Computer Networks

Unit-2: Physical Layer

By
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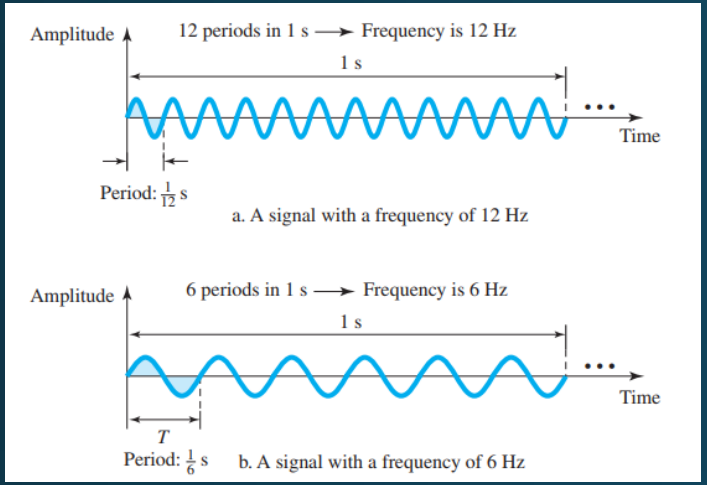
Day 1(22-07-2020): ILO

Upon the completion of todays lecture, students are able to understand the physical properties of a medium.

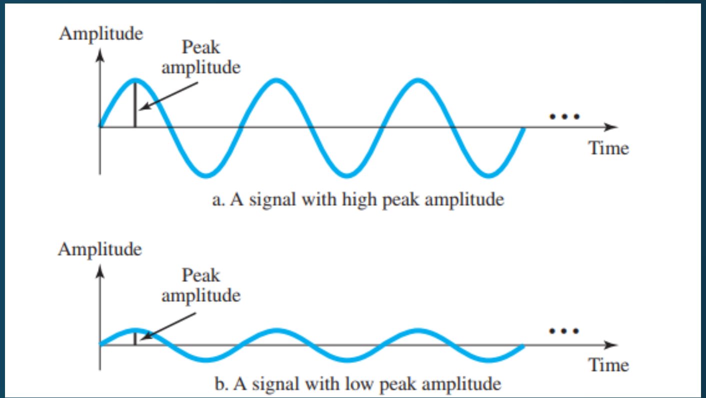
Physical Layer

- **Representation of Bits:** Data in this layer consists of stream of bits. The bits must be encoded into signals for transmission. It defines the type of encoding i.e. how 0's and 1's are changed to signal.
- **Data Rate:** This layer defines the rate of transmission which is the number of bits per second.
- **Synchronization:** It deals with the synchronization of the transmitter and receiver. The sender and receiver are synchronized at bit level.
- **Interface:** The physical layer defines the transmission interface between devices and transmission medium.
- **Line Configuration:** This layer connects devices with the medium: Point to Point configuration and Multipoint configuration.
- **Topologies:** Devices must be connected using the following topologies: Mesh, Star, Ring and Bus.
- **Transmission Modes:** Physical Layer defines the direction of transmission between two devices: Simplex, Half Duplex, Full Duplex.
- Deals with baseband and broadband transmission.



