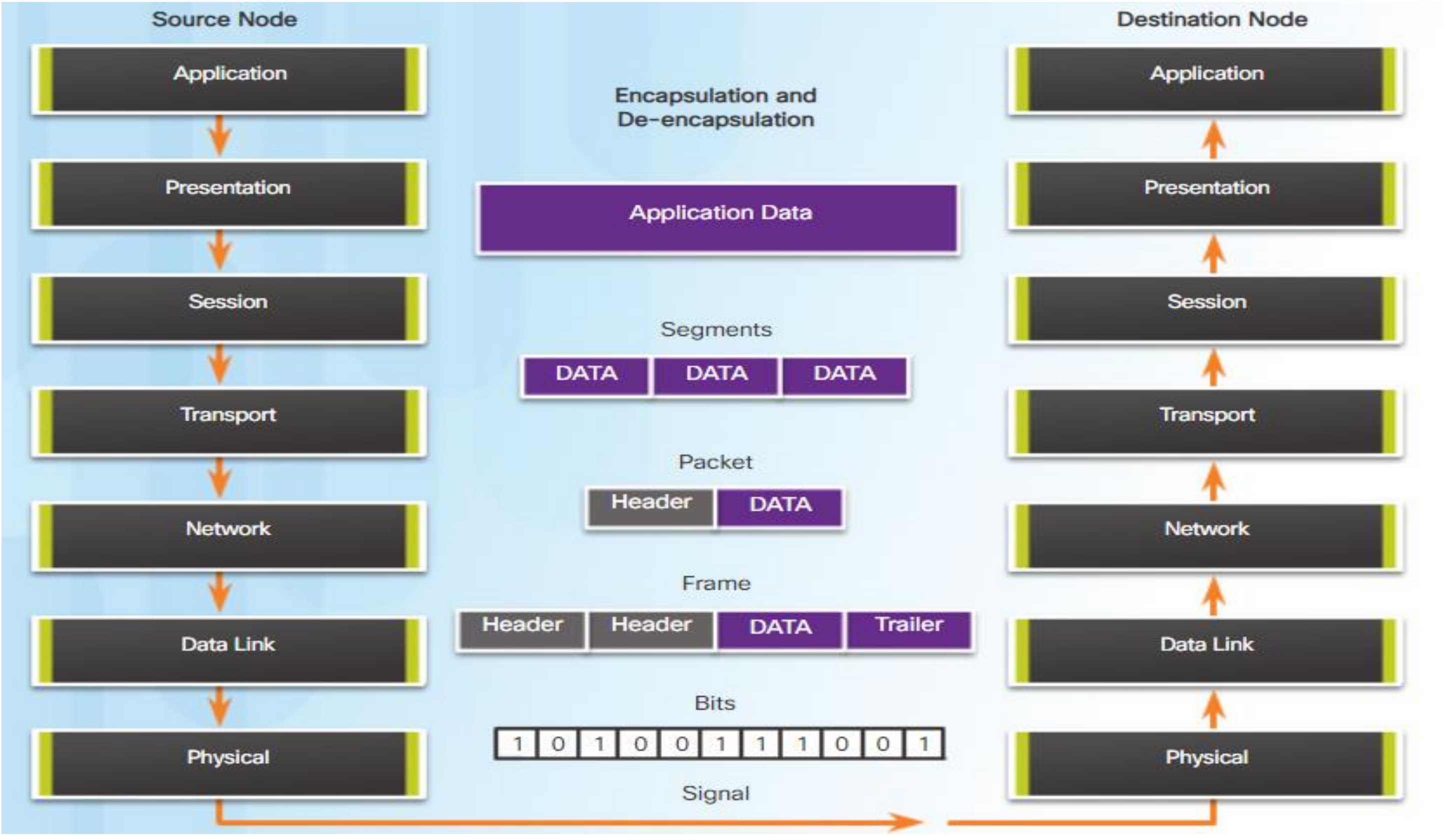
Physical Layer



- Physical layer is responsible for sending bits from one computer to another.
- This layer is not concerned with the meaning of the bits and deals with the setup of physical connection to the network and with transmission and reception of signals.

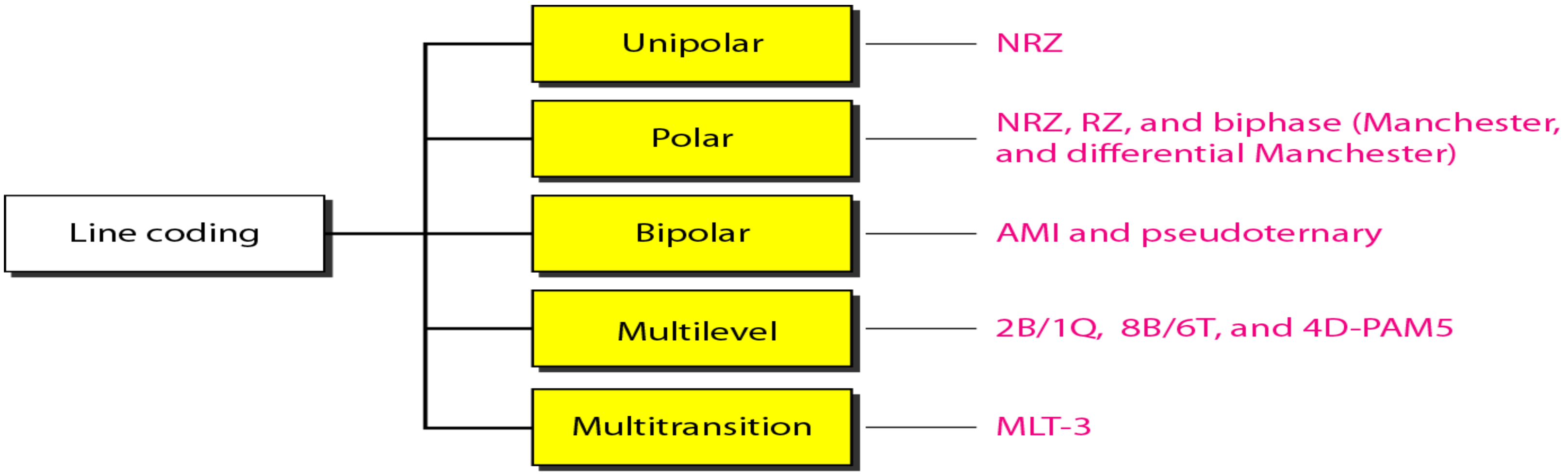
- It includes several methods and functions.

- Topics to be discussed:
- Methods for representation of bits as signals and vice versa.
- Characteristics of transmission media.
- Characteristics of physical interfaces.
- Multiplexing and switching techniques.

- Both data and signals can be represented in either analog and digital form.
- Representation of bits as signals is of four types.

- **Digital to digital transformation**: Digital data is encoded into digital signals.
- Also called as line coding techniques.
- Methods used are Non Return to Zero (NRZ), Return to Zero (RZ), Manchester Encoding, Differential Manchester Encoding etc.
- Used in wired LAN/WAN networks when transmission media is copper/Fiber optic media.

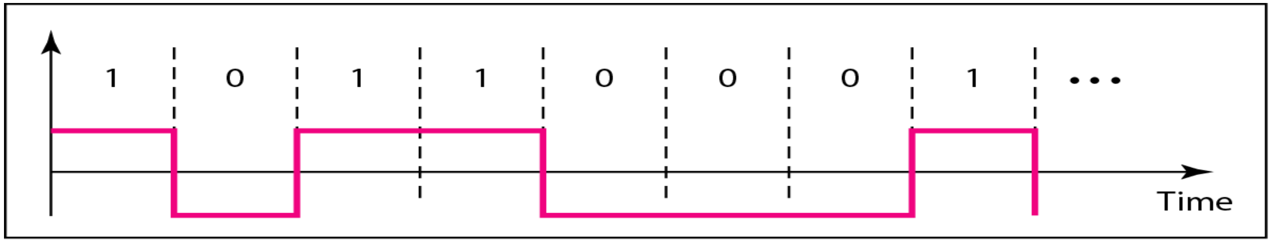
- **Line Coding Techniques**



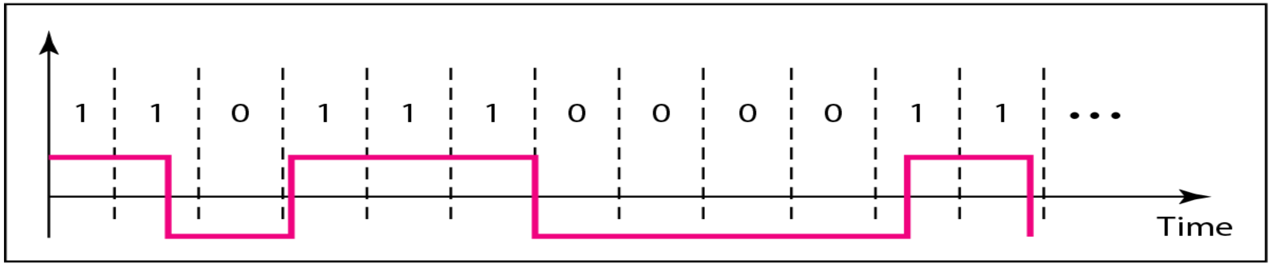
- several line coding schemes are developed ultimately to address two characteristics.
- <u>DC Components:</u> When the voltage level in a digital signal is constant for a while, the spectrum creates very low frequencies (results of Fourier analysis). These frequencies around zero, called DC (direct-current) *components,* present problems for a system that cannot pass low frequencies or a system that uses electrical coupling (via a transformer).

- <u>Self-synchronization:</u> To correctly interpret the signals received from the sender, the receiver's bit intervals must correspond exactly to the sender's bit intervals. If the receiver clock is faster or slower, the bit intervals are not matched and the receiver might misinterpret the signals.

Effect of lack of synchronization

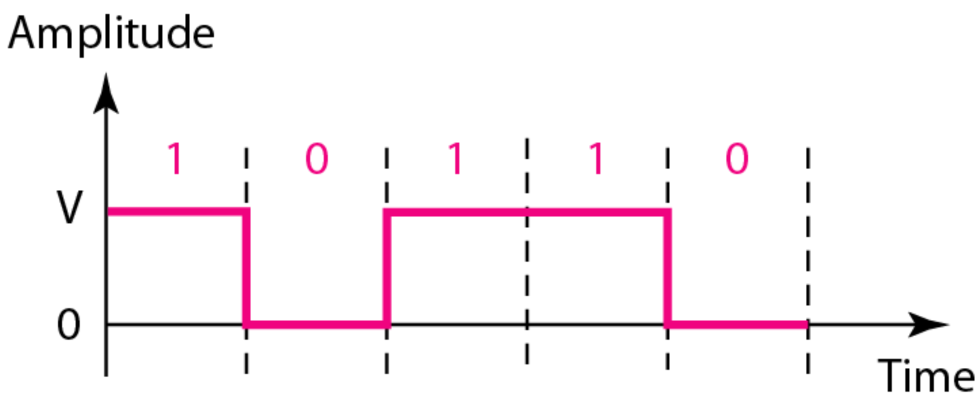


a. Sent



b. Received

- ***Unipolar Scheme***
- In a unipolar scheme, all the signal levels are on one side of the time axis, either above or below.
- **NRZ (Non-Return-to-Zero)**
- Traditionally, a unipolar scheme was designed as a non-return-to-zero (NRZ) scheme in which the positive voltage defines bit 1 and the zero voltage defines bit 0. It is called NRZ because the signal does not return to zero at the middle of the bit.



$$\frac{1}{2}V^2 + \frac{1}{2}(0)^2 = \frac{1}{2}V^2$$

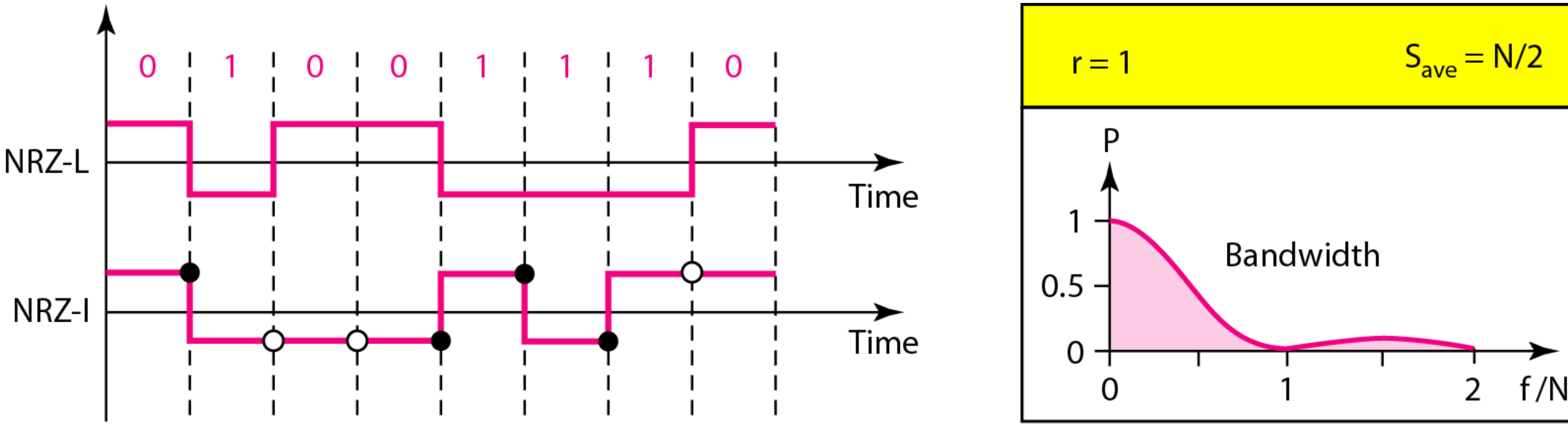
Normalized power

- **Advantages**
- The advantages of Unipolar NRZ are −
- It is simple.
- A lesser bandwidth is required.

- **Disadvantages**
- Presence of low frequency components may cause the signal droop.
- No self synchronization is present. Loss of synchronization is likely to occur (especially for long strings of **1s** and **0s**).

- ***Polar Schemes***
- In polar schemes, the voltages are on the both sides of the time axis. For example, the voltage level for 0 can be positive and the voltage level for1 can be negative.
- **Non-Return-to-Zero (NRZ)**
- In polar NRZ encoding, we use two levels of voltage amplitude. We can have two versions of polar NRZ: NRZ-Land NRZ-I.
- In the first variation, NRZ-L (NRZ-Level), the level of the voltage determines the value of the bit.
- In the second variation, NRZ-I (NRZ-Invert), the change or lack of change in the level of the voltage determines the value of the bit. If there is no change, the bit is 0; if there is a change, the bit is 1.

- ***Polar NRZ-L and NRZ-I schemes***

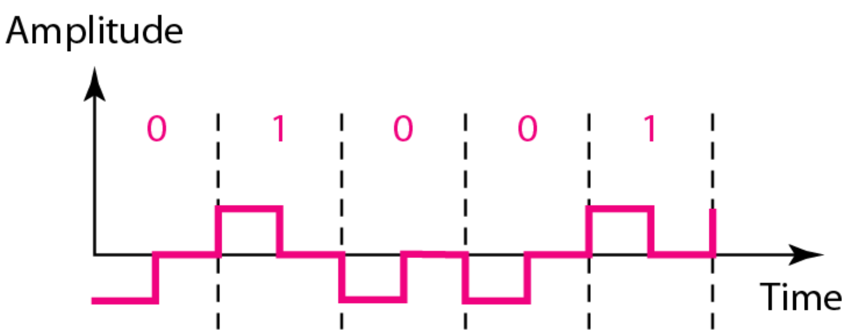


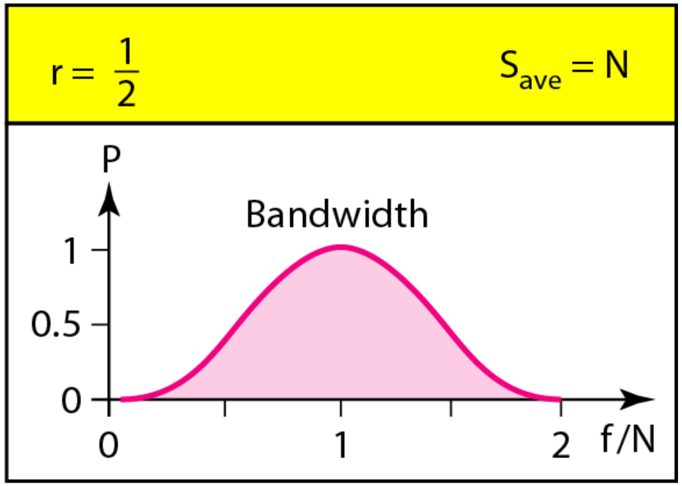
○ No inversion: Next bit is 0 ● Inversion: Next bit is 1

- <u>*DC bias*</u> If there is a long sequence of 0s or 1s in NRZ-L, the average signal power becomes skewed. The receiver might have difficulty discerning the bit value. In NRZ-I this problem occurs only for a long sequence of 0s.
- <u>*Self synchronization*</u> The synchronization problem (sender and receiver clocks are not synchronized) also exists in both schemes. Again, this problem is more serious in NRZ-L than in NRZ-I. While a long sequence of 0s can cause a problem in both schemes, a long sequence of 1s affects only NRZ-L.

