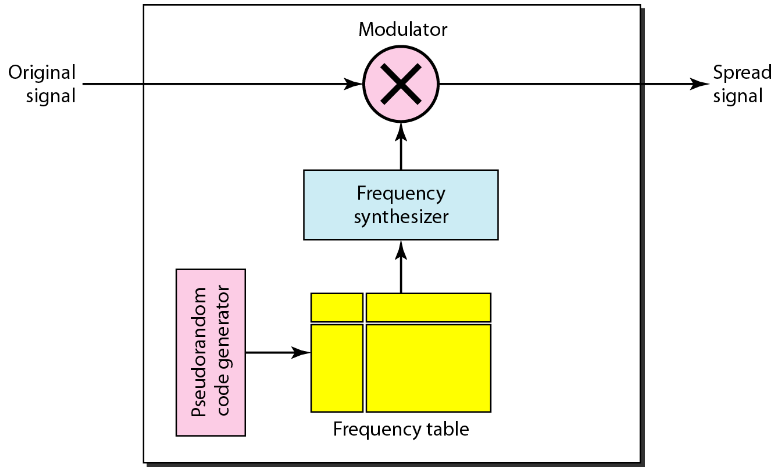
II. Direct sequence spread spectrum (DSSS).

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 $B_{FHSS} >> B$.

Figure shows the general layout for FHSS.

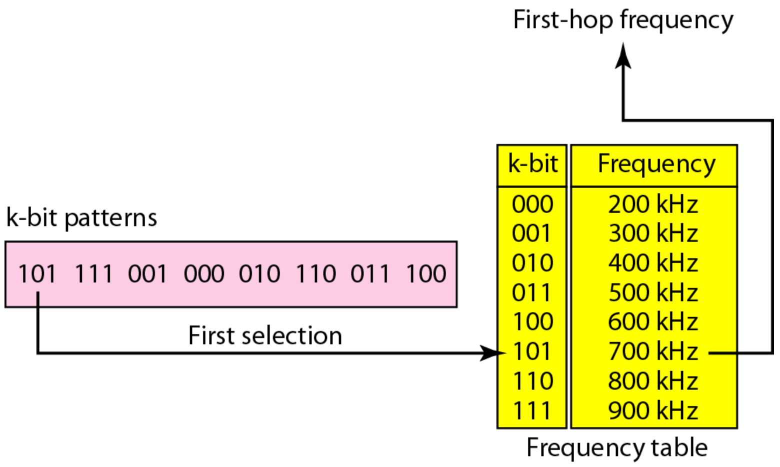
Figure *Frequency hopping spread spectrum (FHSS)*



A pseudorandom code generator, called pseudorandom noise (PN), creates a k-bit pattern for every hopping period T_h. 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.

Suppose we have decided to have eight hopping frequencies. In this case, *M is 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.

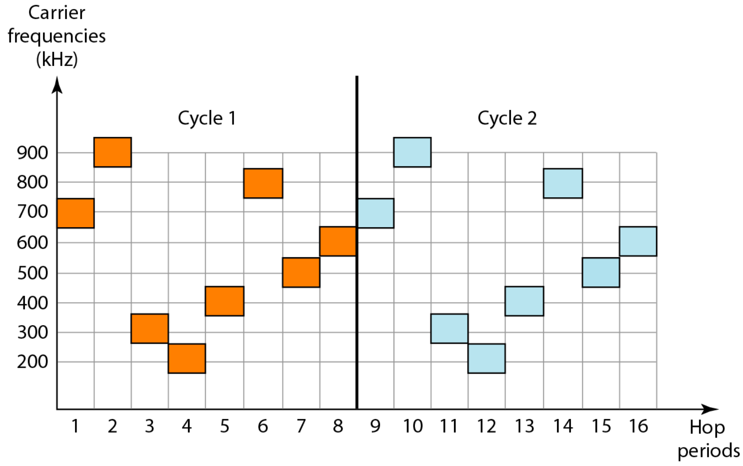
Figure : *Frequency selection in FHSS*



The pattern for this station is 101, 111, 001, 000, 010, 011, 100. 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 shows how the signal hops around from carrier to carrier.

Figure : *FHSS cycles*



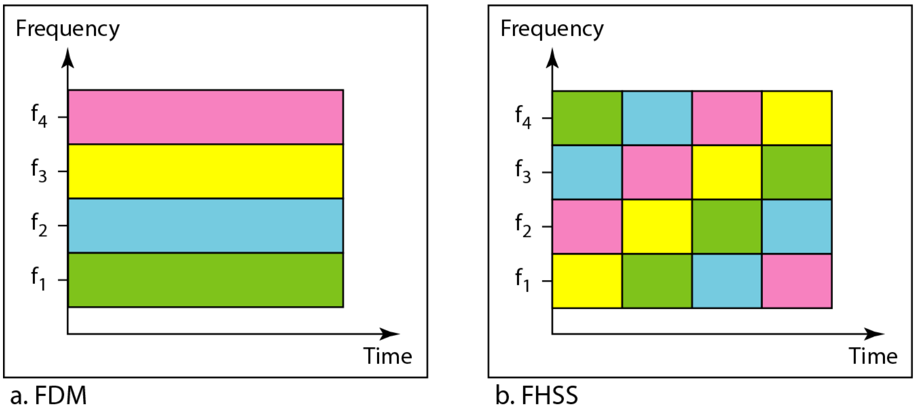
Bandwidth Sharing

If the number of hopping frequencies is *M, we can multiplex M channels into one by using* the same B_{ss} bandwidth. This is possible because a station uses just one frequency in each hopping period; *M-1 other frequencies can be used by other M-1 stations. In other* words, *M different stations can use the same* $B_{ss.}$

FHSS is similar to FDM.

Figure shows an example of four channels using FDM and four channels using FHSS.

Figure : *Bandwidth sharing*



In FDM, each station uses *1/M of the bandwidth*, *but the allocation is* fixed; in FHSS, each station uses *1/M of the bandwidth*, *but the allocation changes hop* to hop.

Direct Sequence Spread Spectrum

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 shows the concept of DSSS.

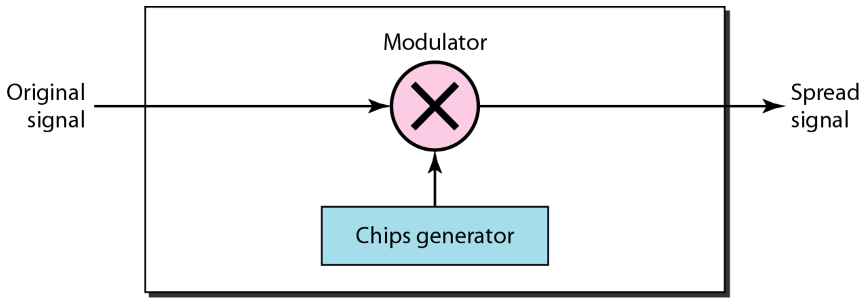
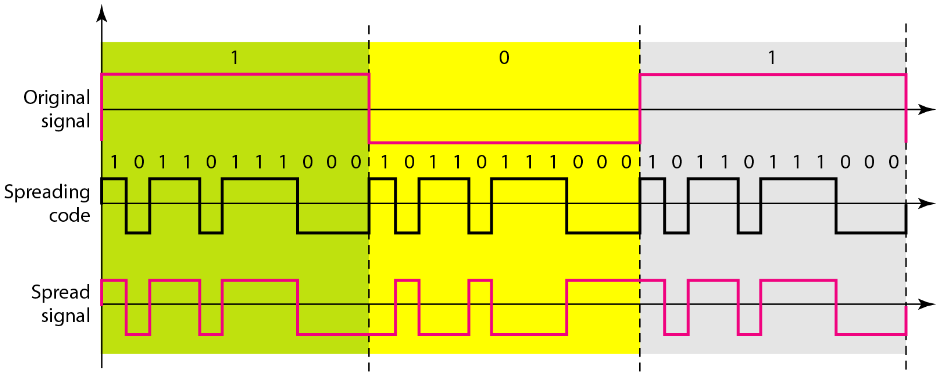


Figure shows the chips and the result of multiplying the original data by the chips to get the spread signal.