$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$

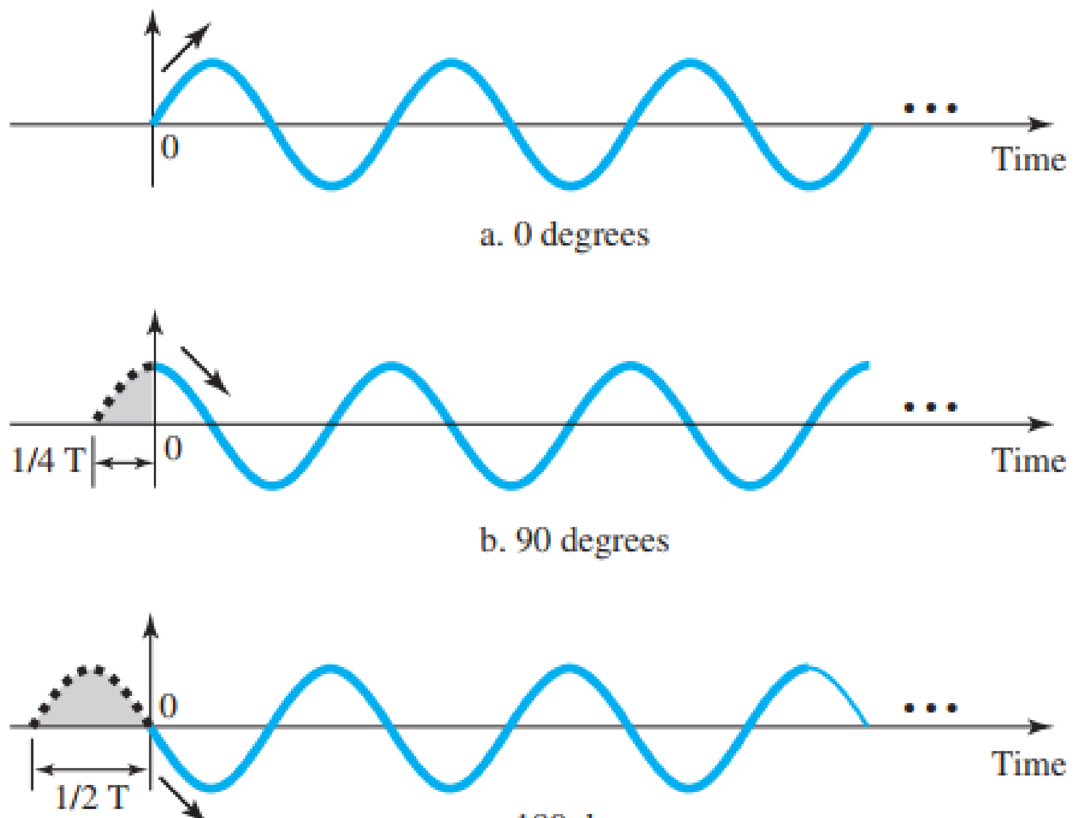
Frequency and period are the inverse of each other.



Periodic Analog Signals

Periodic Analog Signals

Three sine waves with the same amplitude and frequency, but different phases



Fourier Analysis

- In the early 19th century, the French mathematician Jean-Baptiste Fourier proved that any reasonably behaved periodic function, *g*(*t*) with period *T*, can be constructed as the sum of a (possibly infinite) number of sines and cosines.
- where $f = 1/T$ is the fundamental frequency, *an* and *bn* are the sine and cosine amplitudes of the *n*th **harmonics** (terms), and *c* is a constant. Such a decomposition is called a **Fourier series**.

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi n f t) + \sum_{n=1}^{\infty} b_n \cos(2\pi n f t)$$

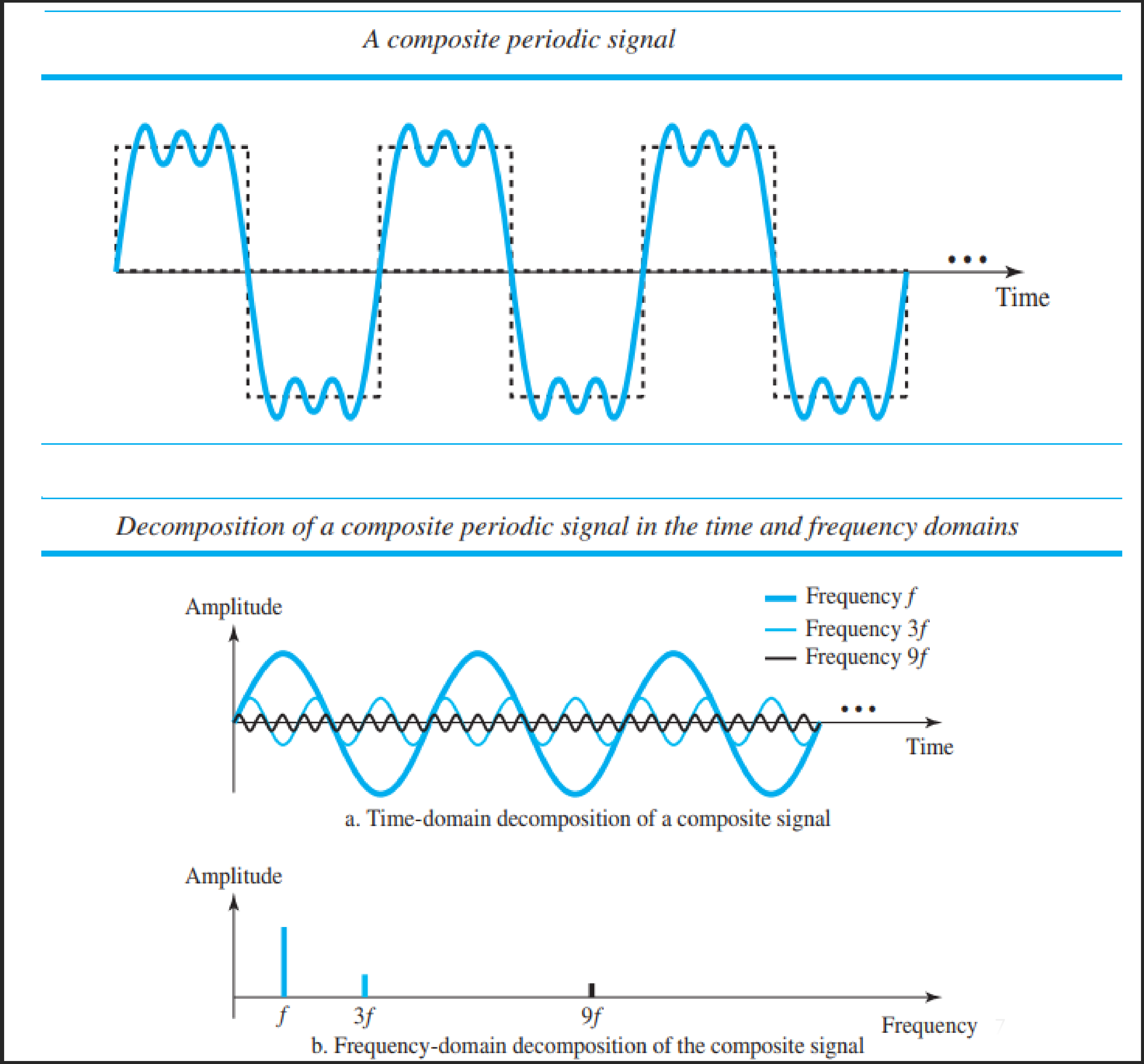
$$a_n = \frac{2}{T}\int_0^T g(t)\sin(2\pi n f t)\,dt$$