- **Return to Zero (RZ)** The main problem with NRZ encoding occurs when the sender and receiver clocks are not synchronized. The receiver does not know when one bit has ended and the next bit is starting.
- One solution is the return-to-zero (RZ) scheme, which uses three values: positive, negative, and zero.
- In RZ, the signal changes not only between bits but during the bit also. The signal goes to 0 in the middle of each bit. It remains there until the beginning of the next bit.

Polar RZ scheme



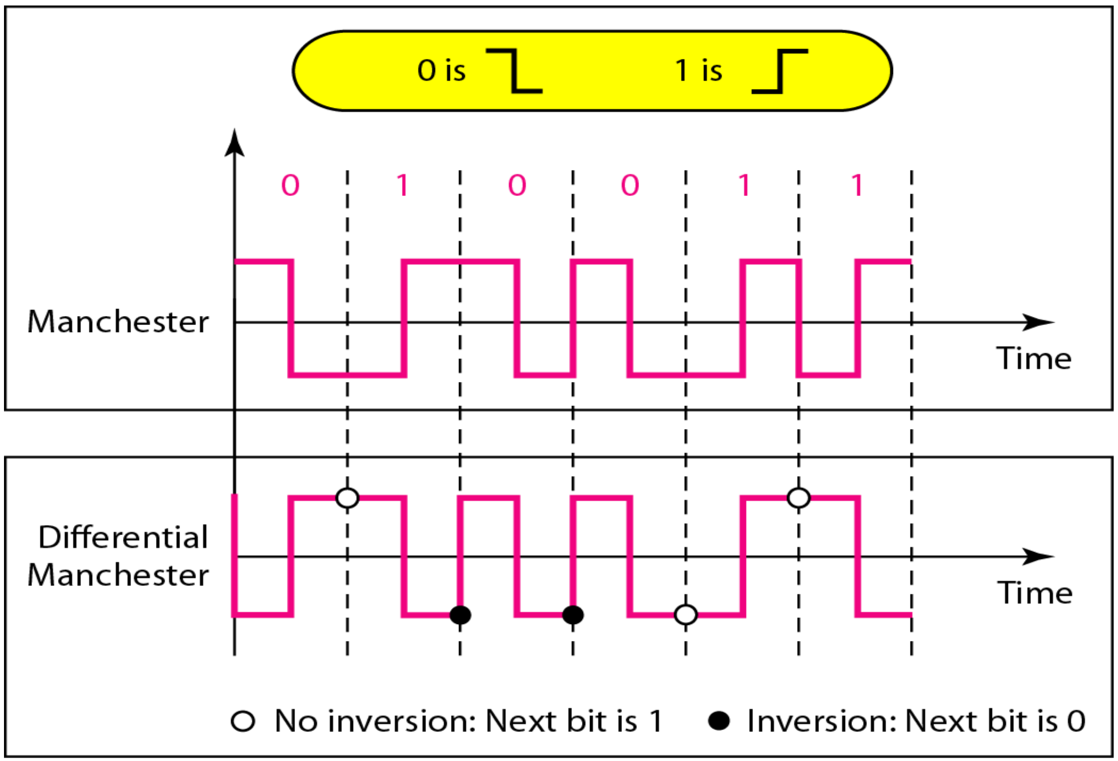


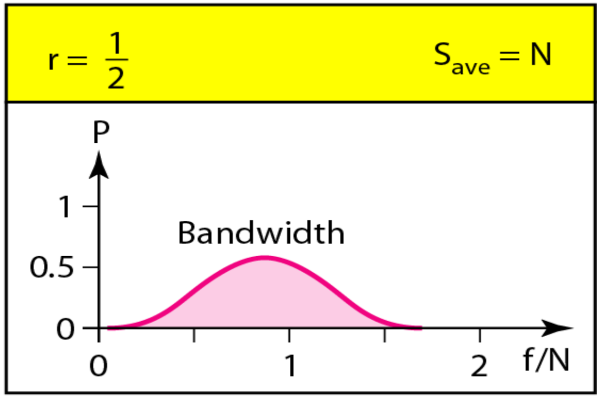
Self synchronization is achieved since there a transition during every bit interval. DC component still exits.

- The main disadvantage of RZ encoding is that it requires two signal changes to encode a bit and therefore occupies greater bandwidth.

- **Biphase: Manchester and Differential Manchester**
- The idea of RZ (transition at the middle of the bit) and the idea of NRZ-L are combined into the Manchester scheme.

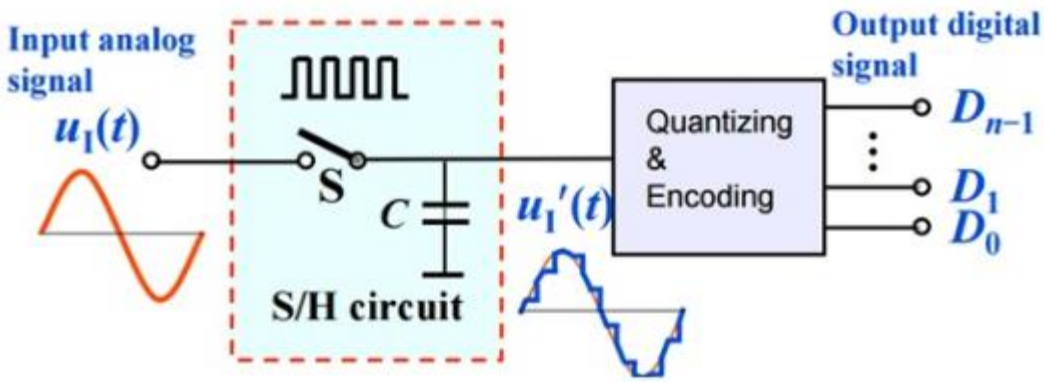
- ***Polar biphase: Manchester and differential Manchester schemes***





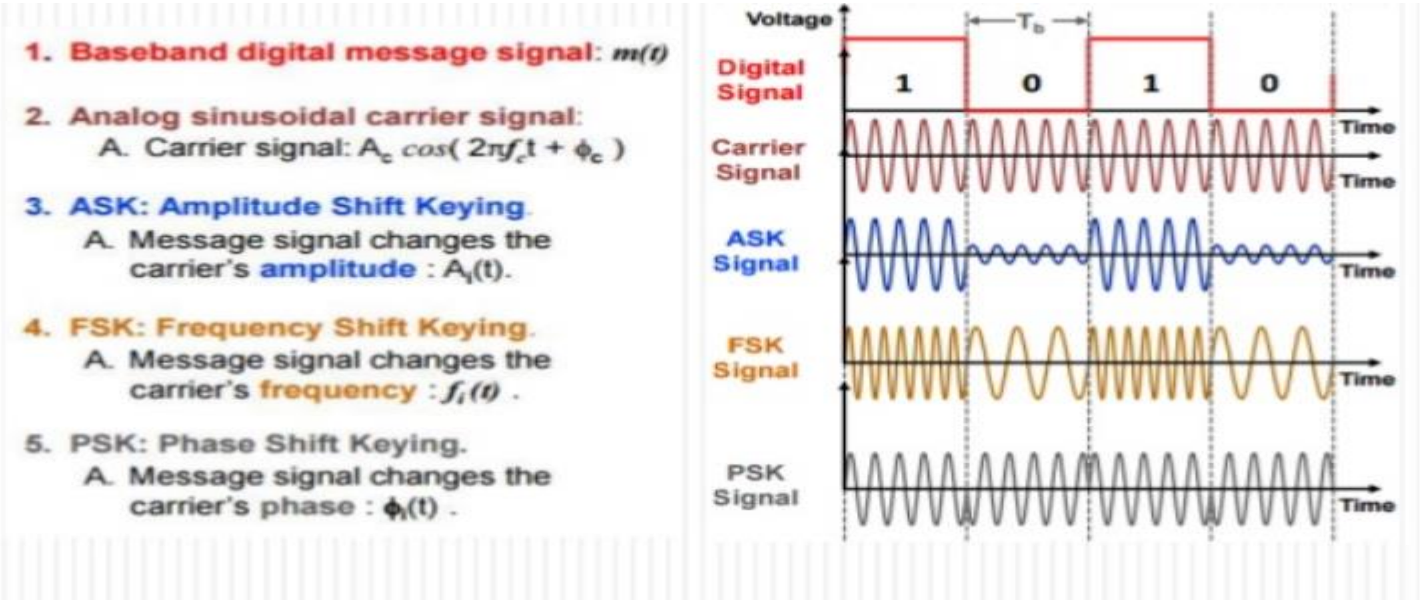
- In Manchester encoding, the duration of the bit is divided into two halves. The voltage remains at one level during the first half and moves to the other level in the second half. The transition at the middle of the bit provides synchronization.
- Differential Manchester, on the other hand, combines the ideas of RZ and NRZ-I. There is always a transition at the middle of the bit, but the bit values are determined at the beginning of the bit. If the next bit is 0, there is a transition; if the next bit is 1, there is none.
- The Manchester scheme overcomes several problems associated with NRZ-L, and differential Manchester overcomes several problems associated with NRZ-I.
- There is no DC component because each bit has a positive and negative voltage contribution.
- Self synchronization is achieved.
- The only drawback is the signal rate. The signal rate for Manchester and differential Manchester is double that for NRZ.

- **Analog to digital transformation:** Analog signal is coded to digital signals.



- Methods used are PCM, DPCM, Delta modulation etc.
- Used in mobile devices called as codecs to transform analog voice data into digital data.

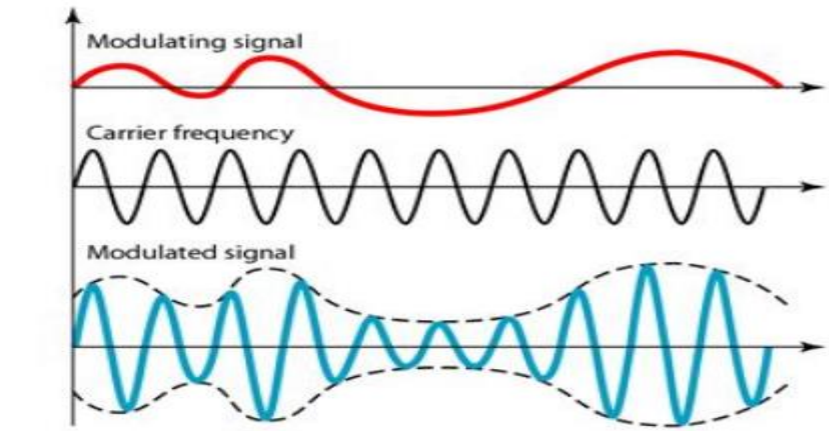
- **Digital to analog transformation:** Digital data modulated on to an analog carrier.
- Methods used are ASK, FSK, PSK(BPSK), M-ary PSK, QPSK, QAM etc.

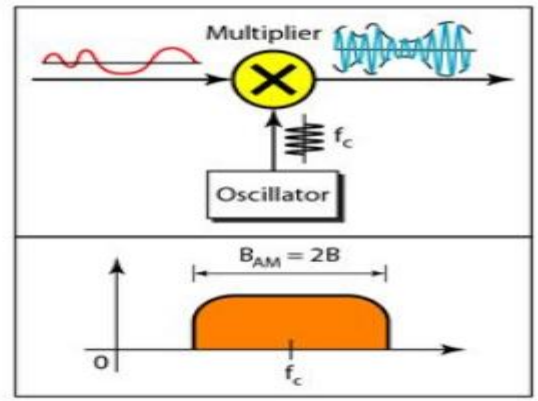


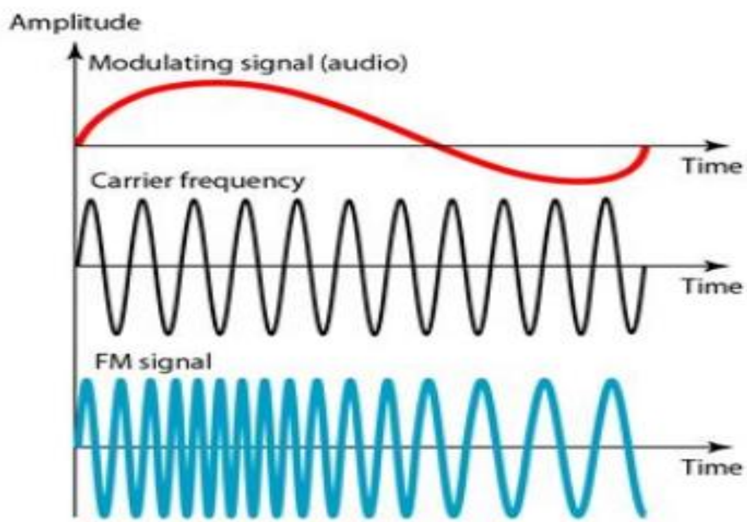
- Applied when the transmission medium is Wireless from a laptop or mobile such as WIFI and mobile data connection (4G).

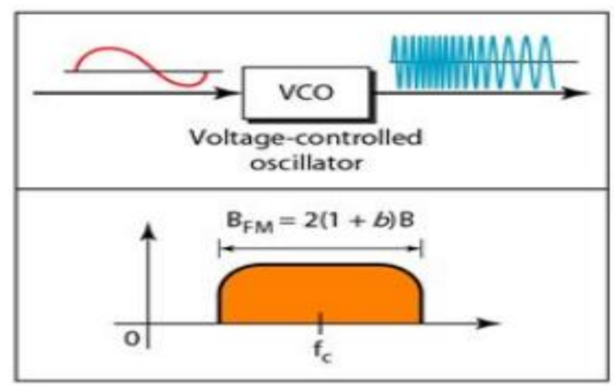
- **Analog to analog transformation:** Analog data modulated on to analog carrier.

- Methods used are AM, FM etc.



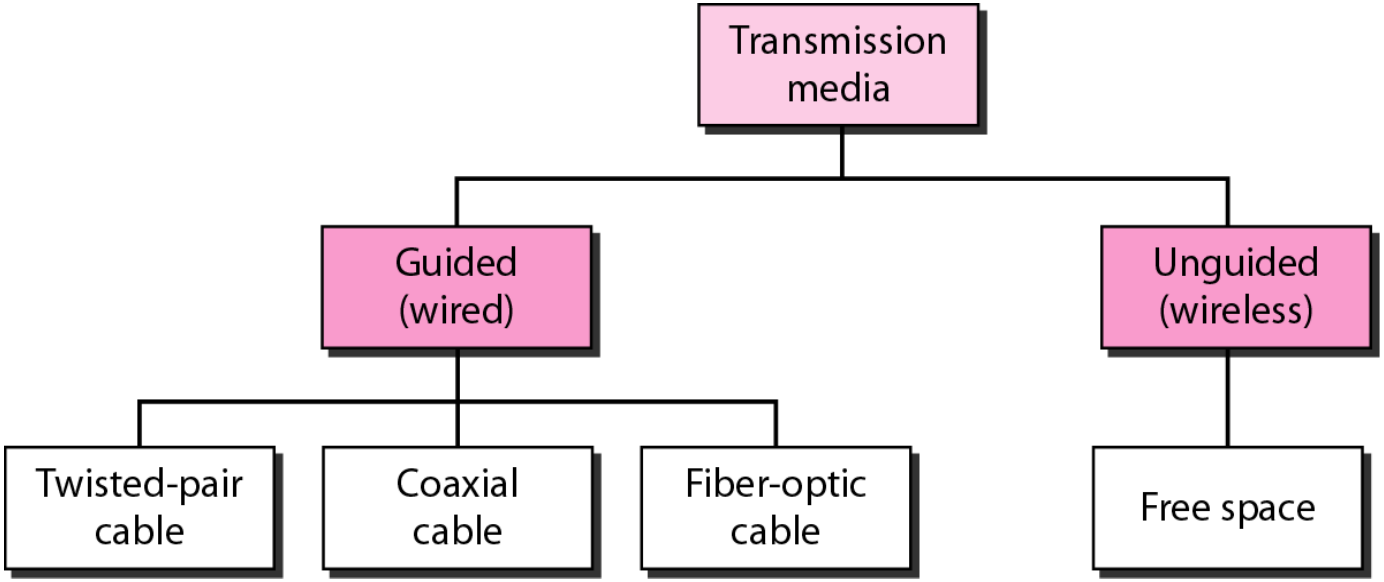




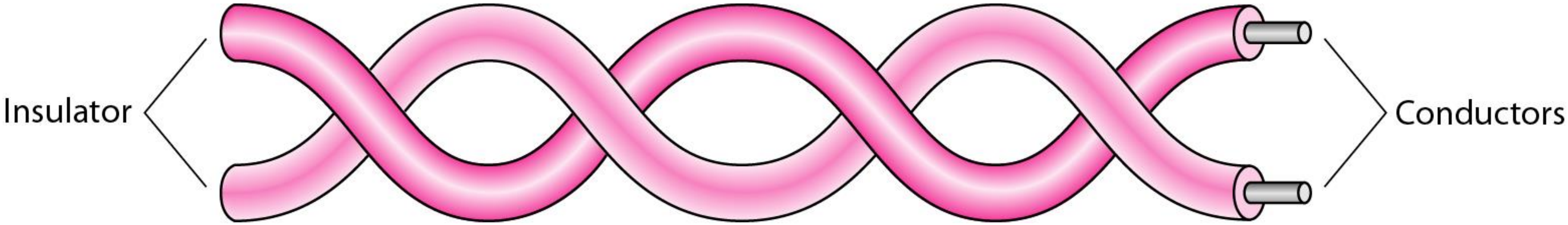


Transmission Media (Physical Media)

- A transmission medium can be broadly defined as anything that can carry information from a source to a destination.
- Transmission media are located below the physical layer.
- The transmission medium is usually free space, metallic cable, or fiber-optic cable.