In Figure the spreading code is 11 chips having the pattern **10110111000**. If the original signal rate is *N, the rate of the spread signal is 11N. This* means that the required bandwidth for the spread signal is **11** times larger than the bandwidth of the original signal. The spread signal can provide privacy if the intruder does not know the code.

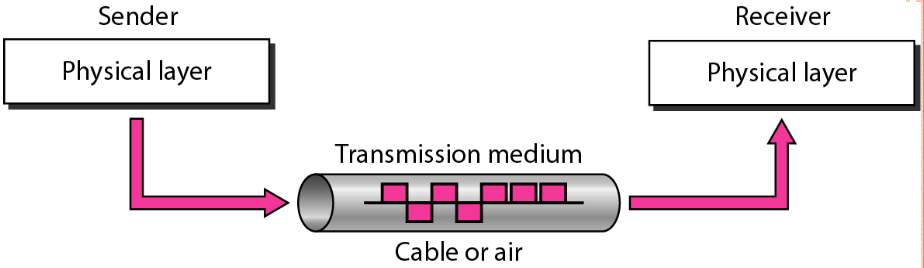
TRANSMISSION MEDIA

- Transmission media are actually located below the physical layer and are directly controlled by the physical layer.
- A transmission medium can be broadly defined as **anything that can carry information from a source to a destination.**
- In data communications ,

  Transmission medium is usually free space, metallic cable, or fiber-optic cable.

  Information is usually a signal

Figure : *Transmission medium and physical layer*



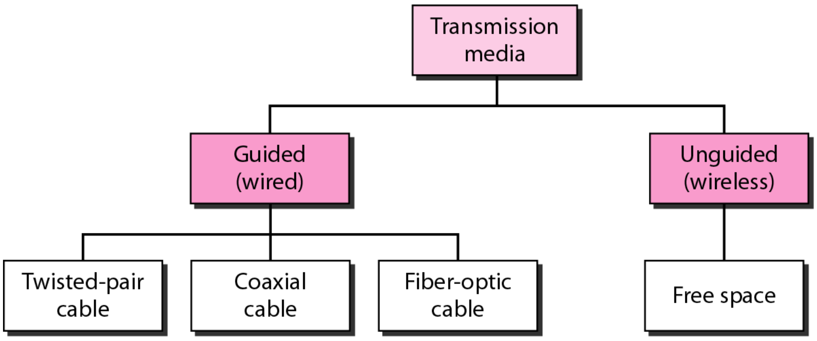
In telecommunications, transmission media can be divided into two broad categories:

Guided and unguided.

Guided media include twisted-pair cable, coaxial cable, and fiber-optic cable.

Unguided medium is free space.

Figure : *Classes of transmission media*



GUIDED MEDIA

Guided media, which are those that provide a conduit from one device to another.

I. Twisted-pair cable.

II. Coaxial cable.

III. Fiber-optic cable.

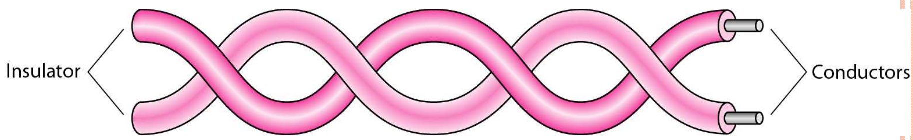
Twisted-pair and coaxial cable use metallic (copper) conductors that accept and transport signals in the form of electric current.

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.

Figure : *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.

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. 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. The receiver calculates the difference between the two, receives no unwanted signals. The unwanted signals are mostly canceled out.

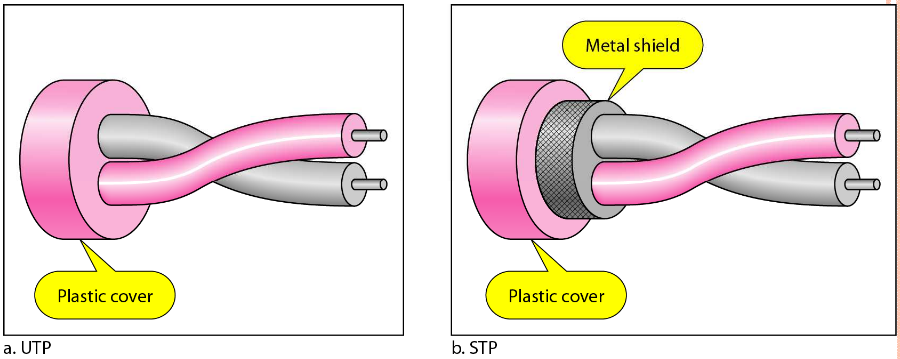
Unshielded Versus Shielded Twisted-Pair Cable

The most common twisted-pair cable used in communications is referred to as unshielded twisted-pair (UTP).

IBM has also produced a version of twisted-pair cable for its use called shielded twisted-pair (STP).

STP cable has a metal foil or braided mesh covering that encases each pair of insulated conductors.

Figure : *UTP and STP cables*



Categories

The Electronic Industries Association (EIA) has developed standards to classify unshielded twisted-pair cable into seven categories. Categories are determined by cable quality, with 1 as the lowest and 7 as the highest. Each EIA category is suitable for specific uses.

Table shows these categories.

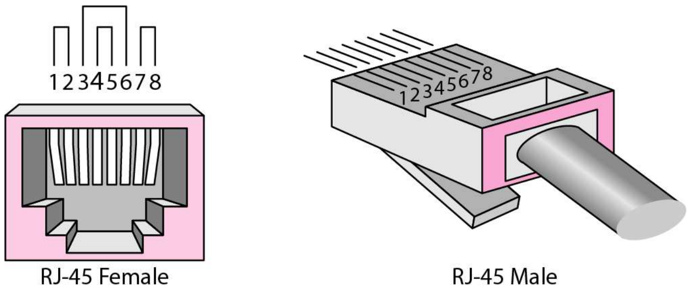
Table : *Categories of unshielded twisted-pair cables*

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

Connectors

The most common UTP connector is RJ45 (RJ stands for registered jack). The RJ45 is a keyed connector, meaning the connector can be inserted in only one way.

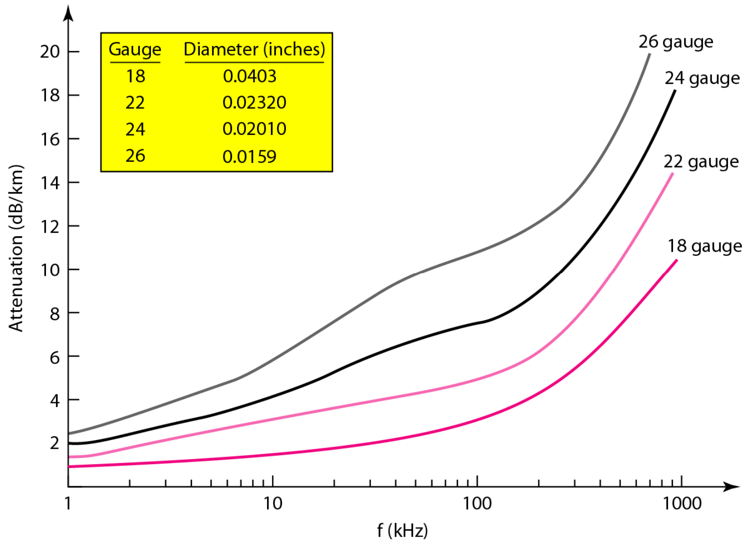
Figure : *UTP connector*



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. The attenuation, measured in decibels per kilometer (dB/km), sharply increases with frequencies above 100 kHz. Note that *gauge is a measure of the thickness of the wire.*

Figure : *UTP performance*



Applications

- Twisted-pair cables are used in telephone lines to provide voice and data channels.