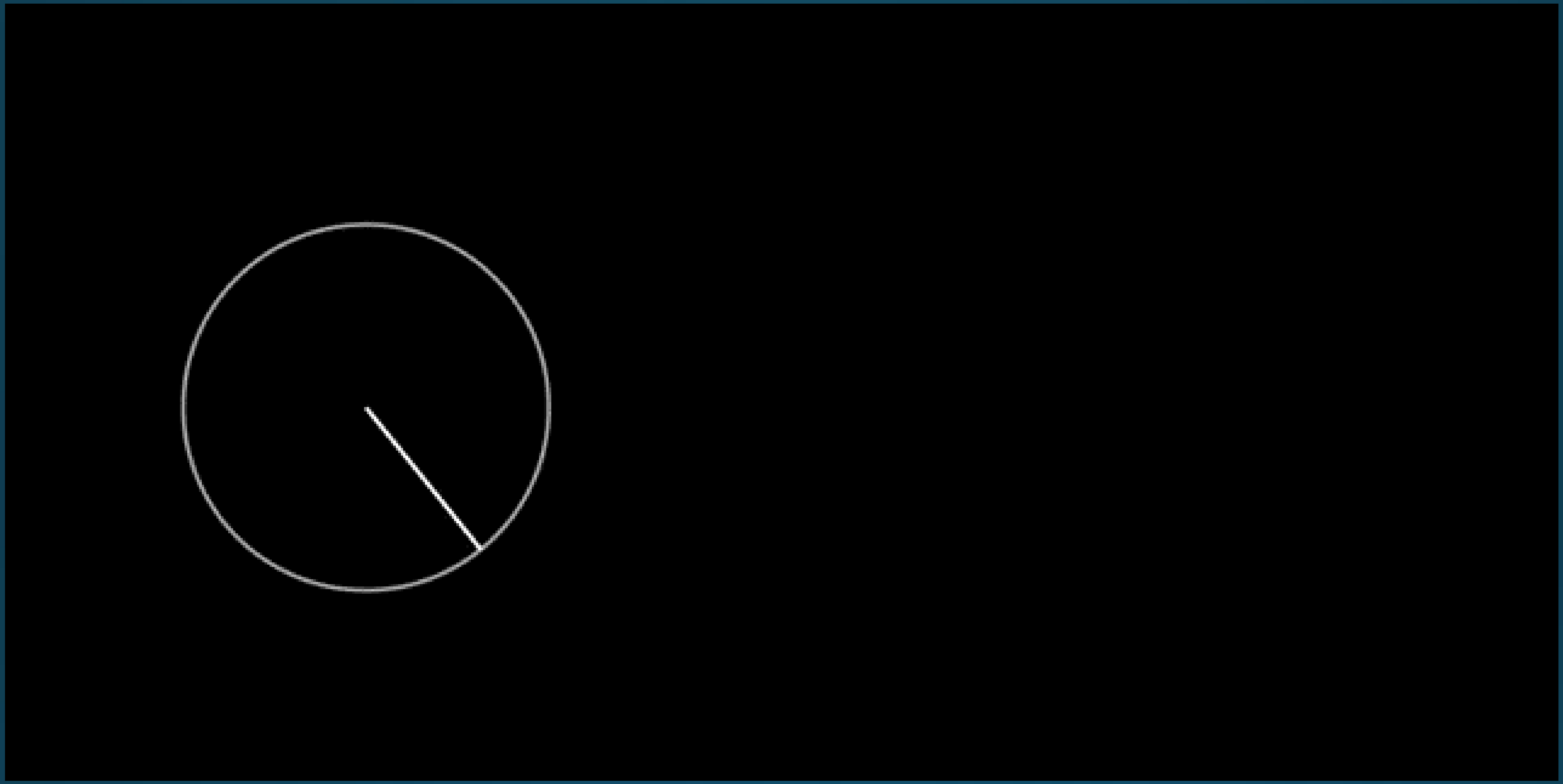
$$b_n = \frac{2}{T}\int_0^T g(t)\cos(2\pi n f t)\,dt$$