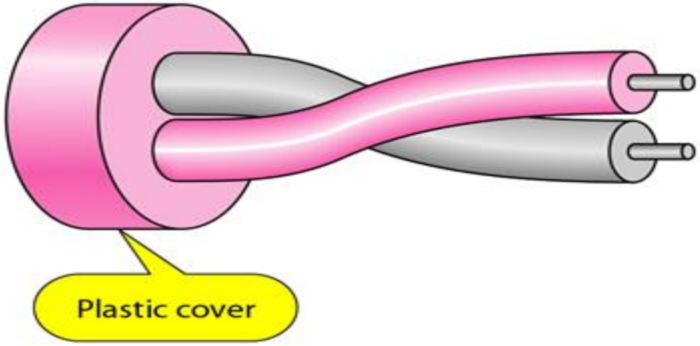


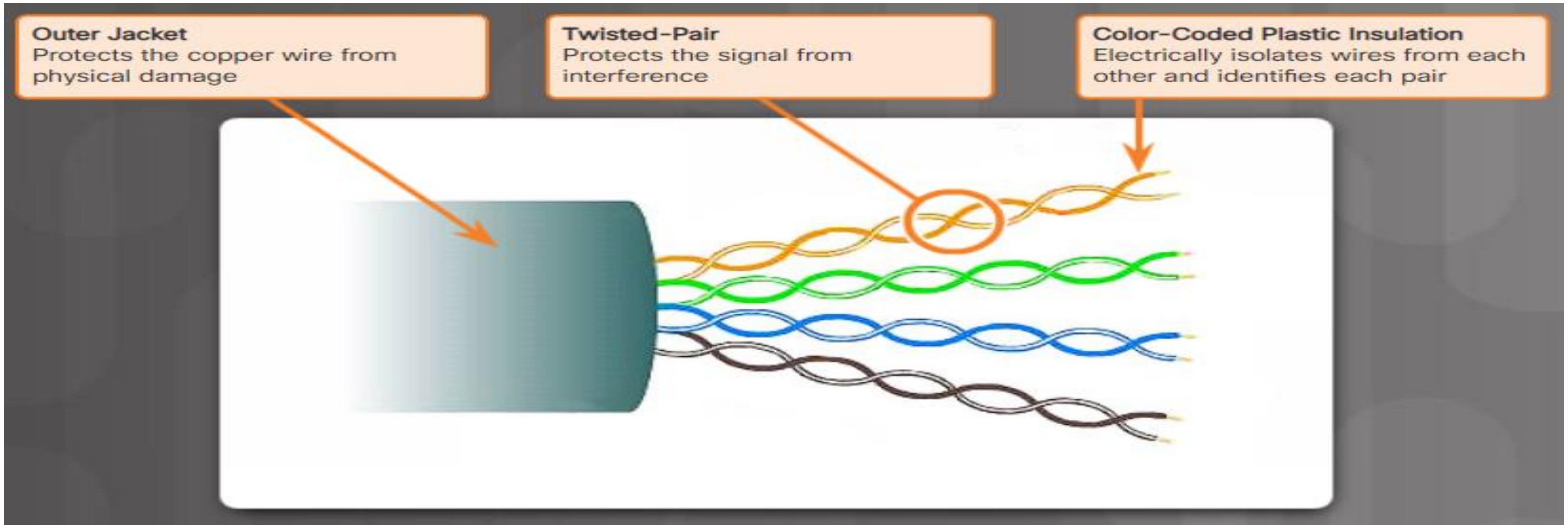
- **Twisted-Pair Cable**
- A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together.



- 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.
- 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.

- Unshielded Twisted-Pair (UTP) cable:
- UTP cable consists of pairs of color-coded wires that have been twisted together and then encased in a flexible plastic sheath that protects from minor physical damage.

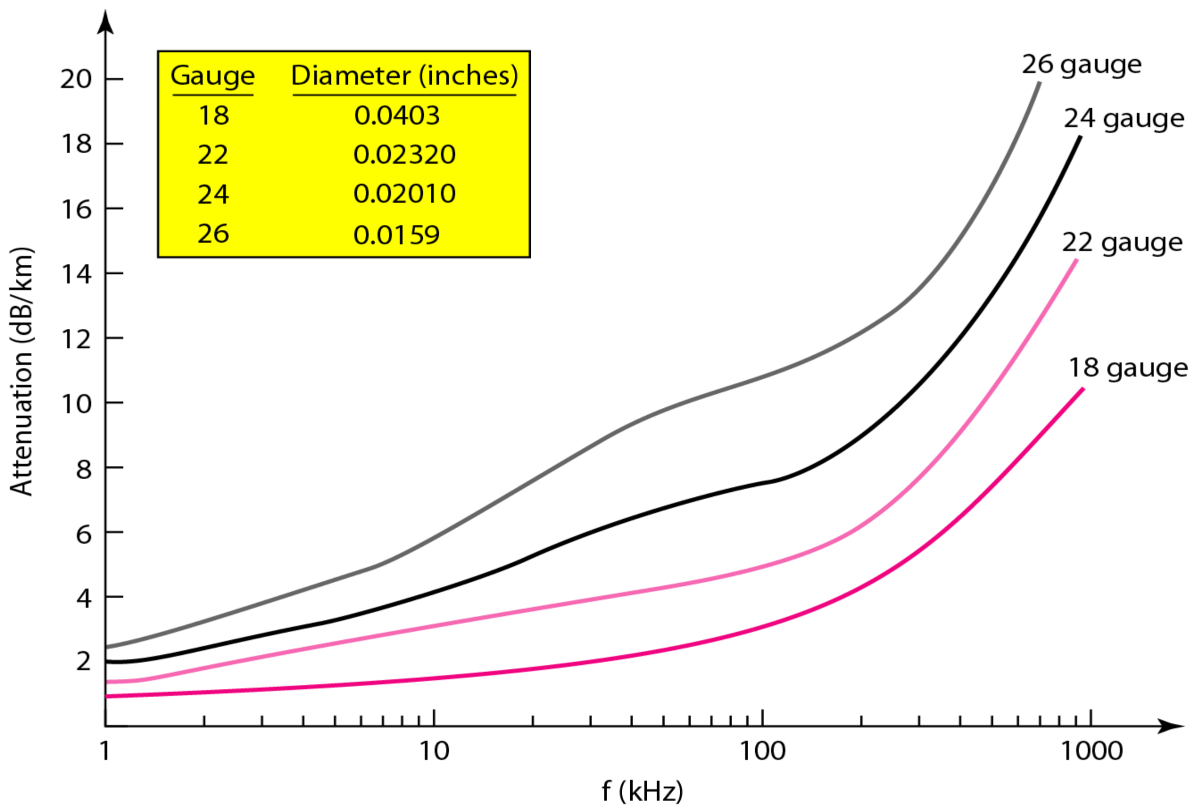




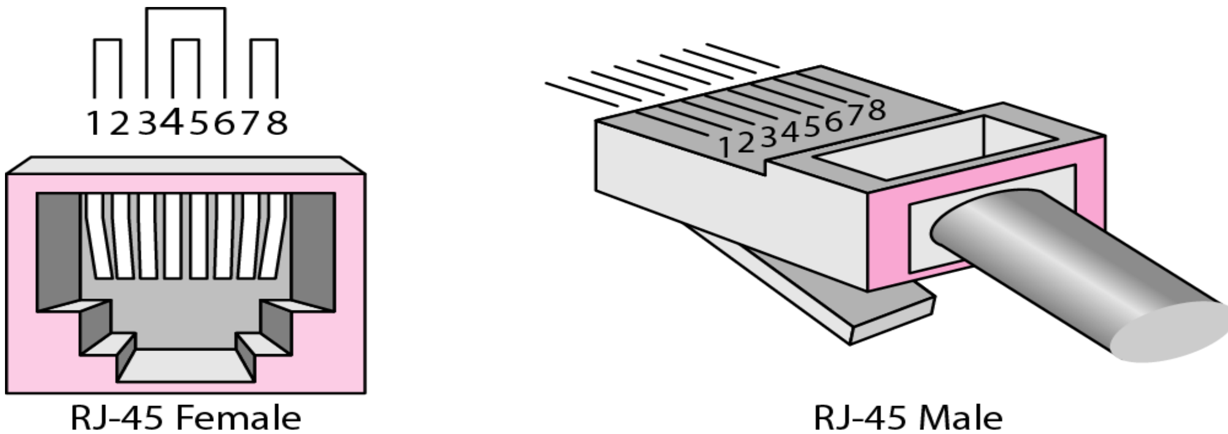
- Unshielded twisted-pair (UTP) cabling is the most common networking media. Is used for interconnecting network hosts with intermediate networking devices, such as switches and routers.
- Applications: Telephone Lines, DSL lines and LANs.
- Categories of UTP

CAT Ratings for Twisted Pair Cables					
CAT Rating	Max Frequency	Max Bandwidth or Data Rate	Max Length	Status with TIA/EIA	Application
CAT 1	<1 MHz	Analog phone lines only	-	No longer recognized	Old telephone cable
CAT 2	4 MHz	4 Mbps	-	No longer recognized	Token Ring networks
CAT 3	16 MHz	16 Mbps	100m	Recognized	Token Ring and 10-Base-T Ethernet
CAT 4	20 MHz	20 Mbps	100m	No longer recognized	Token Ring Networks
CAT 5	100 MHz	100 Mbps	100m	No longer recognized	Ethernet, Fast Ethernet, and Token Ring
CAT 5e	100 MHz	1000 Mbps or 1 Gbps	100m	Recognized	Ethernet, Fast Ethernet, and Gigabit Ethernet
CAT 6	250 MHz	10,000 Mbps or 10 Gbps	100m	Recognized	Gigabit Ethernet, 10G Ethernet (55m)
CAT 6a	500 MHz	10,000 Mbps or 10 Gbps	100m	Recognized	Gigabit Ethernet, 10G Ethernet (55m)
CAT 7	600 MHz	10,000 Mbps or 10Gbps	100m	Recognized	Gigabit Ethernet, 10G Ethernet (100m)

- Performance:
- One way to measure the performance of twisted-pair cable is to compare attenuation versus frequency and distance.



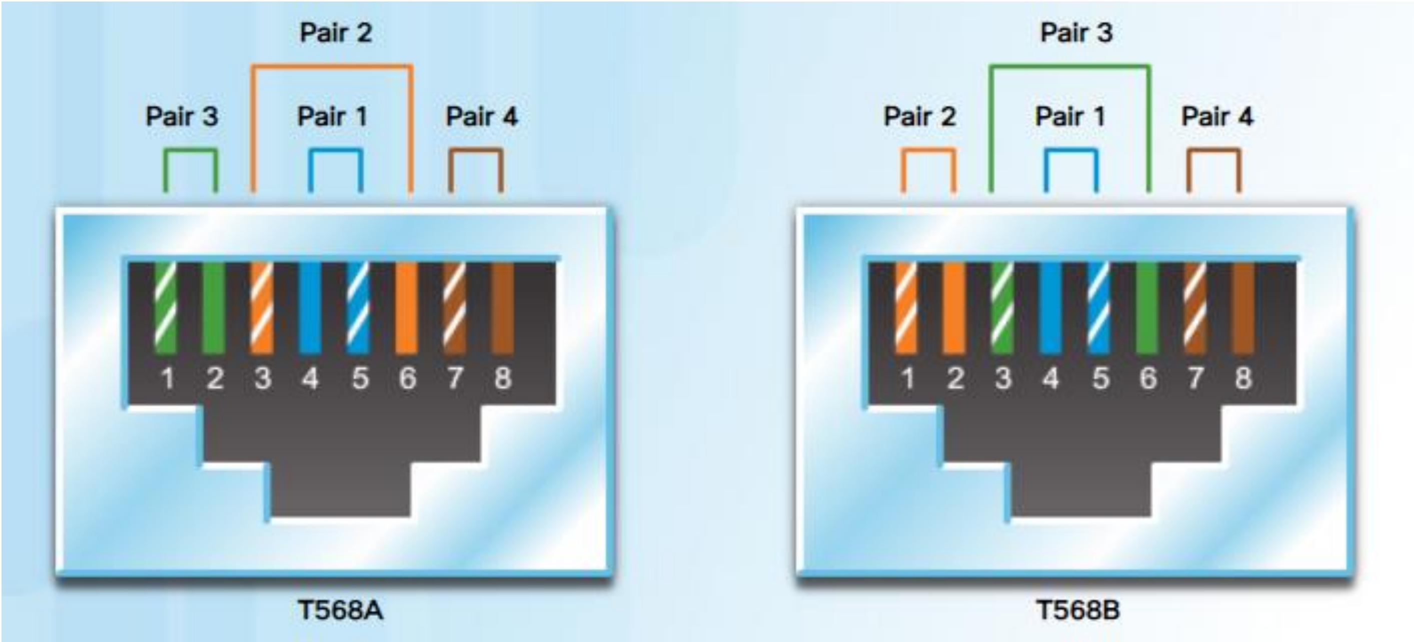
- UTP Connectors:
- UTP cable is usually terminated with an RJ-45 connector.



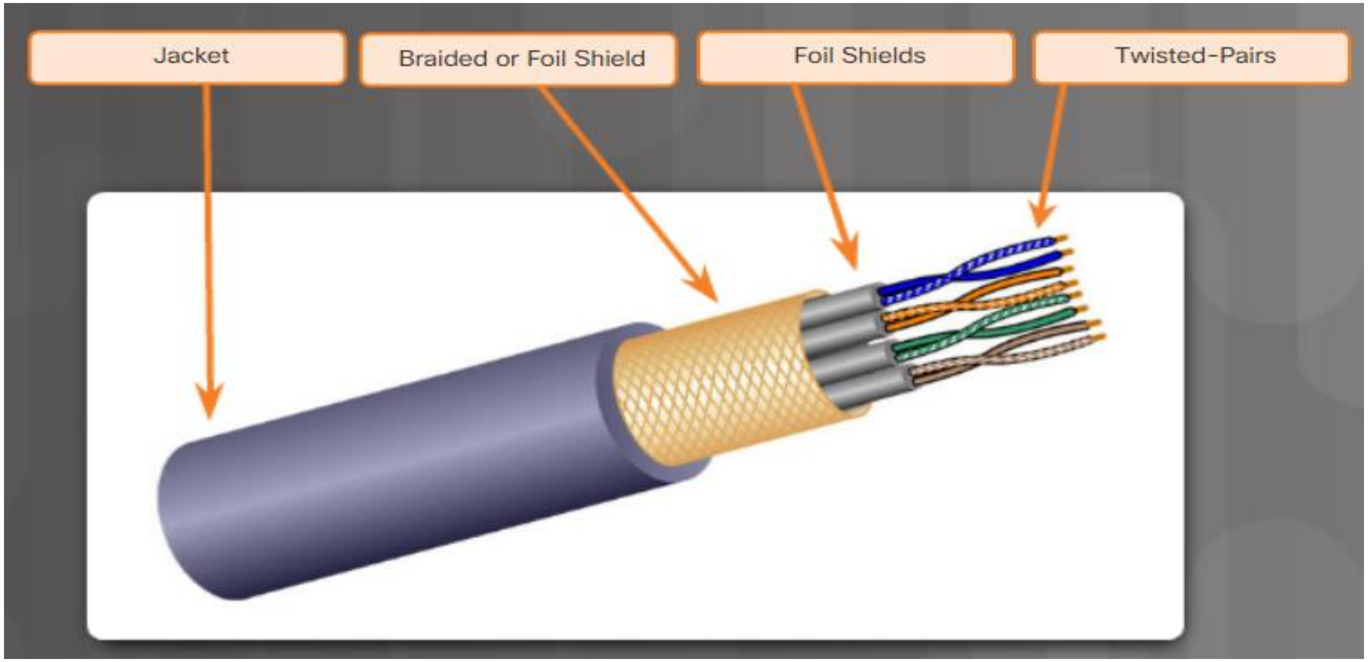
- This connector is used for a range of physical layer specifications, one of which is Ethernet. The TIA/EIA-568 standard describes the wire color codes to pin assignments (pinouts) for Ethernet cables.

- Different situations may require UTP cables to be wired according to different wiring conventions.
- This means that the individual wires in the cable have to be connected in different orders to different sets of pins in the RJ-45 connectors.

Cable Type	Standard	Application
Ethernet Straight-through	Both ends T568A or both ends T568B	Connects a network host to a network device such as a switch or hub.
Ethernet Crossover	One end T568A, Other end T568B	• Connects two network hosts • Connects two network intermediary devices (switch to switch, or router to router)
Rollover	Cisco proprietary	Connects a workstation serial port to a router console port, using an adapter.