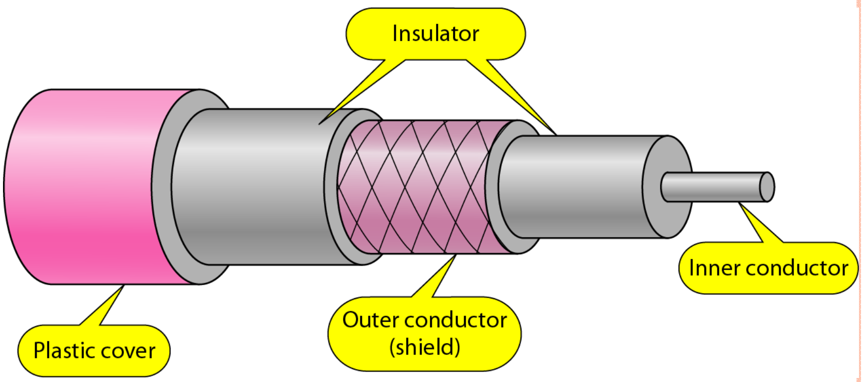
- The DSL lines that are used by the telephone companies to provide high-data-rate connections also use the high-bandwidth capability of unshielded twisted-pair cables.

- Local-area networks, such as 10Base-T and 100Base-T, also use twisted-pair cables.

Coaxial Cable

Coaxial cable (or *coax)* **carries signals of higher frequency ranges than those in twisted pair** cable. 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 : *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.

Table : *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 coaxial connector used today is the Bayone-Neill-Concelman (BNC), connector.

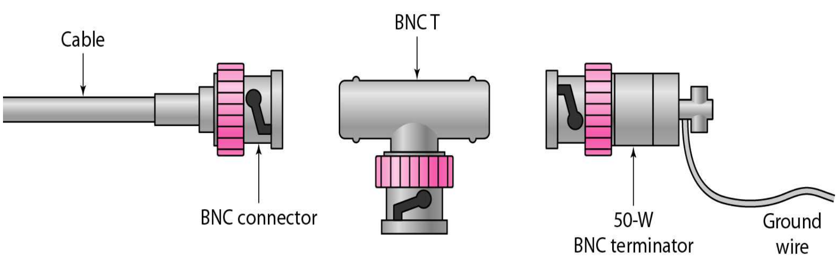
Three popular types of these connectors: the BNC connector, the BNC T connector, and the BNC terminator.

The BNC connector is used to connect the end of the cable to a device, such as a TV set.

The BNC T connector is used in Ethernet networks to branch out to a connection to a computer or other device.

The BNC terminator is used at the end of the cable to prevent the reflection of the signal.

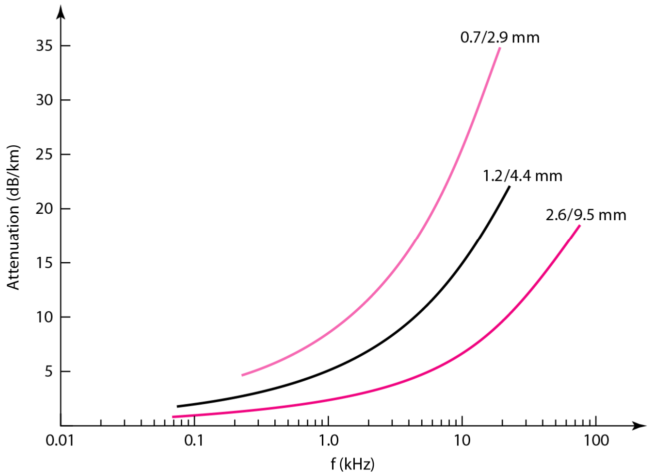
Figure : *BNC connectors*



Performance

The attenuation is much higher in coaxial cables than in twisted-pair cable. In other words, although coaxial cable has a much higher bandwidth, the signal weakens rapidly and requires the frequent use of repeaters.

Figure : *Coaxial cable performance*



Applications

I. 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.

II. Cable TV networks also use coaxial cables.

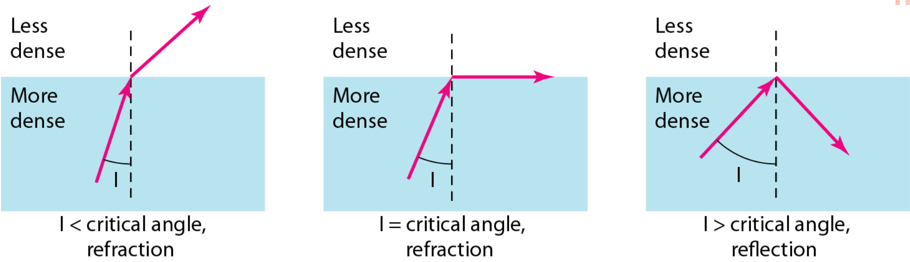
III. Another common application of coaxial cable is in traditional Ethernet LANs.

Fiber-Optic Cable

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

Light travels in a straight line as long as it is moving through a single uniform substance. If a ray of light traveling through one substance suddenly enters another substance the ray changes direction.

Figure : *Bending of light ray*

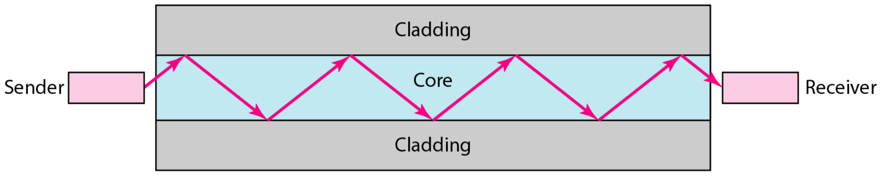


As the figure shows,

- 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.

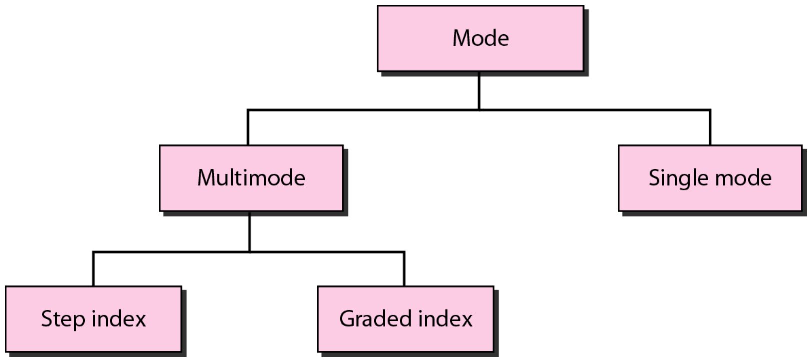
The critical angle is a property of the substance, and its value differs from one substance to another.

Optical fiber



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.

Propagation Modes



Multimode

Multimode is so named because multiple beams from a light source move through the core in different paths.

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.