$$c = \frac{2}{T}\int_0^T g(t)\,dt$$

Fourier Analysis

As shown in the figure, a square wave can be approximated by combining 3 sine waves (3-harmonics) at 3 frequencies.

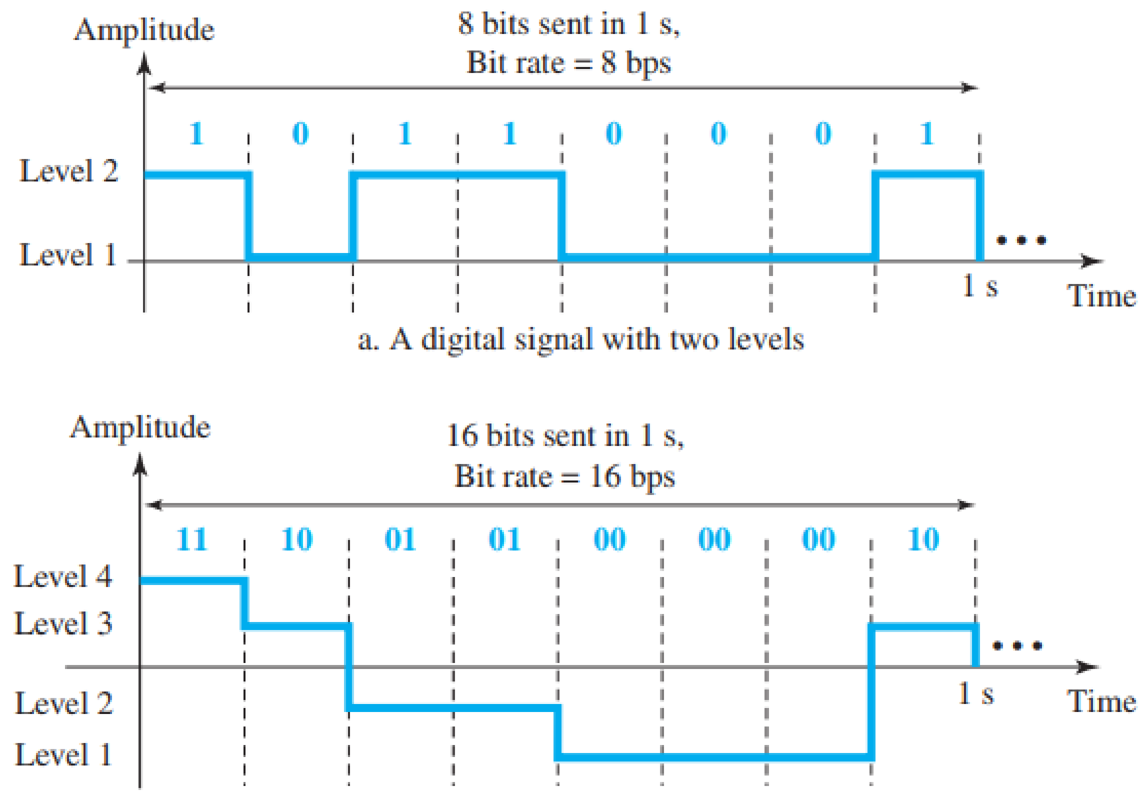




Fourier Analysis

The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.