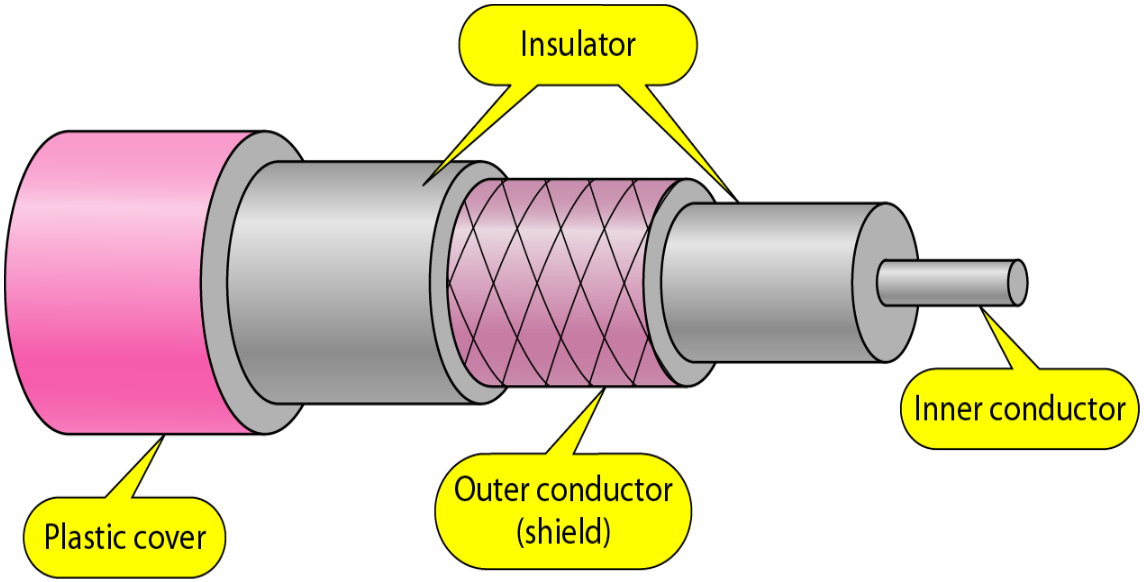


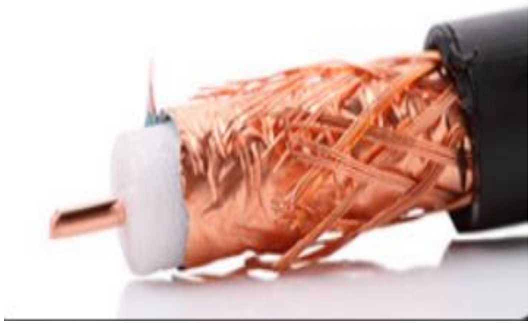
- Shielded Twisted-Pair (STP) cable:
- IBM has also produced a version of twisted-pair cable for its use called shielded twisted-pair (STP).
- STP cable has a metal foil or braided mesh covering that encases each pair of insulated conductors.



- STP cables combine the techniques of shielding to counter EMI and RFI, and wire twisting to counter crosstalk.
- Like UTP cable, STP uses an RJ-45 connector.

- **Co-axial Cable**
- Coaxial cable (or *coax)* carries signals of higher frequency ranges than those in twisted pair cable.





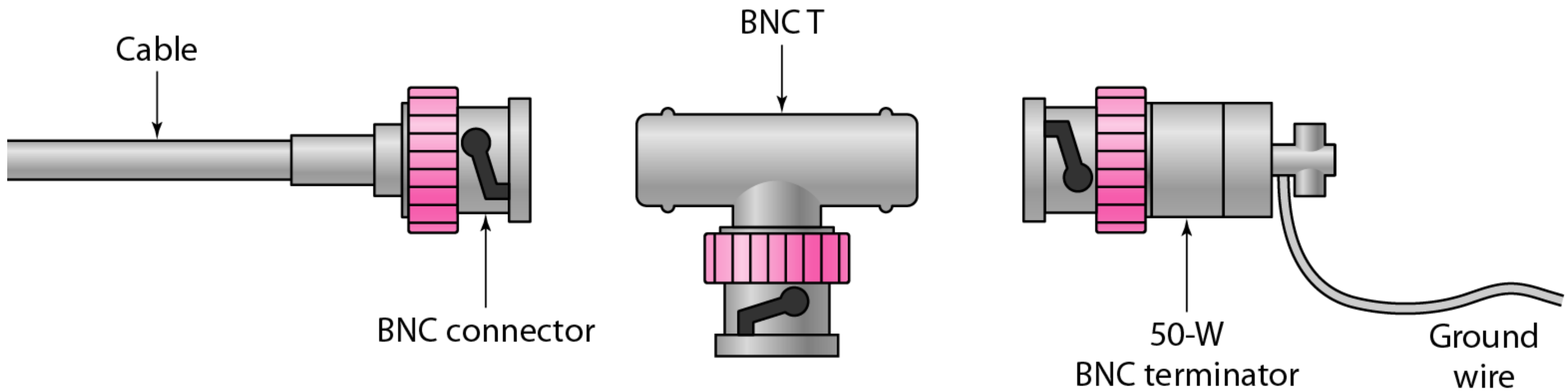
- Instead of having two wires, coax has a central core conductor of solid or stranded wire (usually copper) enclosed in an insulating sheath, which is, in turn, encased in an outer conductor of metal foil, braid, or a combination of the two.
- The outer metallic wrapping serves both as a shield against 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

- **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.

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

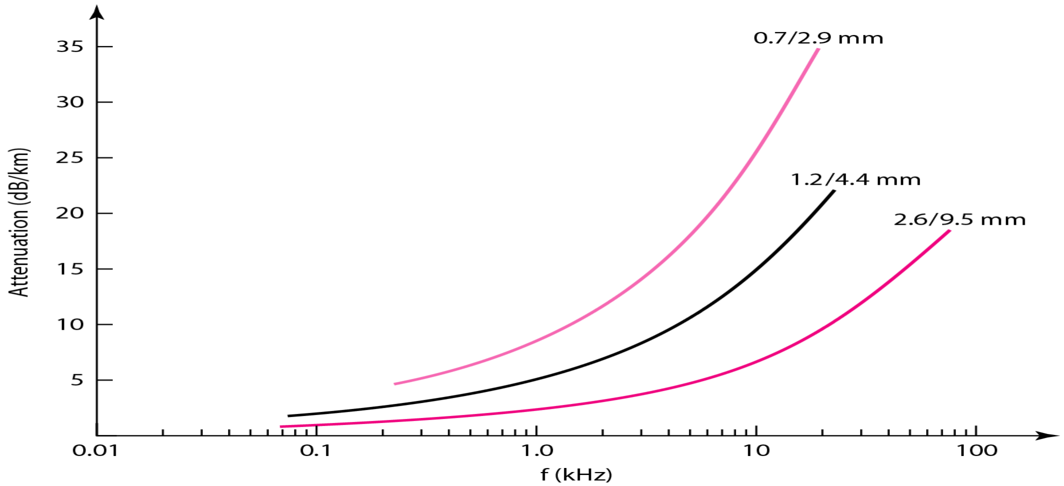
- **Coaxial Cable Connectors**
- The most common type of connector used today is the Bayone-Neill-Concelman (BNC), connector.



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.

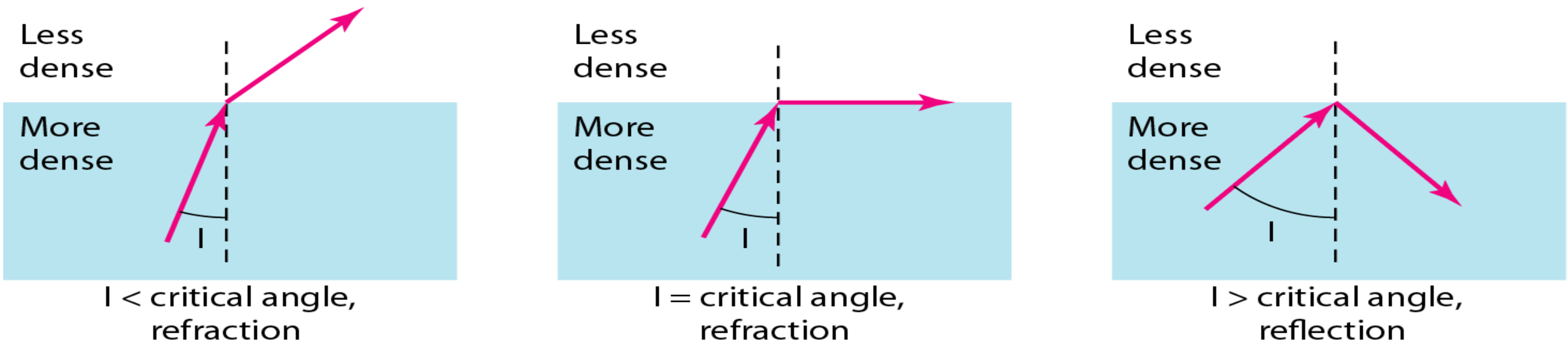
- **Performance**



- Attenuation is much higher in coaxial cables than in twisted-pair cable.
- Although coaxial cable has a much higher bandwidth, the signal weakens rapidly and requires the frequent use of repeaters.
- **Applications**
- Cable TV networks use coaxial cables.
- 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.

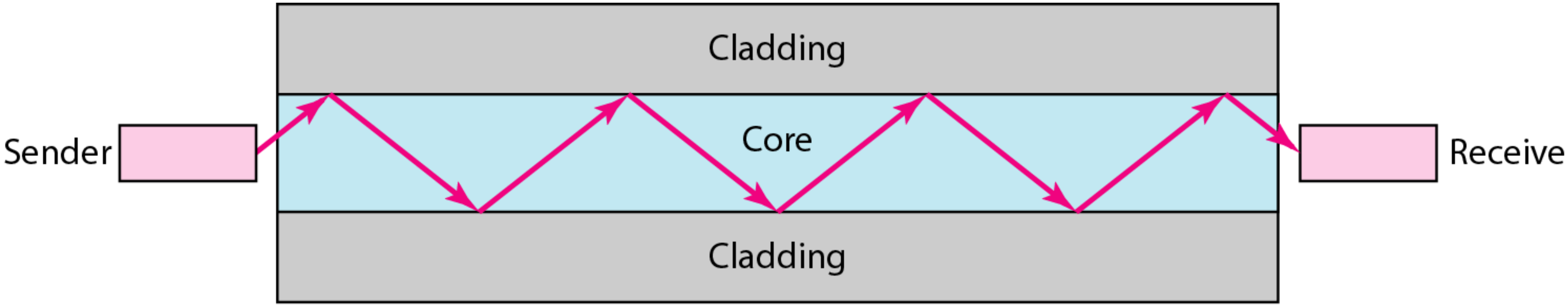
- **Fiber-Optic cable**
- A fiber-optic cable is made of glass or plastic and transmits signals in the form of light.
- Light travels in a straight line as long as it is moving through a single uniform substance. If a ray of light traveling through one substance suddenly enters another substance (of a different density), the ray changes direction.

Bending of light ray



- If the angle of incidence *I* is less than the critical angle, the ray refracts.
- 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 total internal reflection to guide light through a channel.

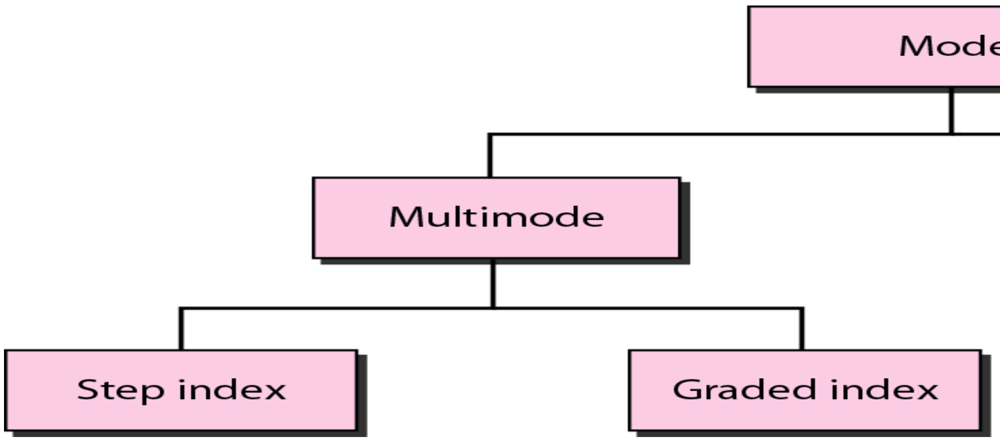


- A glass or plastic core is surrounded by a cladding of less dense glass or plastic.
- The difference in density of the two materials must be such that a beam of light moving through the core is reflected off the cladding instead of being refracted into it.

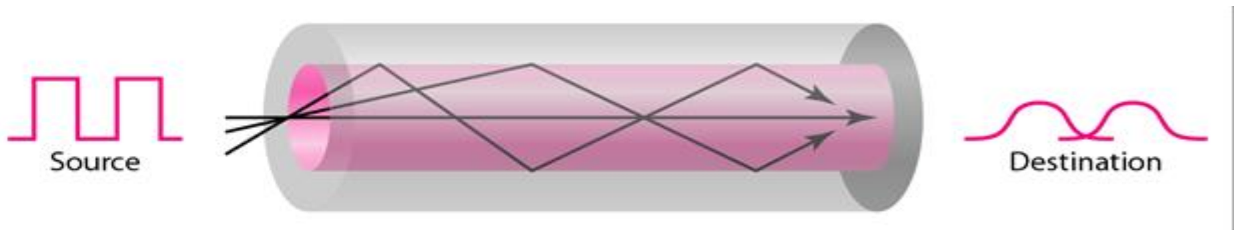
<u>*Propagation Modes*</u>

- Current technology supports two modes (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 or graded-index.

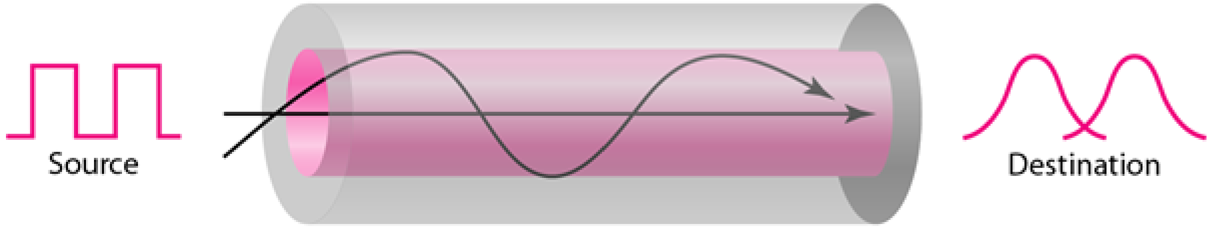


- Multimode is so named because multiple beams from a light source move through the core in different paths.
- In multimode step-index fiber, the density of the core remains constant from the centre to the edges.



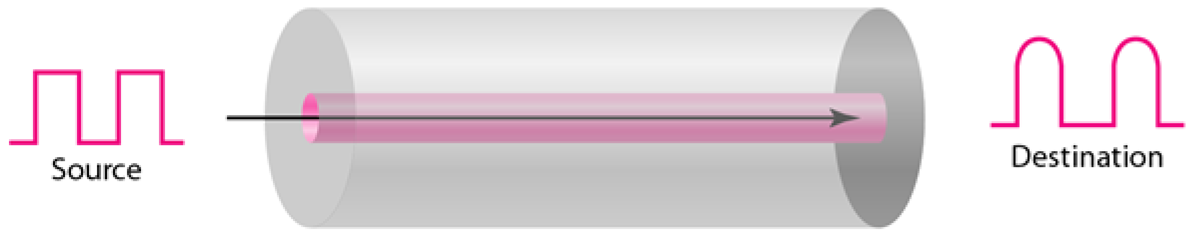
- A beam of light moves through this constant density in a straight line until it reaches the interface of the core and the cladding.

- 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.
- A second type of fiber, called multimode graded-index fiber, decreases this distortion of the signal through the cable.