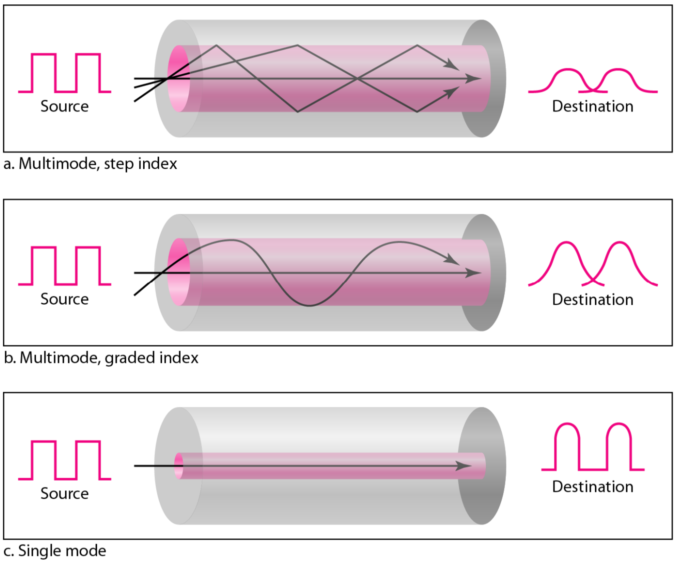
In **multimode graded-index fiber**, decreases the distortion of the signal through the cable. The word index here refers to the index of refraction. A graded-index fiber, is one with varying densities. Density is highest at the center of the core and decreases gradually to its lowest at the edge.

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.

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.

Figure : *Modes*



Fiber Sizes

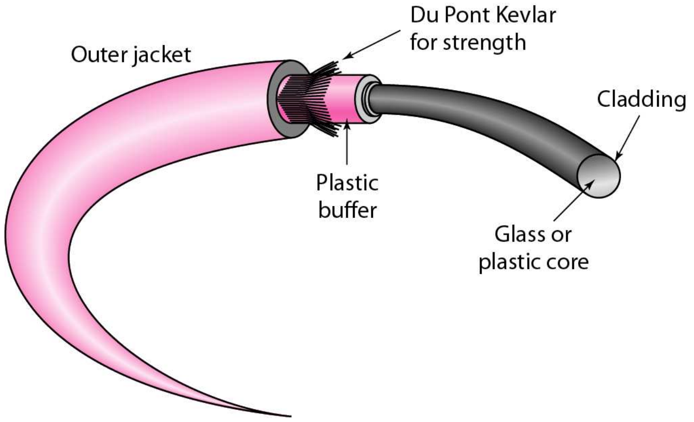
Optical fibers are defined by the ratio of the diameter of their core to the diameter of their cladding, both expressed in micrometers.

Table : ***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

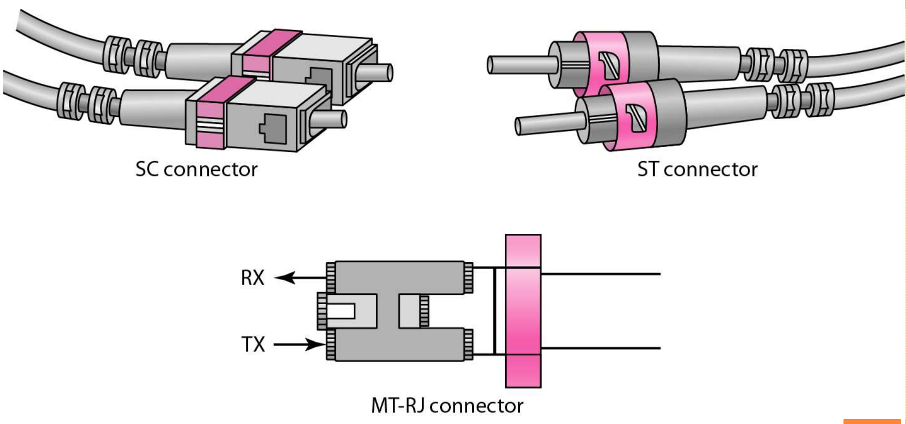
Figure : *Fiber construction*



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.

Fiber-Optic Cable Connectors

Figure : *Fiber-optic cable connectors*



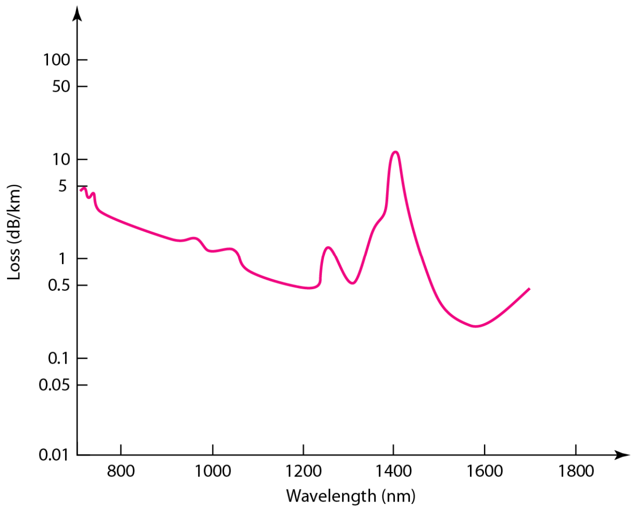
There are three types of connectors for fiber-optic cables,

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

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

MT-RJ is a connector that is the same size as RJ45.

Figure : *Optical fiber performance*



Applications

- SomFiber-optic cable is often found in backbone networks because its wide bandwidth is cost-effective.
- 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.
- 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

1. **Higher bandwidth.**
2. **Less signal attenuation.** :- A signal can run for 50 km without requiring regeneration. We need repeaters every 5 km for coaxial or twisted-pair cable.
3. **Immunity to electromagnetic interference.**
4. **Resistance to corrosive materials.** :- Glass is more resistant to corrosive materials than copper.
5. **Light weight.**
6. **Greater immunity to tapping.**

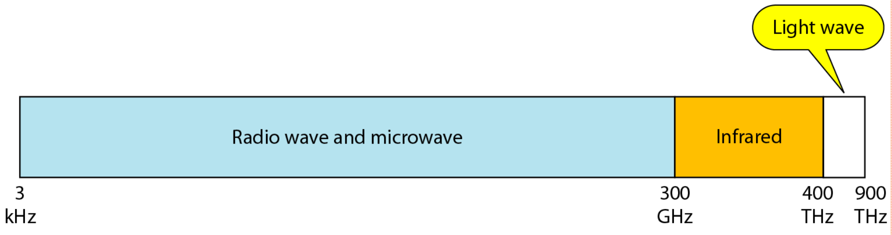
Disadvantages

1. **Installation and maintenance.** :- Fiber-optic cable is a relatively new technology. Its installation and maintenance require expertise that is not yet available everywhere.
2. **Unidirectional light propagation.** :- If we need bidirectional communication, two fibers are needed.
3. **Cost.** :- The cable and the interfaces are relatively more expensive than those of other guided media.

UNGUIDED MEDIA: WIRELESS

Unguided media transport electromagnetic waves without using a physical conductor. This type of communication is often referred to as wireless communication. Signals are normally broadcast through free space and thus are available to anyone who has a device capable of receiving them.

Figure : *Electromagnetic spectrum for wireless communication*



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

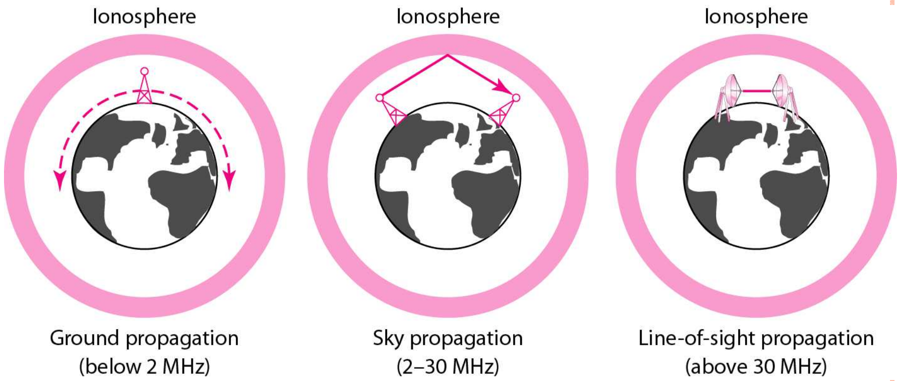
I. Ground propagation
II. Sky propagation
III. Line-of-sight propagation

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

In **sky propagation**, higher-frequency radio waves radiate upward into the ionosphere where they are reflected back to earth. This type of transmission allows for greater distances with lower output power.