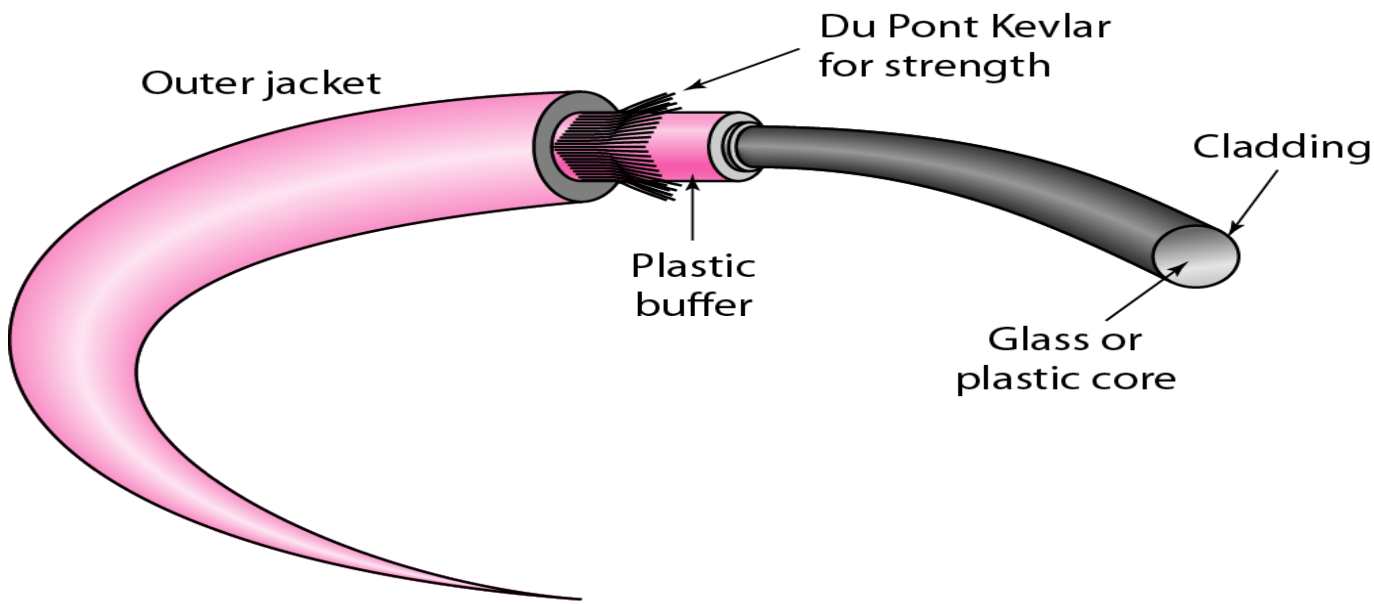
- The word *index* here refers to the index of refraction. As we saw above, the index of refraction is related to density.
- A graded-index fiber, therefore, is one with varying densities.
- Density is highest at the center of the core and decreases gradually to its lowest at the edge.

- <u>Single-Mode</u>: 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.

- *Cable Composition*

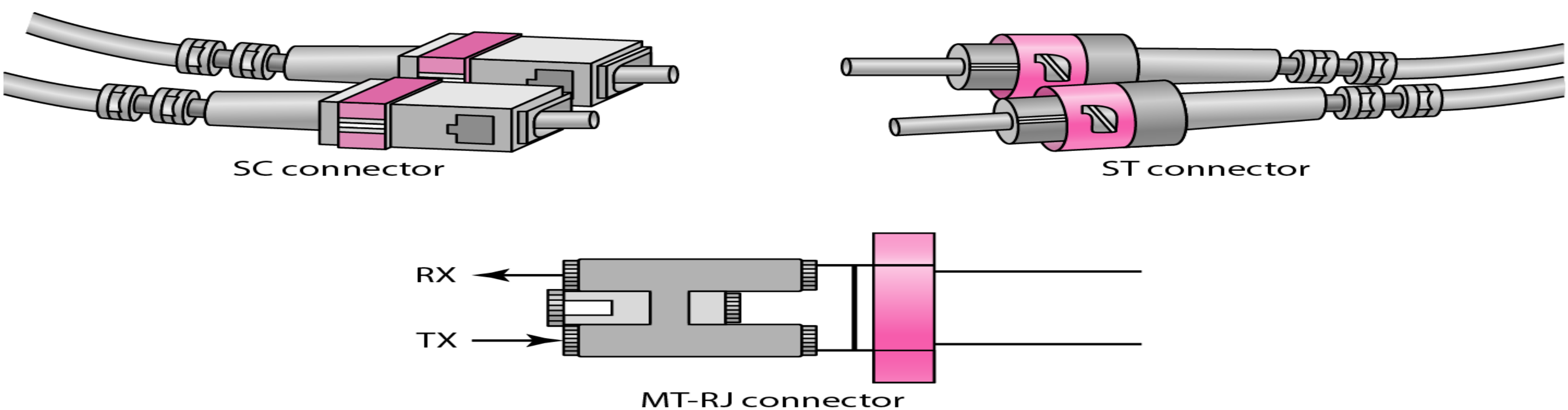


- The outer jacket is made of either PVC or Teflon.
- Inside the jacket are Kevlar strands to strengthen the cable. Kevlar is a strong material used in the fabrication of bulletproof vests.
- Below the Kevlar is another plastic coating to cushion the fiber.
- The fiber is at the center of the cable,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

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

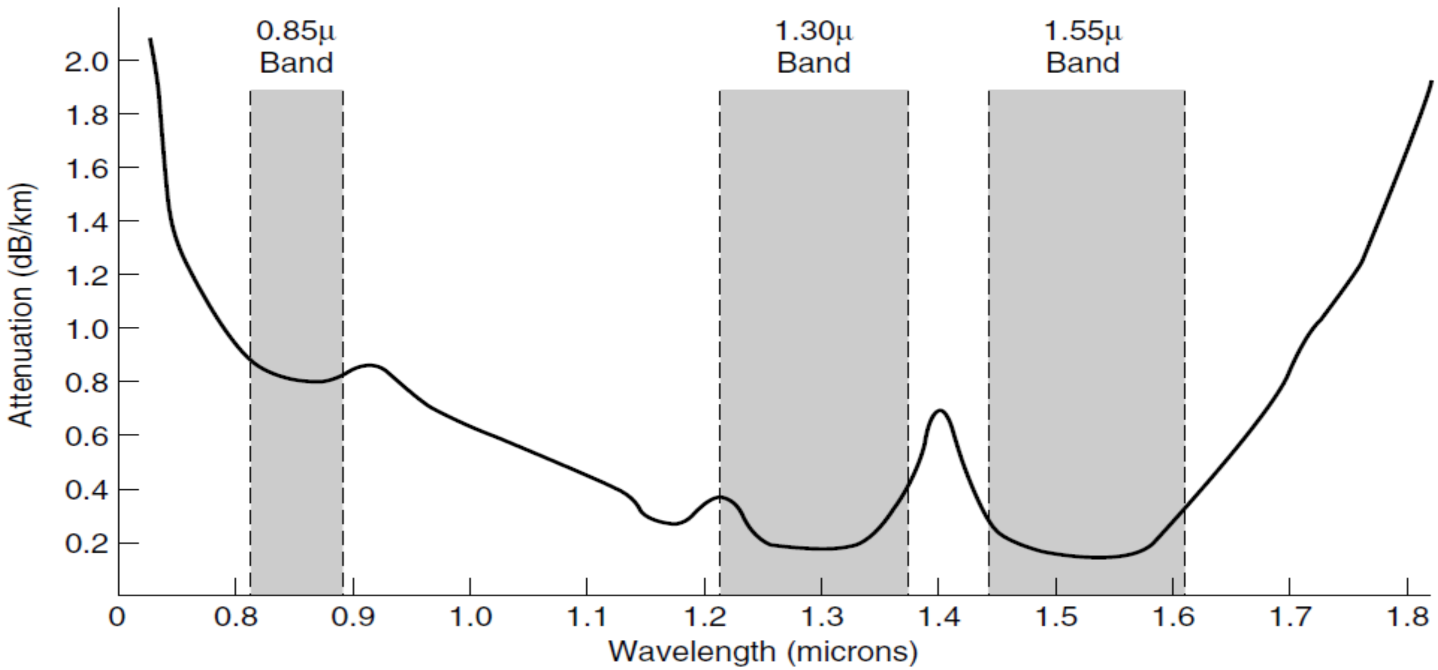
Type	*Core (µm)*	*Cladding (µm)*	*Mode*
50/125	50.0	125	Multimode, graded index
62.5/125	62.5	125	Multimode, graded index
100/125	100.0	125	Multimode, graded index
7/125	7.0	125	Single mode

- ***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.

- <u>*Performance*</u>



- Three wavelength bands are most commonly used at present for optical communication.
- They are centered at 0.85, 1.30, and 1.55 microns, respectively.
- All three bands are 25,000 to 30,000 GHz wide.
- The 0.85-micron band was used first. It has higher attenuation and so is used for shorter distances, but at that wavelength the lasers and electronics could be made from the same material (gallium arsenide).
- The last two bands have good attenuation properties (less than 5% loss per kilometer). The 1.55-micron band is now widely used with erbium-doped amplifiers that work directly in the optical domain.

- *<u>Advantages</u>*
- Higher bandwidth. Fiber-optic cable can support dramatically higher bandwidths (and hence data rates) 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.

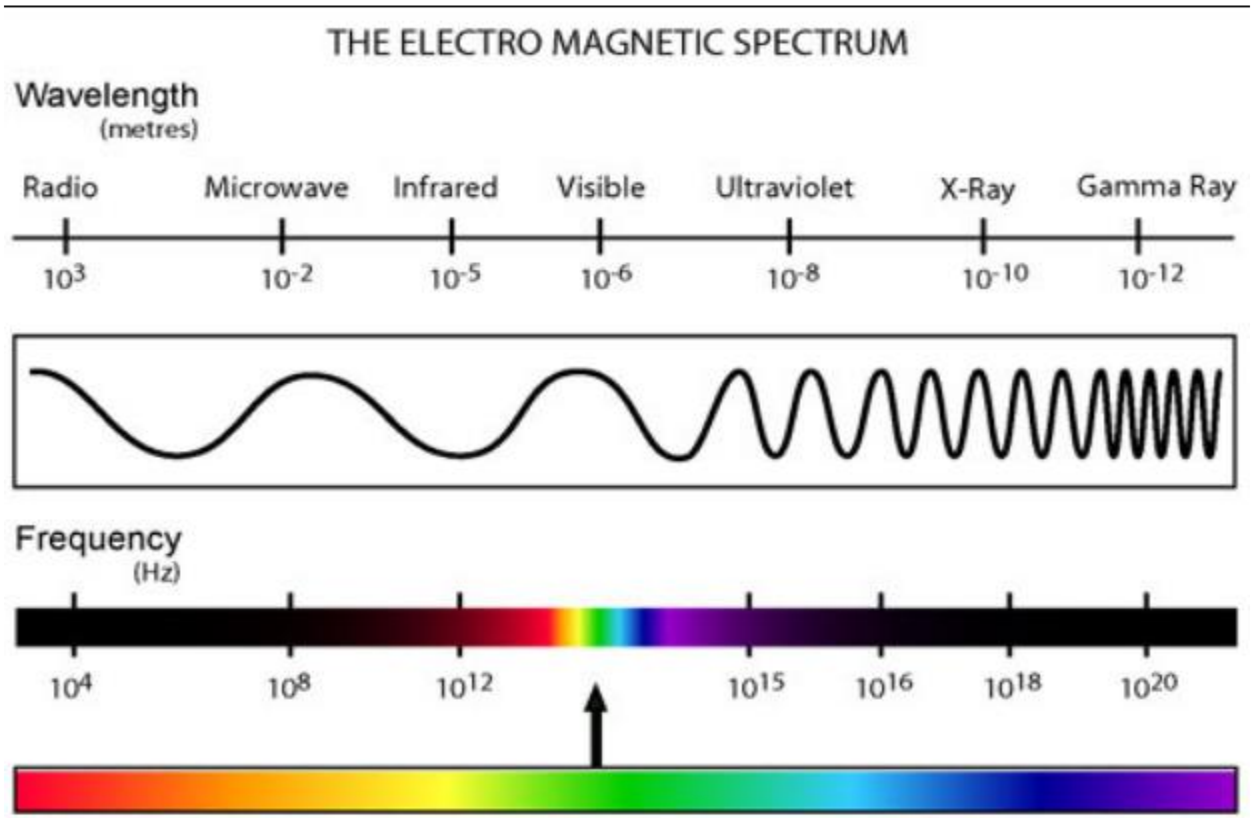
- Less signal attenuation: Fiber-optic transmission distance is significantly greater than that of other guided media. A signal can run for 50 km without requiring regeneration. We need repeaters every 5 km for coaxial or twisted-pair cable.
- Immunity to electromagnetic interference: Electromagnetic 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.

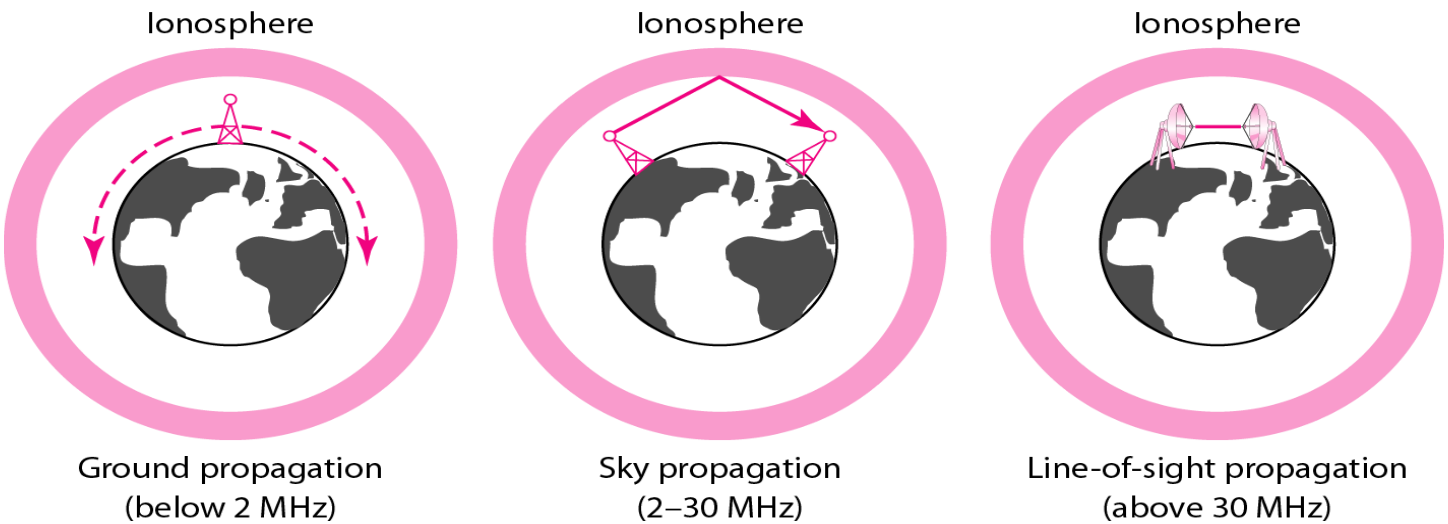
- Cost: The cable and the interfaces are relatively more expensive than those of other guided media. If the demand for bandwidth is not high, often the use of optical fiber cannot be justified.

- *Applications*
- Fiber-optic cable is often found in backbone networks because its wide bandwidth is cost-effective. Today, with wavelength-division multiplexing (WDM), we can transfer data at a rate of 1600 Gbps. The SONET network provides such a backbone.
- Some cable TV companies use a combination of optical fiber and coaxial cable, thus creating a hybrid network.
- Local-area networks such as 100Base-FX network (Fast Ethernet) and 1000Base-X also use fiber-optic cable.

- **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.



- Unguided signals can travel from the source to destination in several ways: ground propagation, sky propagation, and line-of-sight 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.
- 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-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.

- Band designation of Radio waves and microwaves.

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

- Wireless transmission is divided into three broad groups: radio waves, microwaves, and infrared waves.

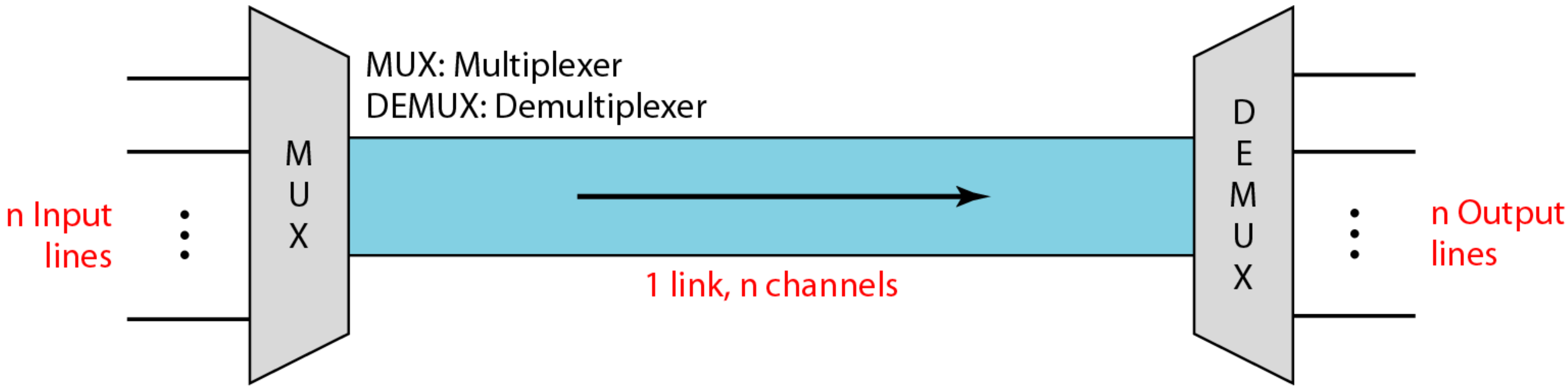
- **Radio Waves**
- Electromagnetic waves ranging in frequencies between 3 kHz and 1 GHz are normally called radio waves.
- Radio waves, for the most part, are omnidirectional.
- Radio waves, particularly those waves that propagate in the sky mode, can travel long distances.
- Radio waves, particularly those of low and medium frequencies, can penetrate walls.
- Almost the entire band is regulated by authorities.
- Radio waves use omnidirectional antennas that send out signals in all directions.
- The omnidirectional characteristics of radio waves make them useful for broadcasting/multicasting, in which there is one sender but many receivers. AM and FM radio, television, maritime radio, cordless phones, and paging are examples of broadcasting/multicasting.