In **line-of-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.

Figure : *Propagation methods*



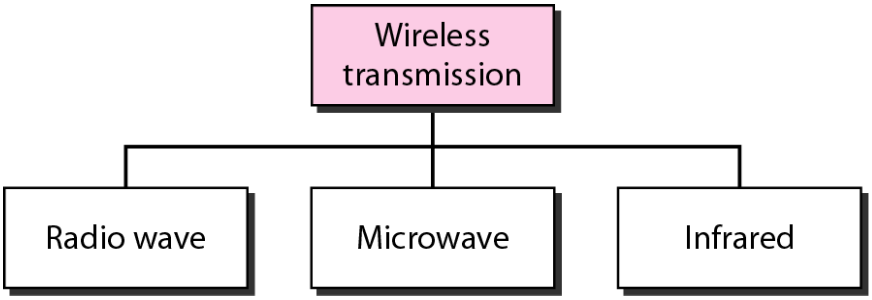
The electromagnetic spectrum defined as radio waves and microwaves is divided into eight ranges, called *band*. These bands are rated from *very low frequency (VLF)* to *extremely high frequency (EHF).*

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

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 can divide wireless transmission into three broad groups: radio waves, microwaves, and infrared waves.

Wireless transmission waves



Radio Waves

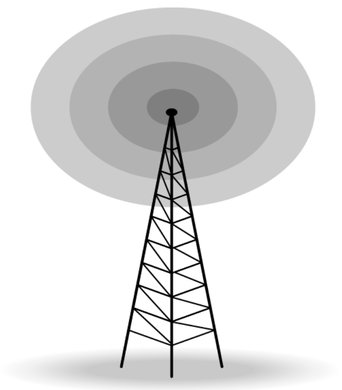
- Electromagnetic waves ranging in frequencies between 3 kHz and 1 GHz are normally called radio waves.

- Radio waves, are omnidirectional. When an antenna transmits radio waves, they are propagated in all directions. A sending antenna sends waves that can be received by any receiving antenna. The omnidirectional property has a disadvantage, too. The radio waves transmitted by one antenna are susceptible to interference by another antenna that may send signals using the same frequency or band.

- Radio waves can travel long distances. This makes radio waves a good candidate for long-distance broadcasting such as AM radio.
- Radio waves can penetrate walls. It is an advantage because an AM radio can receive signals inside a building. It is a disadvantage because we cannot isolate a communication to just inside or outside a building.
- The radio wave band is relatively narrow compared to the microwave band. Leading to a low data rate for digital communications.
- Almost the entire band is regulated by authorities.

Omnidirectional Antenna

Radio waves use omnidirectional antennas that send out signals in all directions.



Applications

Radio waves are used for multicast communications, such as radio and television, and paging systems.

Microwaves

- Electromagnetic waves having frequencies between 1 and 300 GHz are called microwaves.
- Microwaves are unidirectional. The unidirectional property has an obvious 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. 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. High data rate is possible.
- Use of certain portions of the band requires permission from authorities.

Unidirectional Antenna

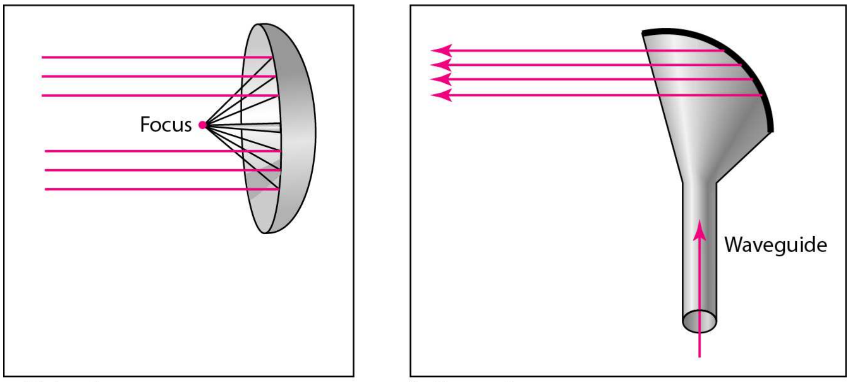
Microwaves need unidirectional antennas that send out signals in one direction.

Two types of antennas are used for microwave communications:

The parabolic dish and The horn.

A parabolic dish antenna is based on the geometry of a parabola. The parabolic dish works as a funnel, catching a wide range of waves and directing them to a common point.

A horn antenna looks like a gigantic scoop. Outgoing transmissions are broadcast up a stem and deflected outward in a series of narrow parallel beams by the curved head.



a. Dish antenna

b. Horn antenna

Applications

Microwaves are used for unicast communication such as cellular telephones, satellite networks, and wireless LANs.

Infrared

- ✓ Infrared waves, with frequencies from 300 GHz to 400 THz can be used for short-range communication.
- ✓ 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.
- ✓ We cannot use infrared waves outside a building because the sun's rays contain infrared waves that can interfere with the communication.

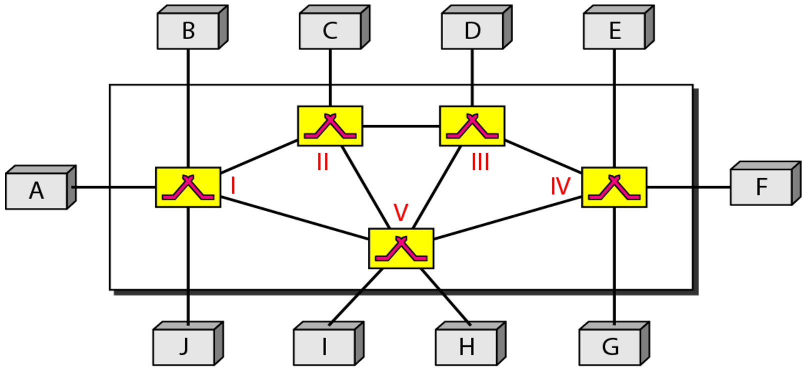
Applications

- The *Infrared 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, mice, PCs, and printers.
- Infrared signals can be used for short-range communication in a closed area using line-of-sight propagation.

SWITCHING

A switched network(switching) 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.

Figure : *Switched network*



Three methods of switching have been important:

circuit switching, packet switching, and message switching.

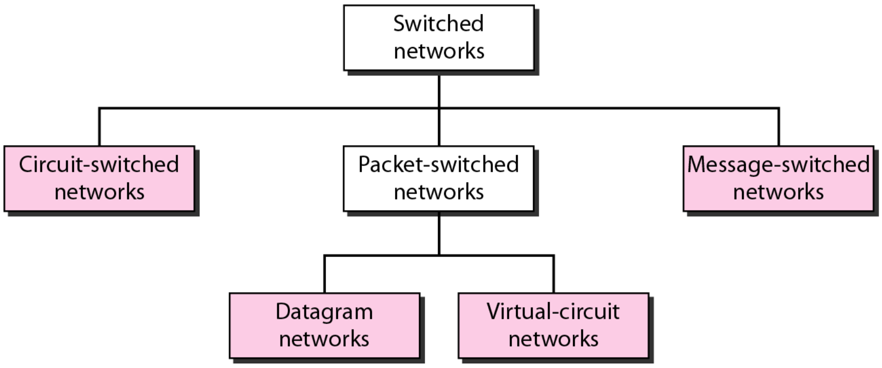
We can divide today's networks into three broad categories:

circuit-switched networks, packet-switched networks and message-switched.

Packet-switched networks can further be divided into two subcategories :

virtual-circuit networks and datagram networks

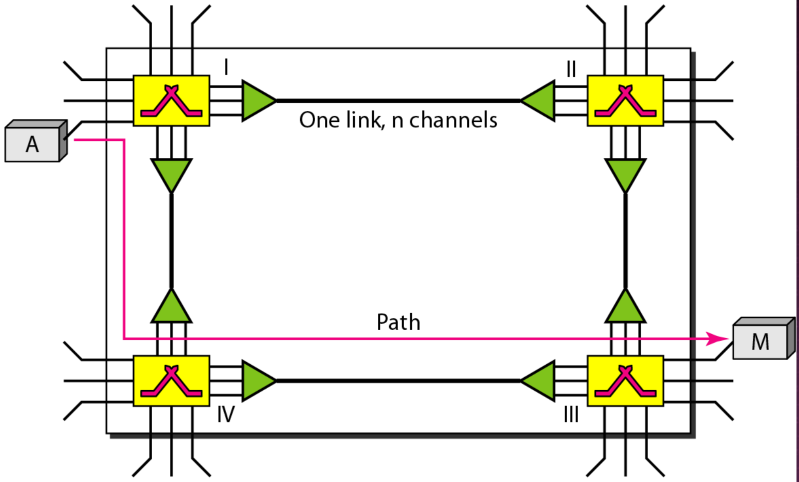
Figure : *Taxonomy of switched networks*



CIRCUIT-SWITCHED NETWORKS

A circuit-switched network is made of a set of switches connected by physical links, in which each link is divided into *n channels* by using FDM or TDM.

Figure : *A trivial circuit-switched network*



The end systems are directly connected to a switch. In figure, 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. 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 torn down.

- 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, switch buffers, switch processing time, and switch input/output ports, must remain dedicated during the entire duration of data transfer.
- Data transferred between the two stations are not packetized.
- There is no addressing involved during data transfer.

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 can communicate, a dedicated circuit 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 example, in Figure, 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.

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 two types of networks because resources are allocated during the entire duration of the connection. These resources are unavailable to other connections.

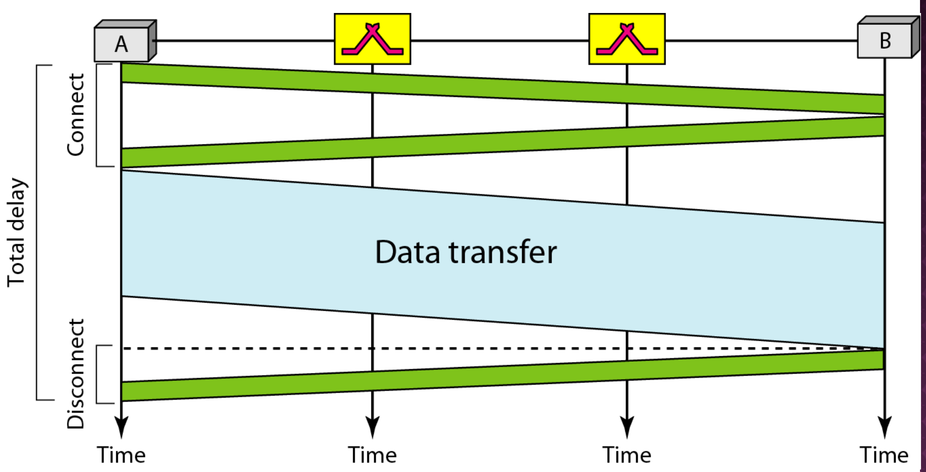
In a telephone network, people normally terminate the communication when they have finished their conversation.

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 shows the idea of delay in a circuit-switched network when only two switches are involved.

Figure : *Delay in a circuit-switched network*



In figure 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:

1) The propagation time of the source computer request
2) The request signal transfer time
3) The propagation time of the acknowledgment from the destination Computer
4) The signal transfer time of the acknowledgment

The delay due to data transfer is the sum of two parts:
the propagation time and data transfer, which can be very long.
The third box shows the time needed to tear down the circuit.

Circuit-Switched Technology in Telephone Networks

Switching at the physical layer in the traditional telephone network uses the circuit-switching approach.

Packet Switched Network

Packet Switching is the standard switching technology for computer-to-computer communications. In packet switching, data are transmitted as discrete blocks, called packets. Each packet contains data to be transferred, and also the control information such as the sender's address and the destination's address.

In packet switching, there is no resource allocation for a packet. 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.

Packet switching can be classified into two types:

1. Datagram approach
2. Virtual circuit approach

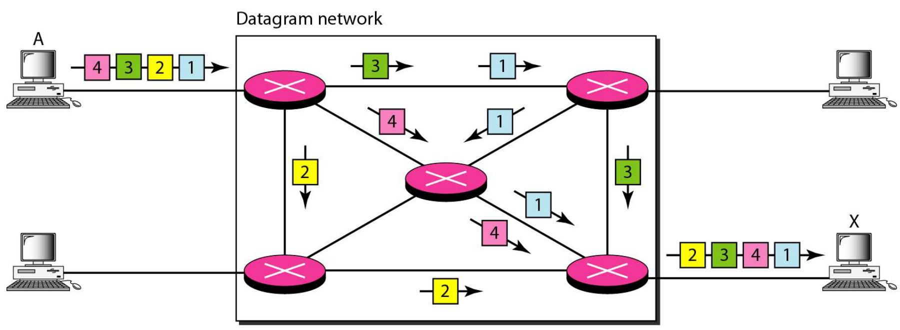
DATAGRAM NETWORKS

In a datagram network, each packet is treated independently of all others. Packets in this approach are referred to as datagrams. Datagram switching is normally done at the network layer.

Figure 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.

Figure : *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. It is the responsibility of an upper-layer protocol to reorder the datagrams.

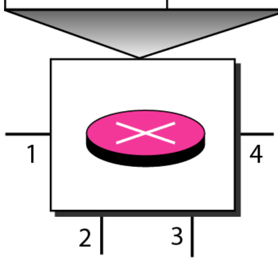
The datagram networks are sometimes referred to as connectionless networks. There are no setup or teardown phases.

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.

Figure : *Routing table in a datagram network*

Destination address	Output port
1232	1
4150	2
⋮	⋮
9130	3



Destination Address

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

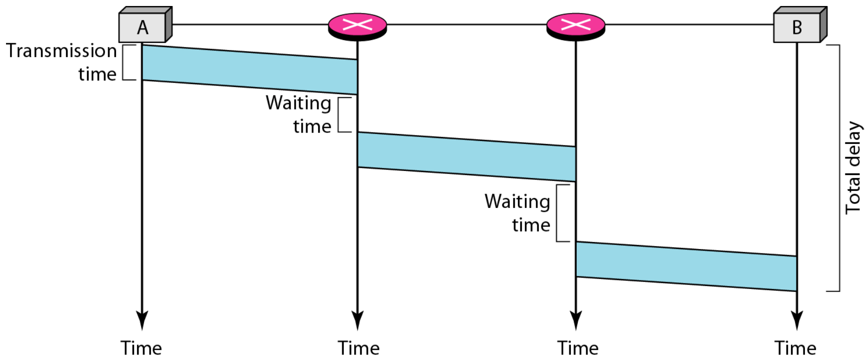
Efficiency

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.

Figure : *Delay in a datagram network*



The packet travels through two switches. There are three transmission times *(3T)*, three propagation delays (slopes 3τ of the lines), and two waiting times ($w_1 + w_2$). *We* ignore the processing time in each switch. The total delay is

$$\text{Total delay} = 3T + 3\tau + w_1 + w_2$$

Datagram Networks in the Internet

Switching in the Internet is done by using the datagram approach to packet switching at the network layer.