- **Microwaves**
- Electromagnetic waves having frequencies between 1 and 300 GHz are called microwaves.
- Microwaves are unidirectional. When an antenna transmits microwave waves, they can be narrowly focused.
- Microwave propagation is line-of-sight.
- Very high-frequency microwaves cannot penetrate walls.
- The microwave band is relatively wide, almost 299 GHz. Therefore wider sub-bands can be assigned, and a high data rate is possible.
- Use of certain portions of the band requires permission from authorities.
- Microwaves need unidirectional antennas that send out signals in one direction. Two of the types of antennas used for microwave communications: the parabolic dish and the horn antenna.
- 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 mobile phones, satellite networks, and wireless LANs etc.

- **Infrared waves**
- Infrared waves, with frequencies from 300 GHz to 400 THz (wavelengths from 1 mm to 770 nm), 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.
- 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.
- 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.

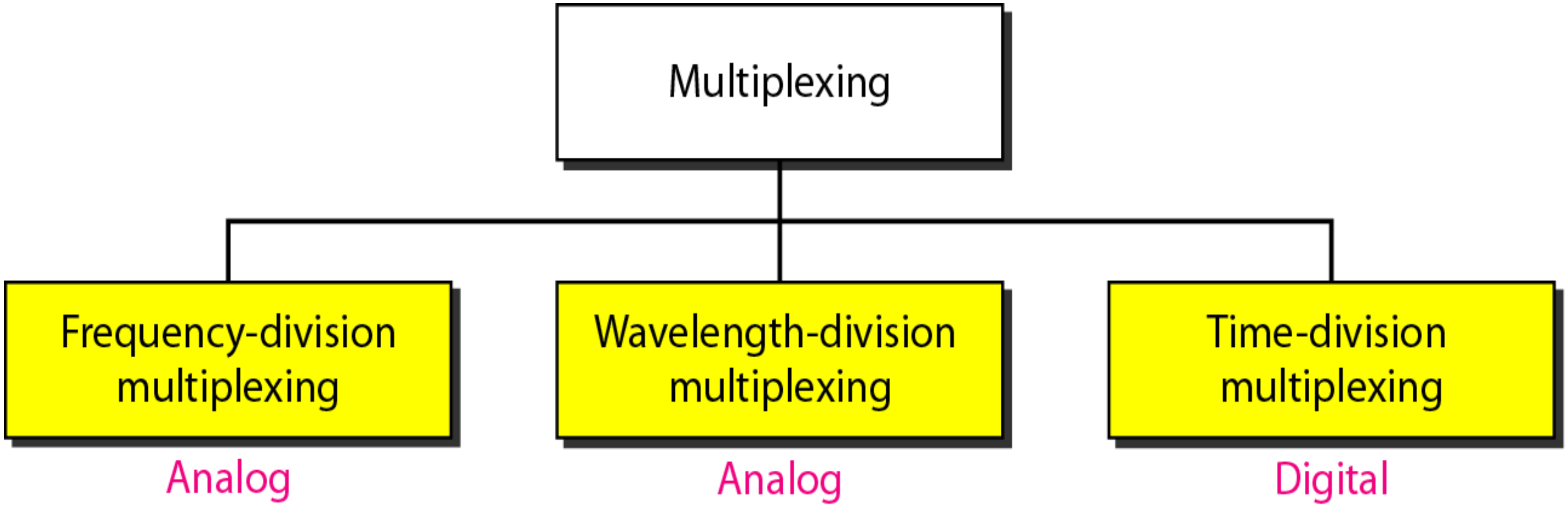
- **Multiplexing**
- Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link.
- As Internet use increases, so does traffic. We can accommodate this increase by continuing to add individual links each time a new channel is needed; or 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.
- In such cases the link can be shared.

- 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.
- 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.

- There are three basic multiplexing techniques: frequency-division multiplexing, wavelength-division multiplexing, and time-division multiplexing.



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

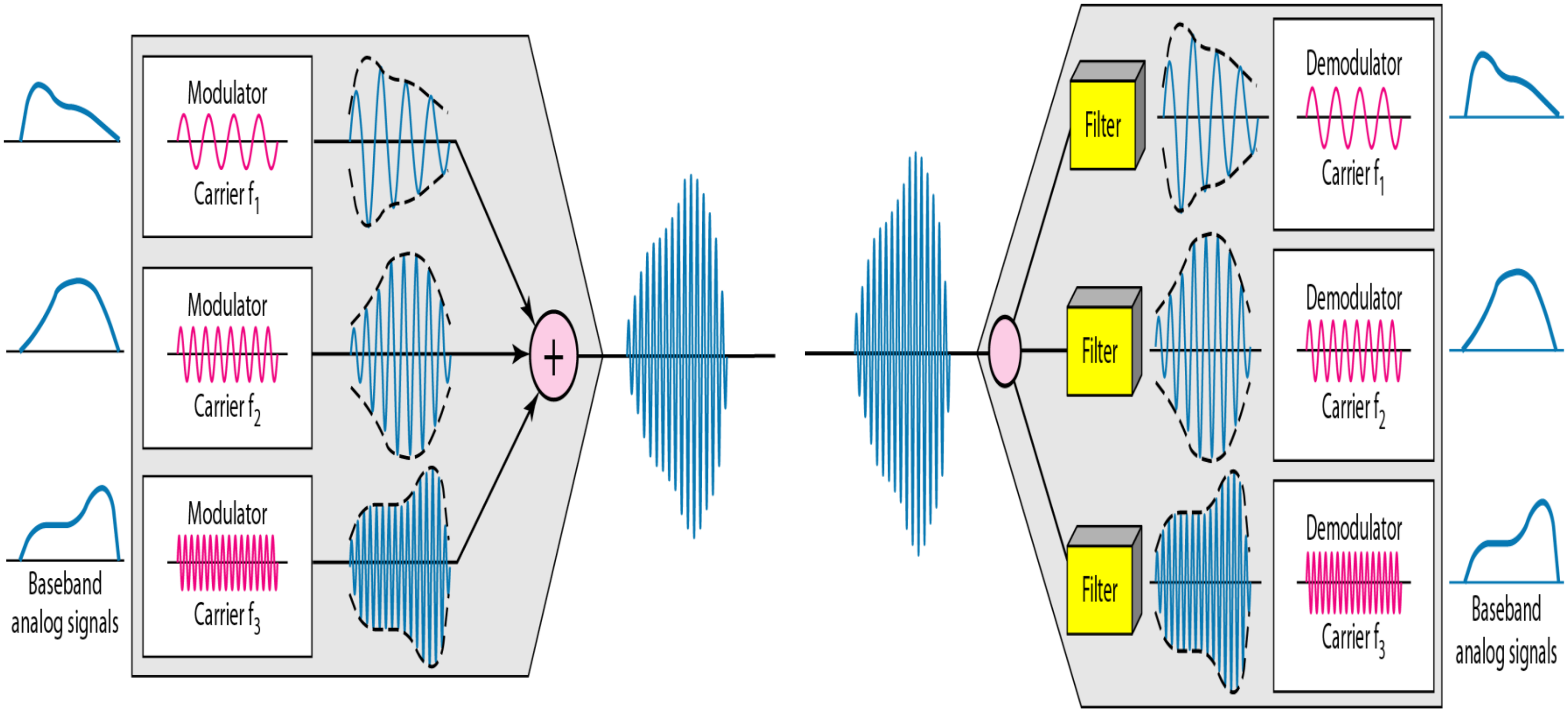
- **Frequency-Division Multiplexing**
- Frequency-division multiplexing (FDM) is an analog technique that can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted.

- 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.

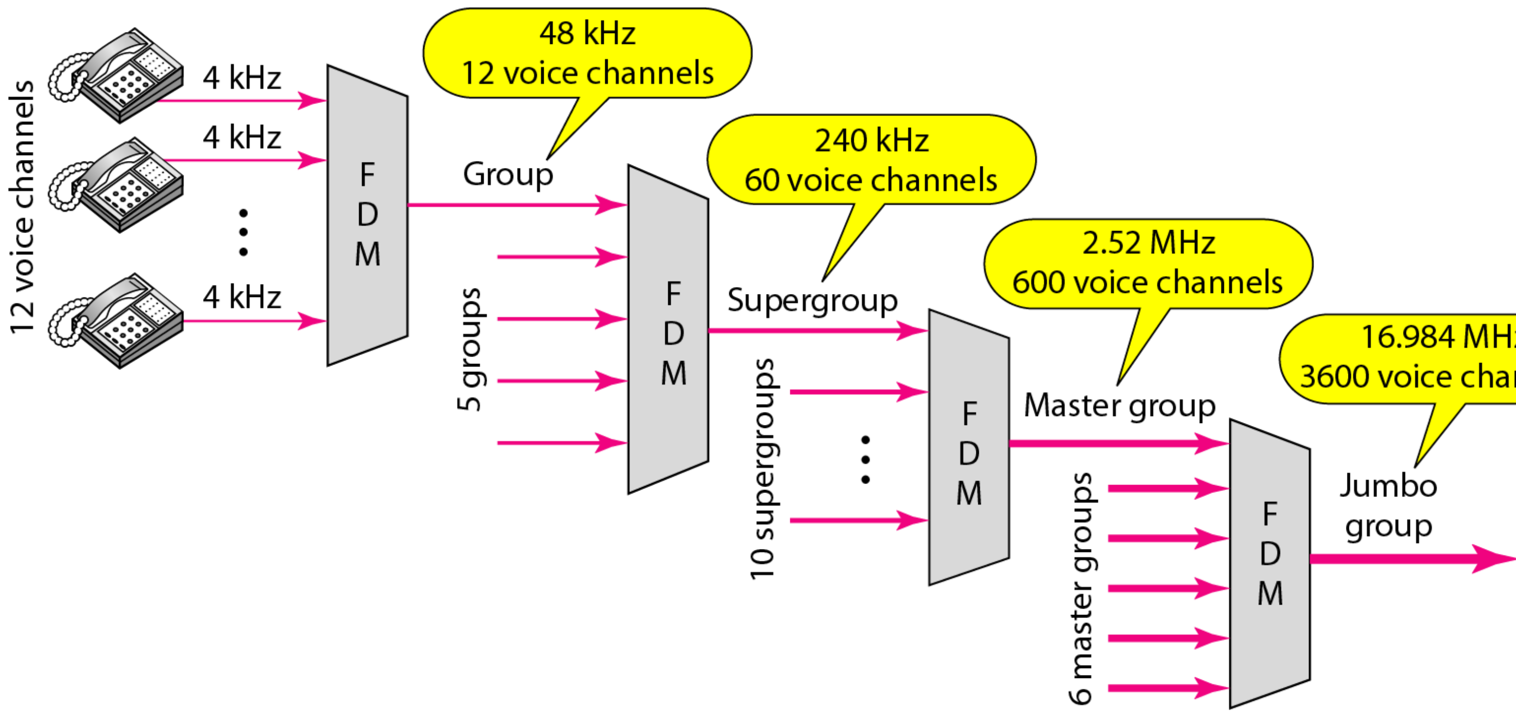
- *Multiplexing and Demultiplexing Process*



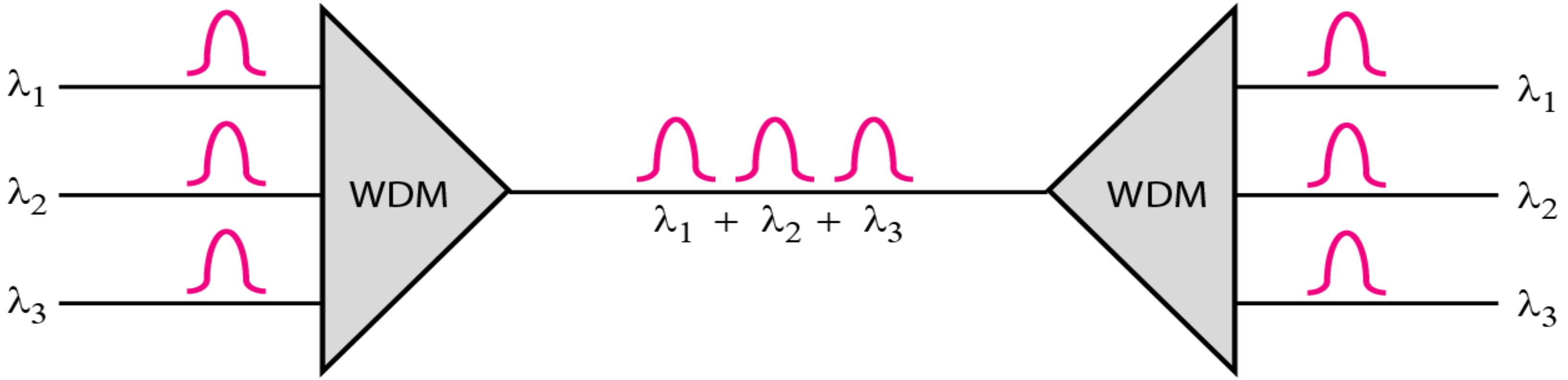
- Each source generates a signal of a similar frequency range.
- Inside the multiplexer, these similar signals modulates different carrier frequencies *(f_1,f_2,f_3).* The resulting modulated signals are then combined into a single composite signal that is sent out over a media link that has enough bandwidth to accommodate it.

- 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.

- *The Analog Carrier System*
- One of these hierarchical systems used by AT&T is made up of groups, super groups, master groups, and jumbo groups.

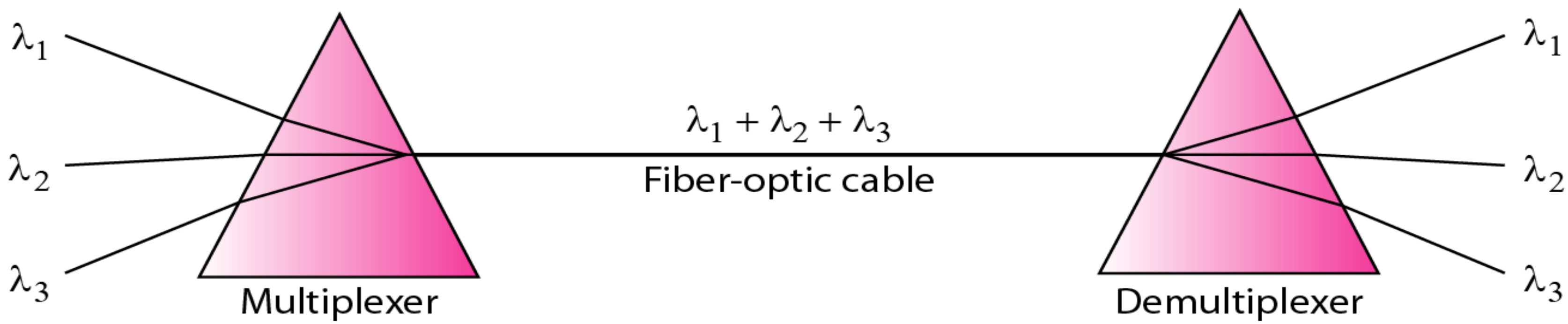


- **Wavelength-Division Multiplexing**
- Wavelength-division multiplexing (WDM) is designed to use the high-data-rate capability of fiber-optic cable.
- WDM is conceptually the same as FDM, except that the multiplexing and demultiplexing involve optical signals transmitted through fiber-optic channels. The difference is that the frequencies are very high.



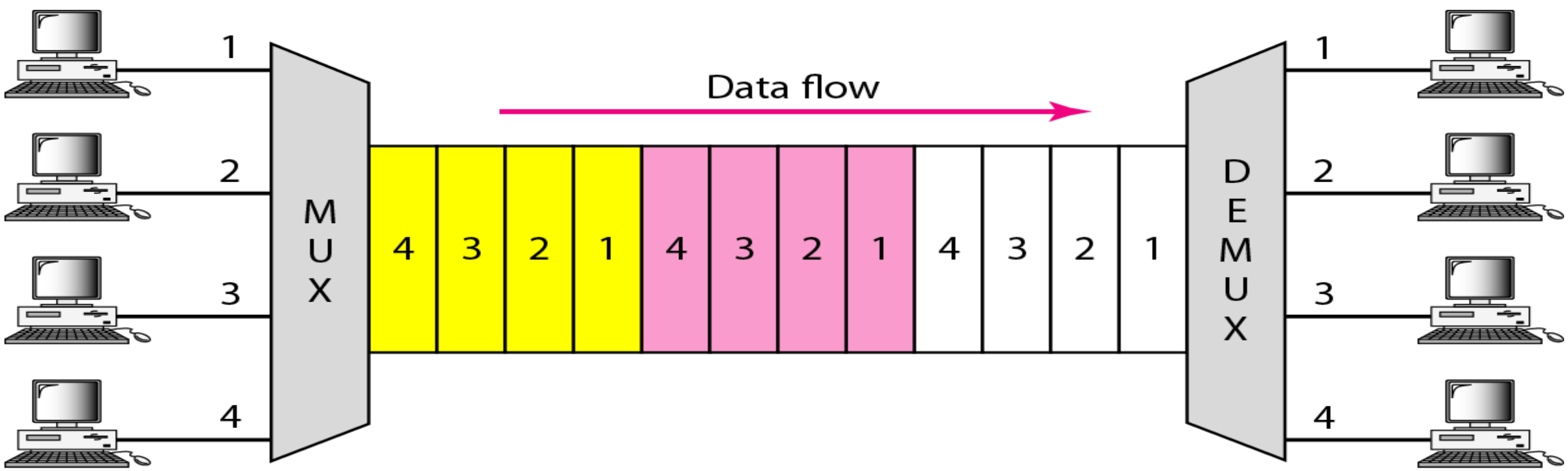
- Very narrow bands of light from different sources are combined to make a wider band of light. At the receiver, the signals are separated by the demultiplexer.
- We want to combine multiple light sources into one single light at the multiplexer and do the reverse at the demultiplexer.