VIRTUAL-CIRCUIT NETWORKS

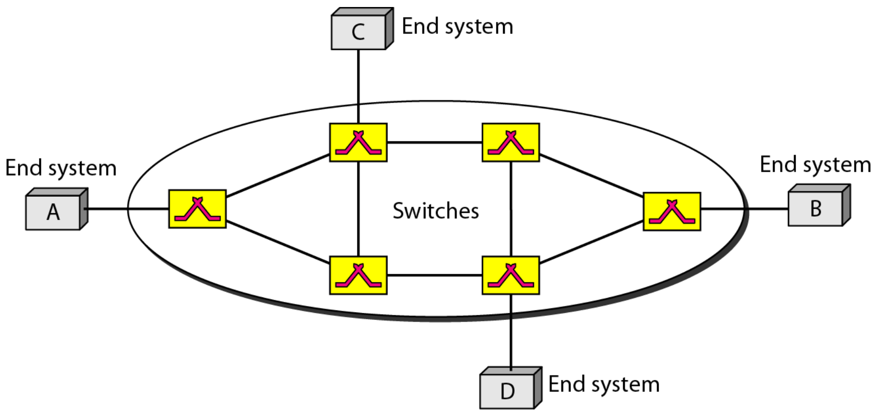
A virtual-circuit network is a cross between a circuit-switched network and a datagram network. It has some characteristics of both.

i. As in a circuit-switched network, there are setup and teardown phases in addition to the data transfer phase.
ii. Resources can be allocated during the setup phase, as in a circuit-switched network, or on demand, as in a datagram network.
iii. As in a datagram network, data are packetized and each packet carries an address in the header.

iii. As in a circuit-switched network, all packets follow the same path established during the connection.

iv. 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.

Figure : *Virtual-circuit network*



Addressing

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

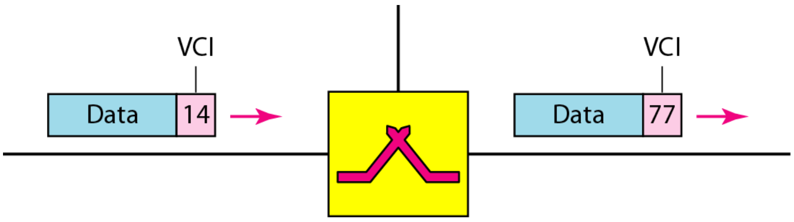
Global Addressing

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 (VCI).** A VCI, 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 VCI.

Figure : *Virtual-circuit identifier*



Three Phases

As in a circuit-switched network, a source and destination need to go through three phases in a virtual-circuit network: setup, data transfer, and teardown.

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 has four columns. This means that the switch holds four pieces of information for each virtual circuit that is already set up.

Figure : *Switch and tables in a virtual-circuit network*

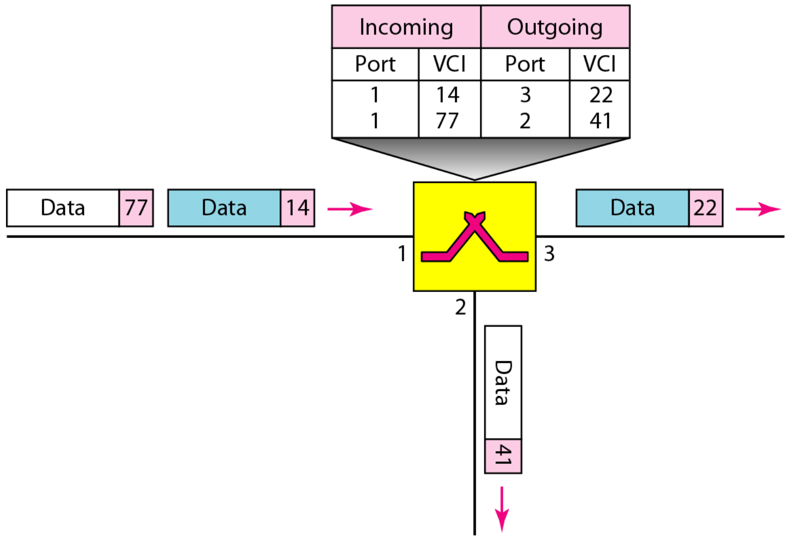
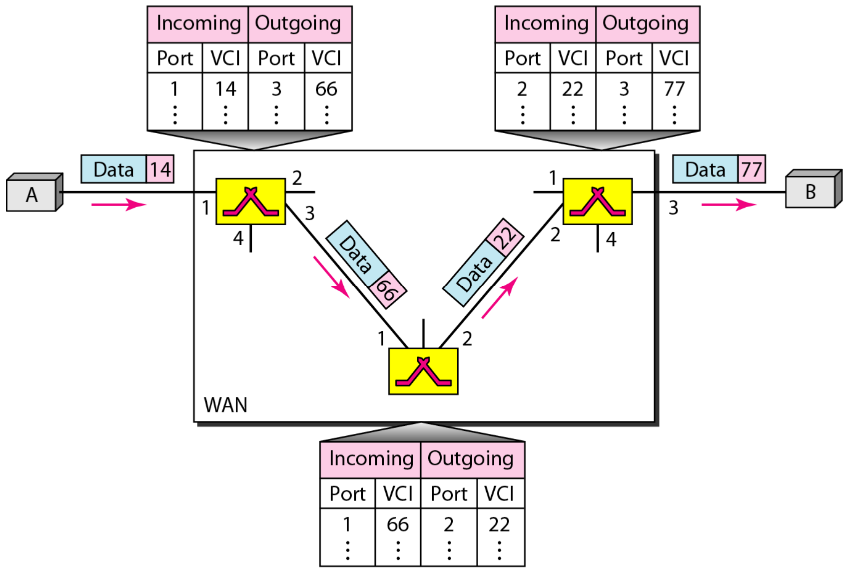


Figure shows a frame arriving at port 1 with a VCI of 14. When the frame arrives, the switch looks in its table to find port 1 and a VCI of 14. When it is found, the switch knows to change the VCI to 22 and send out the frame from port 3.

Figure below 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.

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



The data transfer phase is active until the source sends all its frames to the destination. The process creates a virtual 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.

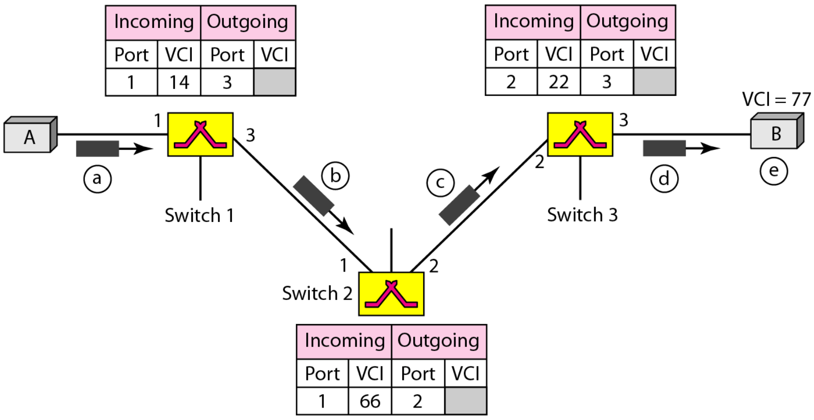
Two steps are required:

the setup request and the acknowledgment.

Setup Request

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

Figure : *Setup request in a virtual-circuit network*



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

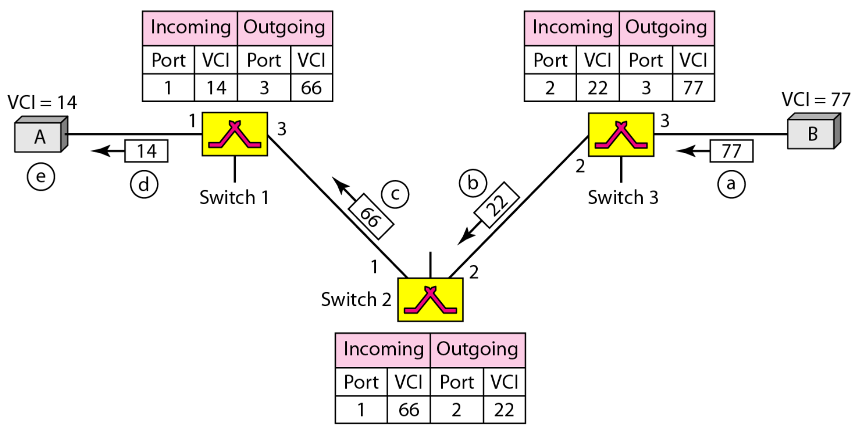
2. Switch 1 receives the setup request frame. It knows that a frame going from A to B goes out through port 3. The switch, in the setup phase, acts as a packet switch; it has a routing table. The switch creates an entry in its table for this virtual circuit, but it is only able to fill three of the four 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.

3. Switch 2 receives the setup request frame. The same events happen here as at switch 1. In this case, incoming port (l), incoming VCI (66), and outgoing port (2).
4. Switch 3 receives the setup request frame. Again, three columns are completed.
5. 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 shows the process.

Figure : *Setup acknowledgment in a virtual-circuit network*



1. 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. 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.
2. Switch 3 sends an acknowledgment to switch 2 that contains its incoming VCI in the table. Switch 2 uses this as the outgoing VCI in the table.
3. Switch 2 sends an acknowledgment to switch 1 that contains its incoming VCI. Switch 1 uses this as the outgoing VCI.

4. Finally switch 1 sends an acknowledgment to source A that contains its incoming VCI in the table.
5. 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.

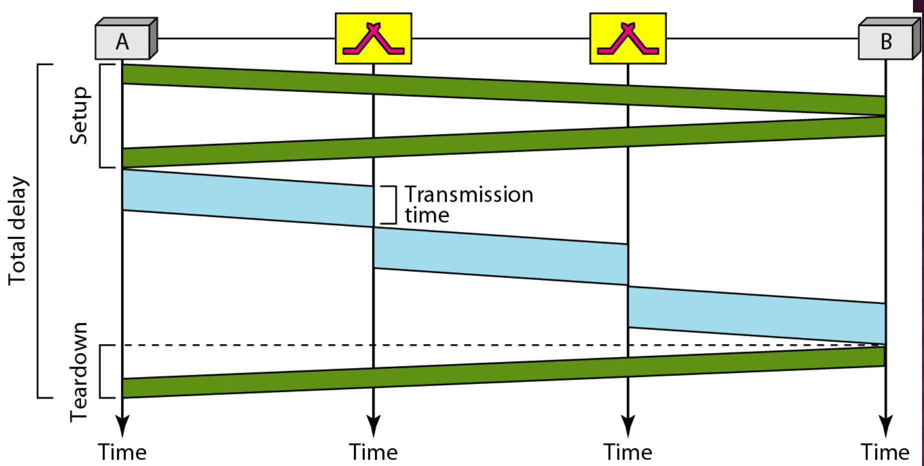
Efficiency

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.

There is one big advantage in a virtual-circuit network even if resource allocation is on demand.

Delay in Virtual-Circuit Networks

Figure : *Delay in a virtual-circuit network*



The packet is traveling through two switches (routers). There are three transmission times *(3T), three propagation times (3τ), data transfer depicted by the sloping* lines, a setup delay (which includes transmission and propagation in two directions), and a teardown delay (which includes transmission and propagation in one direction).

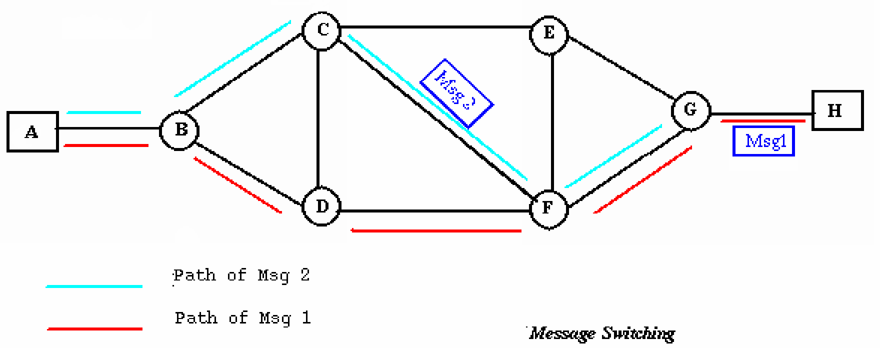
Total delay = $3T + 3\tau$ + *setup delay* + *teardown delay*

Circuit-Switched Technology in WANs

Switching at the data link layer in a switched WAN is normally implemented by using virtual-circuit techniques.

Message Switching

- With message switching there is no need to establish a dedicated path between two stations.
- When a station sends a message, the destination address is appended to the message.
- The message is then transmitted through the network, in its entirety, from node to node.
- Each node receives the entire message, stores it in its entirety on disk, and then transmits the message to the next node.
- This type of network is called a store-and-forward network.



Message Switching

A message-switching node is typically a general-purpose computer. The device needs sufficient secondary-storage capacity to store the incoming messages, which could be long. A time delay is introduced using this type of scheme due to store- and-forward time, plus the time required to find the next node in the transmission path.

COMPARISON

Circuit switching	Message switching	Packet switching
Dedicated path available	No dedicated path	No dedicated path
Data storing is not required	Store and forward	Packets are queued for delivery; they are not stored
Length of transmission is unlimited	No limit	Packets have a maximum length
Switch path is established for the entire connection	Route is established for each message	Route is established for each packet
As the network load increases, more blocking can occur	As the load increases, messages on average experience longer delivery delay	As the load increases, packets on average experience longer queing delay

The connection is blocked if the end user is busy or not available. Once the connection starts no blocking occurs	No messsage blocking can occur as long as the storage capacity is sufficiently large	Packet blocking can occur. However the packets will be retransmitted to the end user
Provides real-time or continuous transmission of data	Too slow for real-time or interactive data transmission	Provides near real-time data transmission
For small messages the data transmission time is negligible compared to the time taken to set-up and tear-down the connection	Message delivery time can be substantially long	Packet delivery time is too short

Circuit switching

Advantages:

- The communication channel (once established) is dedicated.

Disadvantages:

- Possible long wait to establish a connection, (10 seconds, more on long- distance or international calls.) during which no data can be transmitted.
- More expensive than any other switching techniques, because a dedicated path is required for each connection.
- Inefficient use of the communication channel, because the channel is not used when the connected systems are not using it.

Message Switching

Advantages:

I. Channel efficiency can be greater compared to circuit-switched systems, because more devices are sharing the channel.

II. Traffic congestion can be reduced, because messages may be temporarily stored in route.

III. Message priorities can be established due to store-and-forward technique.

IV. Message broadcasting can be achieved with the use of broadcast address appended in the message.

Message Switching

Disadvantages

- Message switching is not compatible with interactive applications.
- Store-and-forward devices are expensive, because they must have large disks to hold potentially long messages.

Packet switching

Advantages:

A. Packet switching is cost effective, because switching devices do not need massive amount of secondary storage.
B. Packet switching offers improved delay characteristics, because there are no long messages in the queue (maximum packet size is fixed).
C. Packet can be rerouted if there is any problem, such as, busy or disabled links.
D. The advantage of packet switching is that many network users can share the same channel at the same time. Packet switching can maximize link efficiency by making optimal use of link bandwidth.

Packet switching

Disadvantages:

1. Protocols for packet switching are typically more complex.
2. It can add some initial costs in implementation.
3. If packet is lost, sender needs to retransmit the data.
4. Another disadvantage is that packet-switched systems still can't deliver the same quality as dedicated circuits in applications requiring very little delay - like voice conversations or moving images.