- The combining and splitting of light sources are easily handled by a prism.



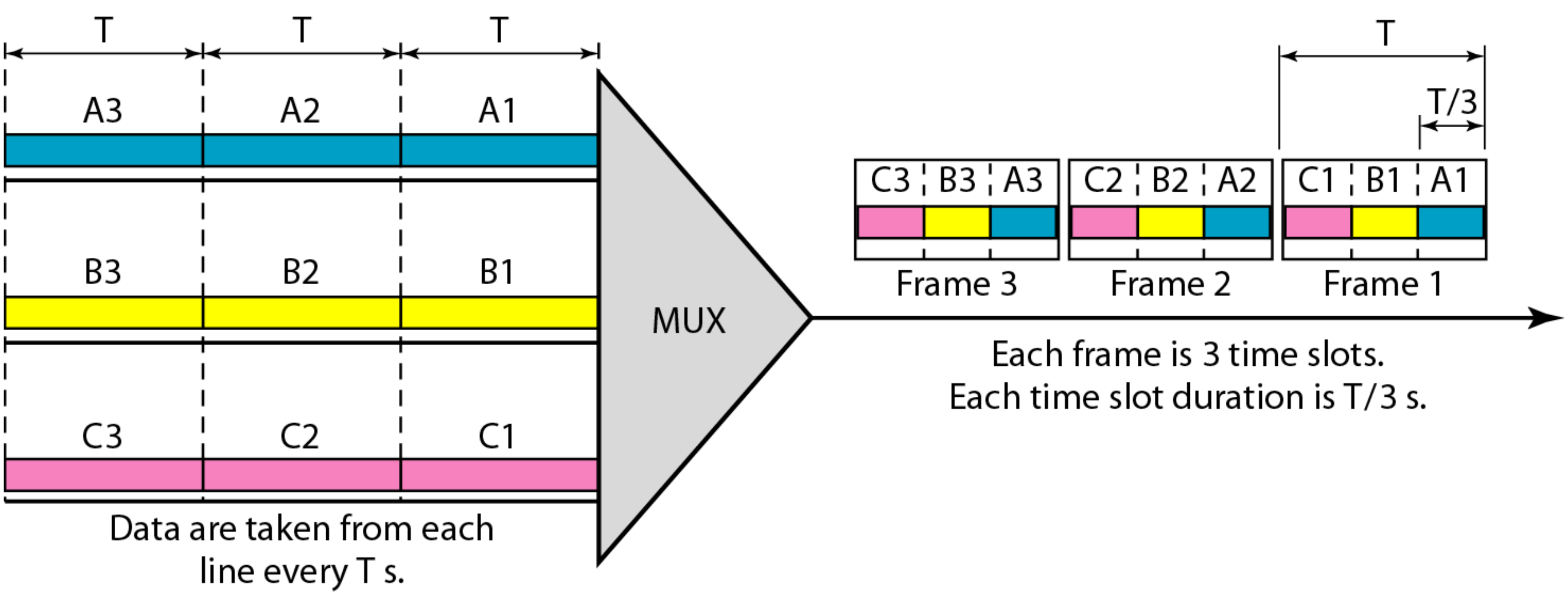
- A prism bends a beam of light based on the angle of incidence and the frequency. Using this technique, a multiplexer can be made to combine several input beams of light, each containing a narrow band of frequencies, into one output beam of a wider band of frequencies.
- A demultiplexer can also be made to reverse the process.
- One application of WDM is the SONET network in which multiple optical fiber lines are multiplexed and demultiplexed.

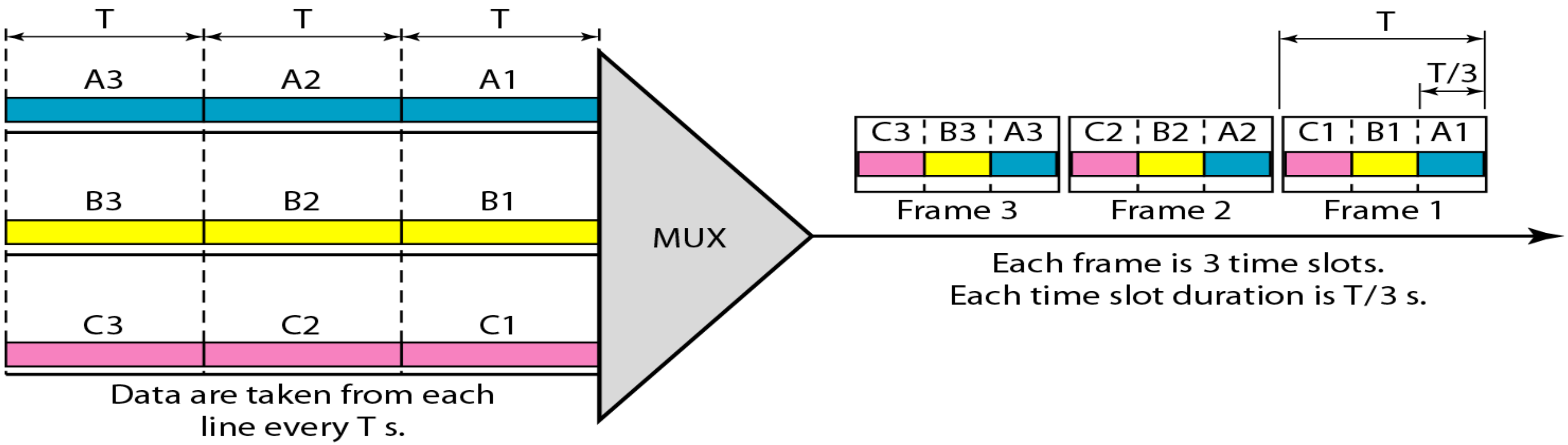
- **Time-Division Multiplexing**
- Time-division multiplexing (TDM) is a **digital** process that allows several connections to share the high bandwidth of a line Instead of sharing a portion of the bandwidth as in FDM, **time** is shared.
- Each connection occupies a portion of time in the link.



- 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.
- We can divide TDM into two different schemes: synchronous and statistical.

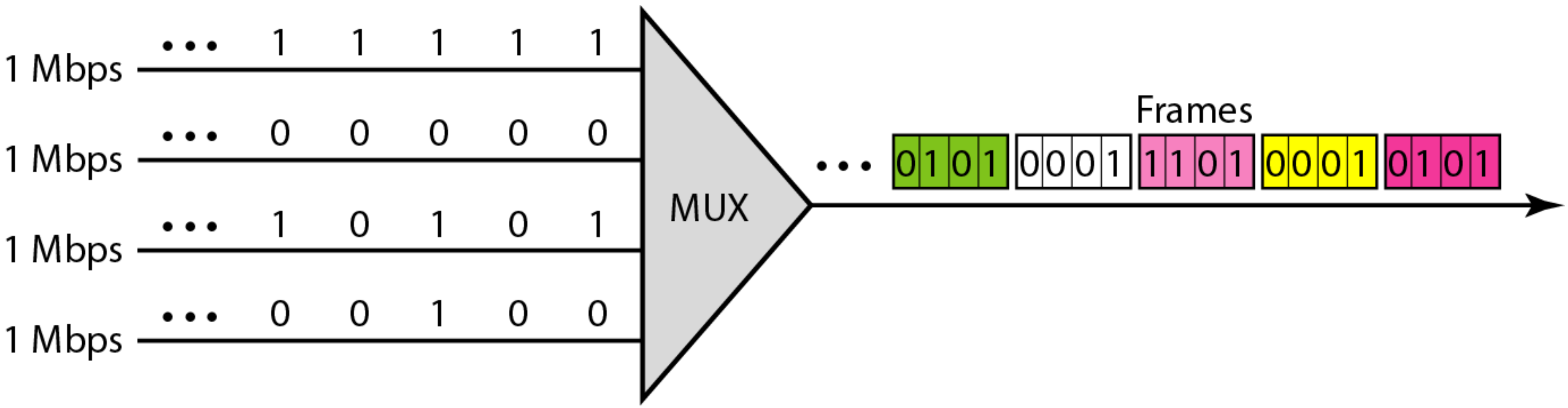
- **Synchronous TDM**
- In synchronous TDM, each input connection has a fixed allotment in the output line.
- The time allotment is called time slot. Time slots are fixed even if the input line is not sending data.
- The data flow of each input connection is divided into units, where each unit occupies one input time slot.
- Each input unit becomes one output unit and occupies one output time slot. Figure shows an example of synchronous TDM where *n* is 3.



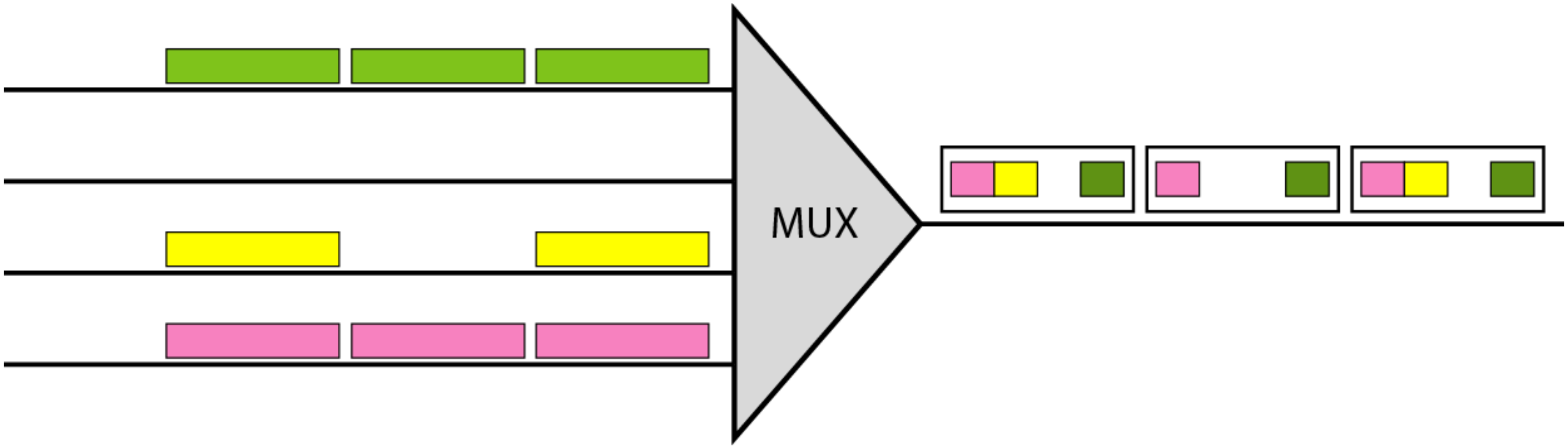


- A round of data units from each input connection is collected into a frame.
- Time slots are grouped into frames. A frame consists of one complete cycle of time slots, with one slot dedicated to each sending device.
- In a system with *n* input lines, each frame has *n* slots, with each slot allocated to carrying data from a specific input line.
- If the duration of the input unit is *T,* the duration of each slot is *Tin* 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.

- *Figure shows synchronous TDM with a data stream for each input and one data stream for the output. The unit of data is 1 bit. Find (a) the input bit duration, (b) the output bit duration, (c) the output bit rate, and (d) the output frame rate.*

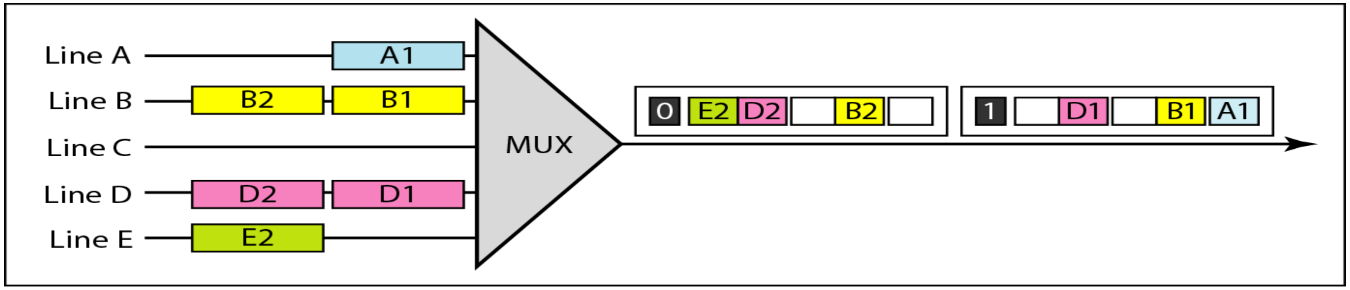


- A multiplexer combines four 100-kbps channels using a time slot of 2 bits. Show the output with four arbitrary inputs. What is the frame rate? What is the frame duration? What is the bit rate? What is the bit duration?

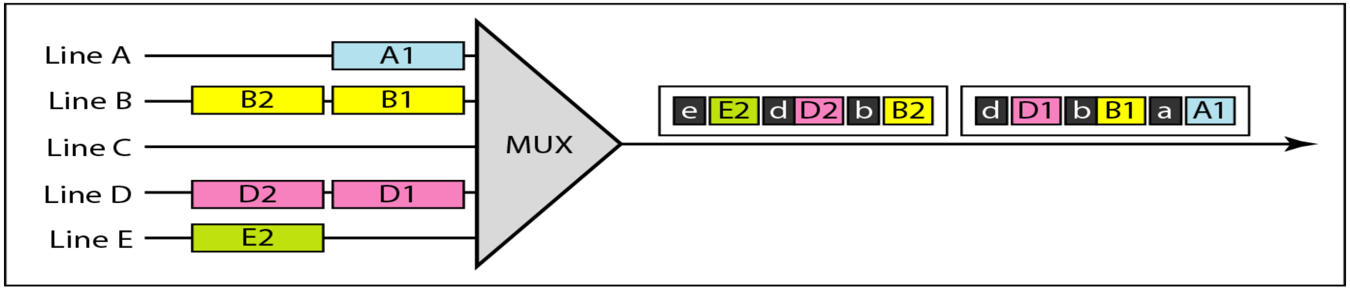


- Synchronous TDM is not as efficient as it could be. If a source does not have data to send, the corresponding slot in the output frame is empty.
- Figure shows a case in which one of the input lines has no data to send and one slot in another input line has discontinuous data.
- The first output frame has three slots filled, the second frame has two slots filled, and the third frame has three slots filled. No frame is full.
- This is because each input line has a reserved slot in the output frame.
- This can be inefficient if some input lines have no data to send.

- **Statistical Time-Division Multiplexing**
- In statistical time-division multiplexing, slots are dynamically allocated to improve bandwidth efficiency.



a. Synchronous TDM

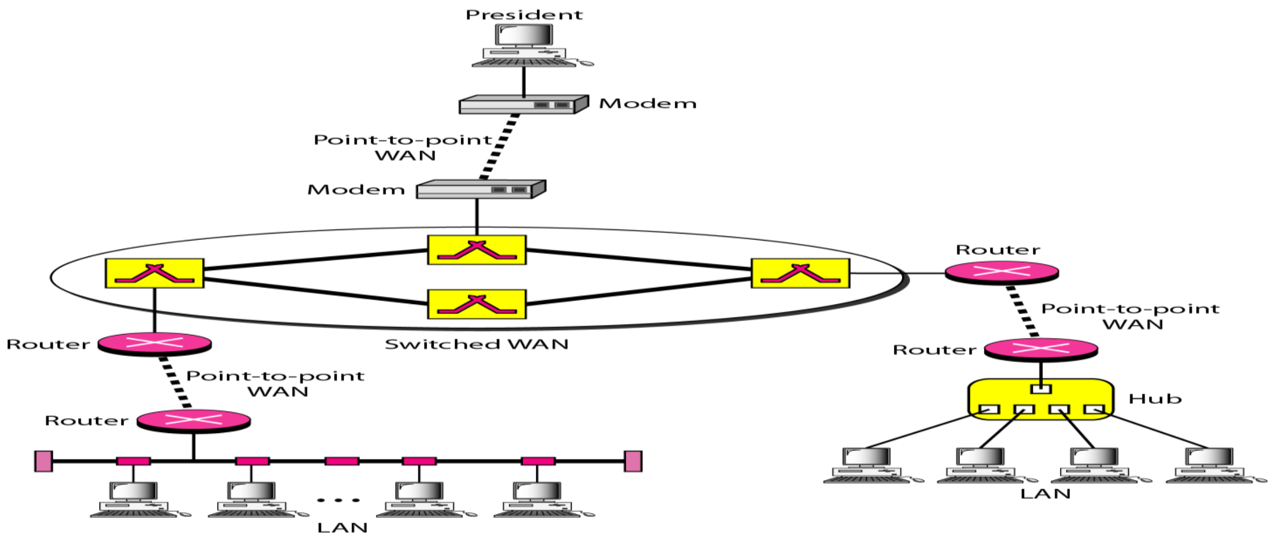


b. Statistical TDM

- Only when an input line has a slot's worth of data to send is it given a slot in the output frame.
- 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.

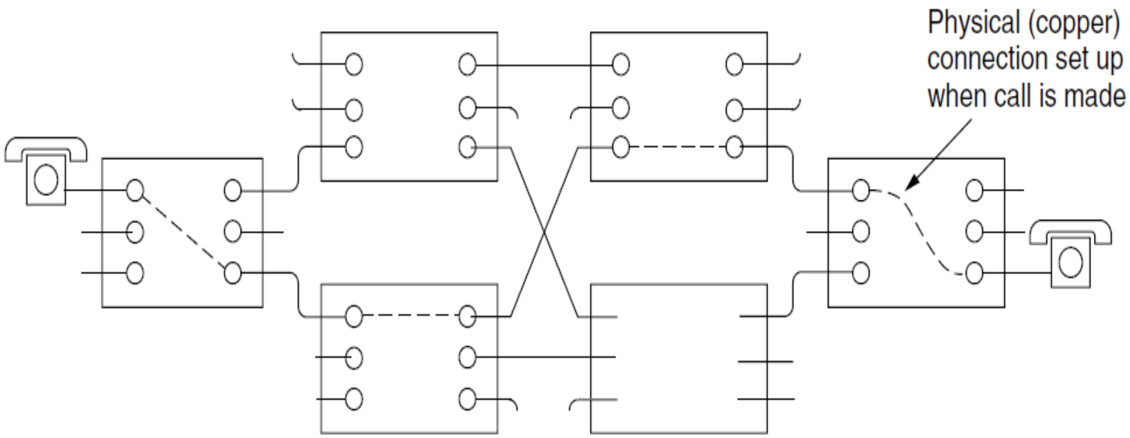
- No slot is left empty as long as there are data to be sent by any input line.
- An output slot in synchronous TDM is totally occupied by data; in statistical TDM, a slot needs to carry data as well as the address of the destination.
- In statistical multiplexing, there is no fixed relationship between the inputs and outputs because there are no pre assigned or reserved slots.
- We need to include the address of the receiver inside each slot to show where it is to be delivered. The addressing in its simplest form can be n bits to define N different output lines with $N = 2^n$.
- In statistical TDM, the capacity of the link is normally less than the sum of the capacities of each channel.

- **Switching Techniques**
- Across internetworks there might be multiple paths linking sender and receiver.



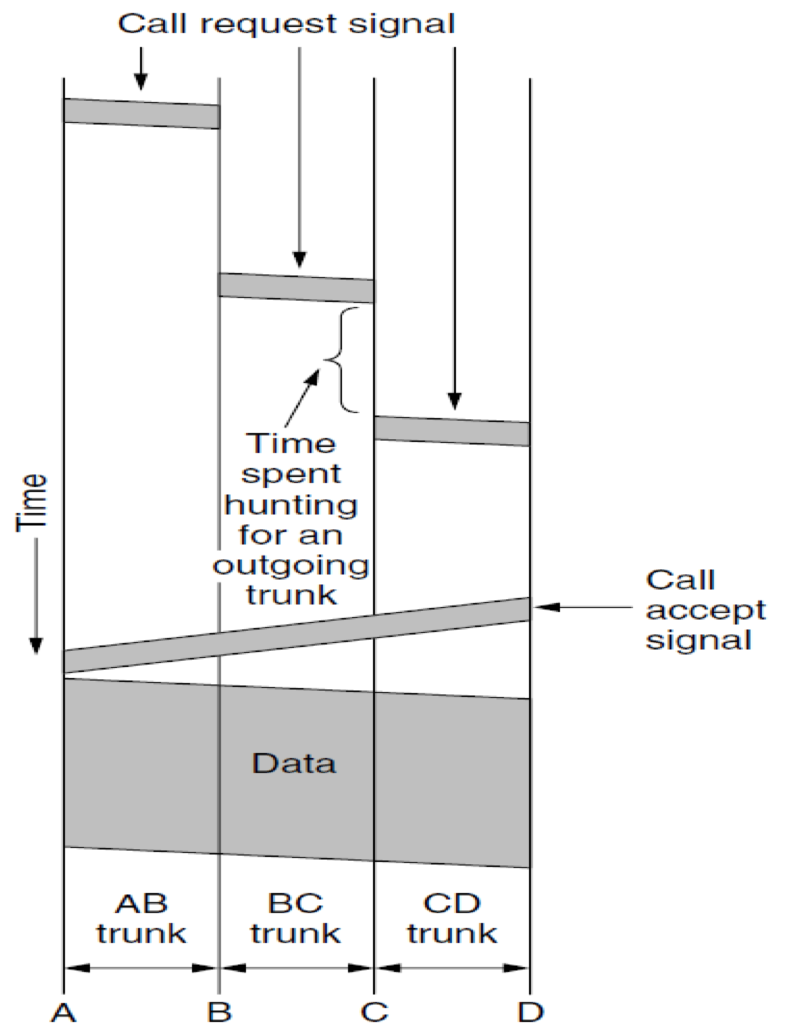
- Information may be switched as it travels through various communication channels.
- There are three typical switching techniques available for digital traffic.
  - Circuit Switching
  - Packet Switching

- **Circuit Switching**
- Circuit switching is modelled around connection oriented service.
- For data transfer to happen, a physical path is established from sender to receiver.



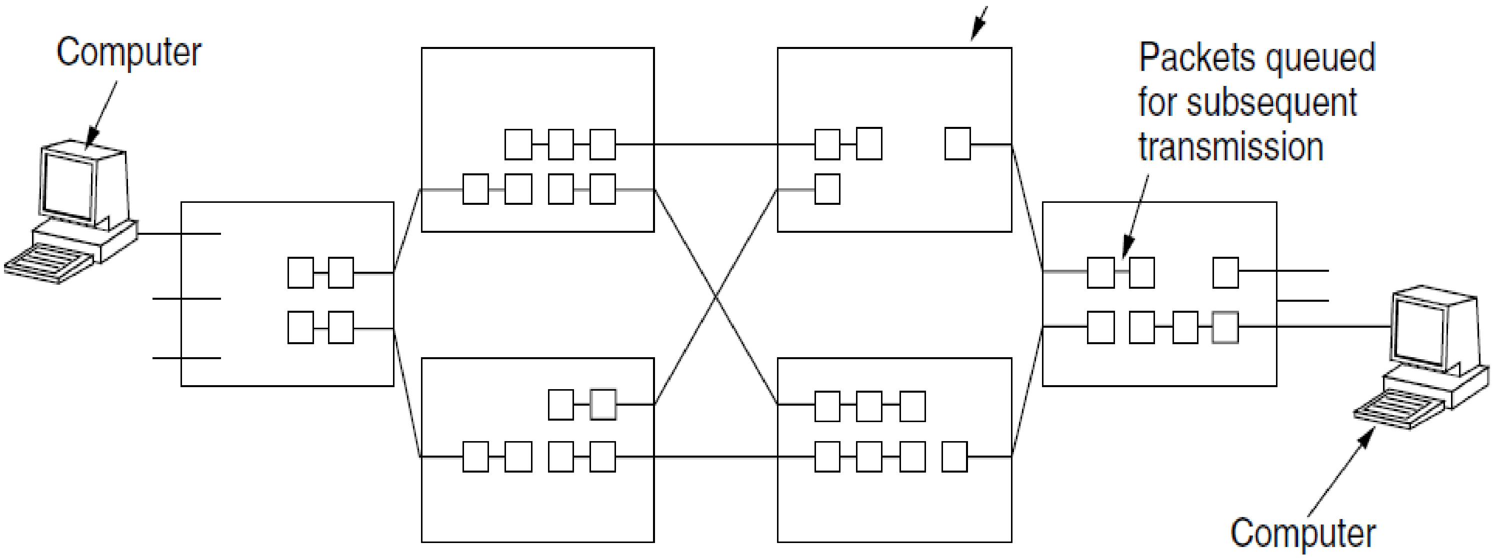
- Once a connection has been set up, a dedicated path between both ends exists and will continue to exist until the connection is finished.
- An important property of circuit switching is the need to set up an end-to-end path *before* any data can be sent.

- The elapsed time for connection set up is significant for long distance connections.
- During this time interval, the network system searches for a path.
- Note that before data transmission can even begin, the call request signal must propagate all the way to the destination and be acknowledged.
- As a consequence of the reserved path between the calling parties, once the setup has been completed, the only delay for data is the propagation time for the electromagnetic signal.



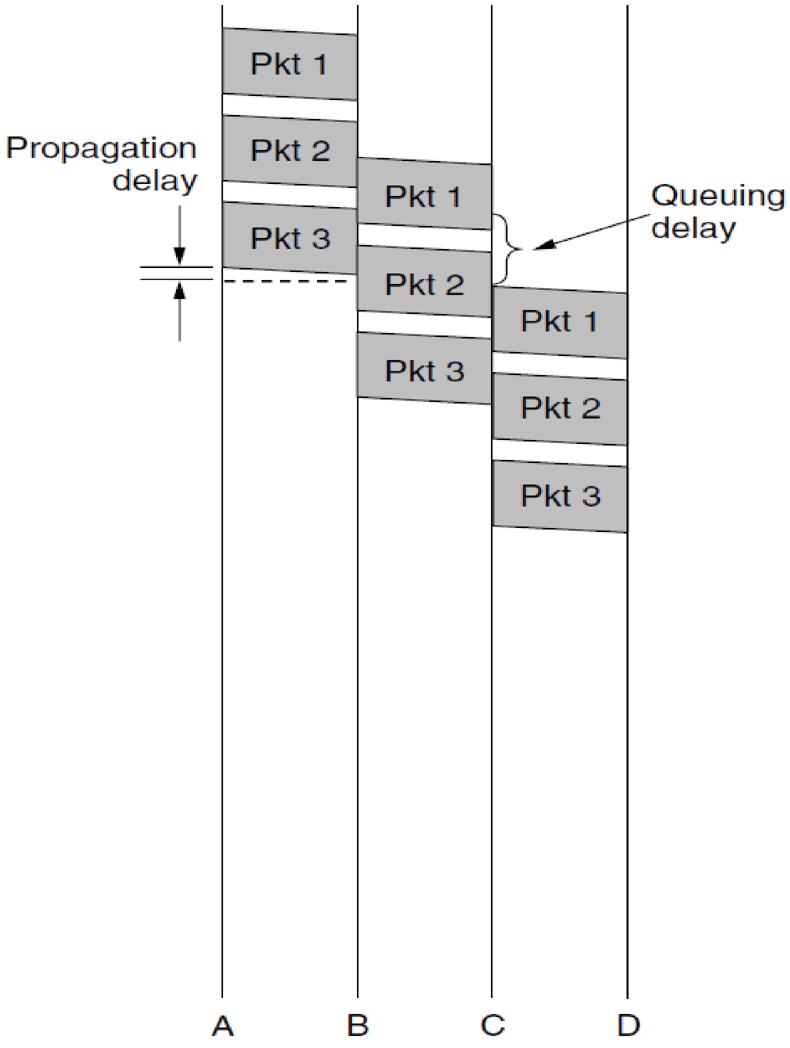
- Also as a consequence of the established path, there is no danger of congestion

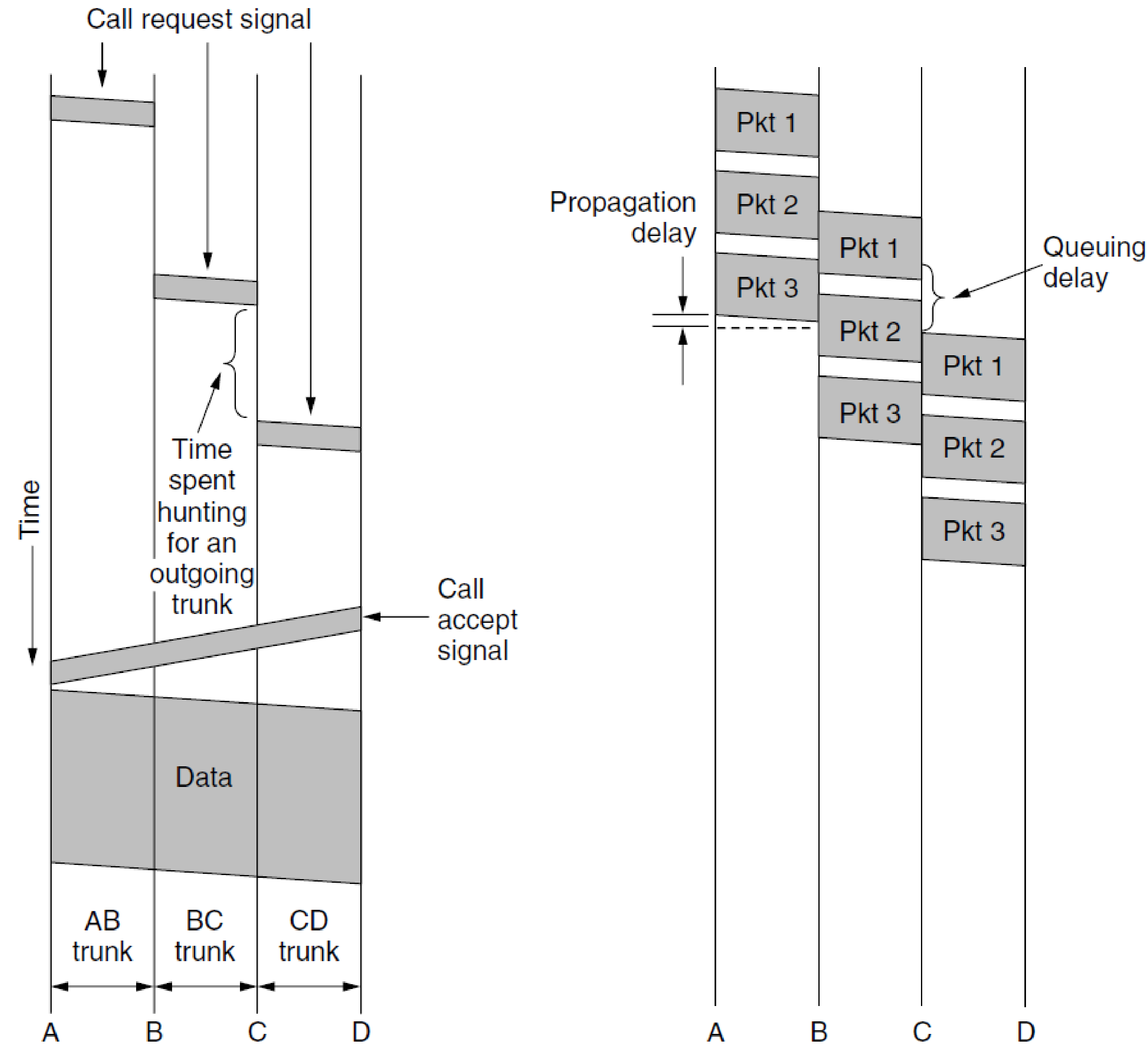
- Among other properties, having all the data follow the same path means that it cannot arrive out of order.
- For many computer applications, long setup times are undesirable.
- **Packet Switching**
- With this technology, packets are sent as soon as they are available.



- There is no need to set up a dedicated path in advance, unlike with circuit switching.
- It is up to routers to use store-and-forward transmission to send each packet on its way to the destination on its own.

- With packet switching there is no fixed path, so different packets can follow different paths, depending on network conditions at the time they are sent, and they may arrive out of order.
- Packet-switching networks place a tight upper limit on the size of packets, so that packet-switched networks can handle interactive traffic.
- It also reduces delay since the first packet of a long message can be forwarded before the second one has fully arrived.
- Because no bandwidth is reserved with packet switching, packets may have to wait to be forwarded.
- This introduces **queuing delay** and congestion.





Call request signal
Time
Time spent hunting for an outgoing trunk
Call accept signal
Data
AB trunk
BC trunk
CD trunk
A
B
C
D
Pkt 1
Pkt 2
Pkt 3
Propagation delay
Queuing delay
A
B
C
D

Item	Circuit Switched	Packet Switched
Call setup	yes	no
Dedicated physical path	required	Not required
Each packet follows the same route	yes	no
Packets arrive in order	yes	no
Is a switch crash fatal	YES	no
Bandwidth available	fixed	dynamic
Time of possible congestion	Call set up	For every packet
Potentially wasted bandwidth	YEs	no
Store-and-forward transmission	no	yes
Charging	Per time	Per packet