Digital Signals



a. A digital signal with two levels

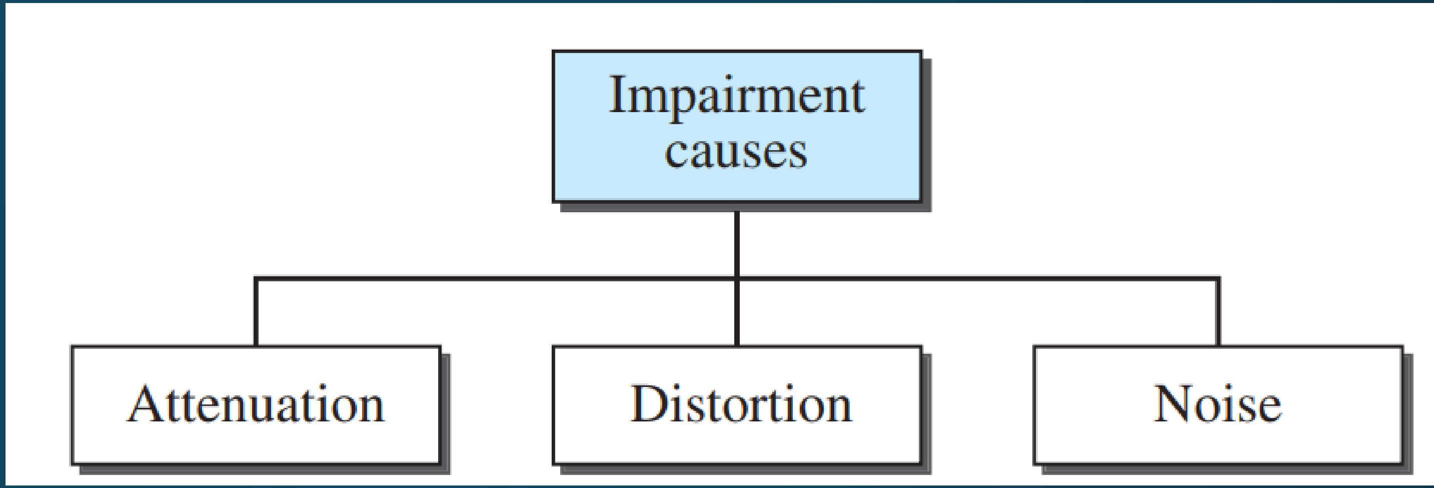
b. A digital signal with four levels

Digital Signals

- **Bit Rate**: The **bit rate** is the number of bits sent in 1s, expressed in **bits per second (bps)**
- **Bit Length:** The **bit length** is the distance one bit occupies on the transmission medium.
- Based on Fourier analysis, a digital signal is a composite analog signal. The bandwidth is infinite, as you may have guessed.
- Since a digital signals carry infinite number of frequencies and since there is no carrier that is available to carry all the frequencies, using Fourier analysis only a proration of the frequency harmonics will be used.

Transmission Impairment

Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. What is sent is not what is received.



- **Attenuation:** When a signal, simple or composite, travels through a medium, it loses some of its energy in overcoming the resistance of the medium. (DB)
- **Distortion:** The signal changes its form or shape, as the signal is a composite of multiple frequencies, each frequency may react differently to the medium(Like light travelling through a prism.).
- **Noise:** Several types of noise, such as thermal noise, induced noise, crosstalk, and impulse noise, may corrupt the signal.

$$\mathrm{dB} = 10 \log_{10} \frac{P_2}{P_1}$$

Data Rate

- A very important consideration in data communications is how fast we can send data, in bits per second, over a channel. Data rate depends on three factors:
  - The bandwidth available
  - The level of the signals we use
  - The quality of the channel (the level of noise)

- **Noiseless Channel: Nyquist Bit Rate**

$$\text{BitRate} = 2 \times \text{bandwidth} \times \log_2 L$$

- **Noisy Channel: Shannon Capacity**

$$\text{Capacity} = \text{bandwidth} \times \log_2(1 + \text{SNR})$$

$$\text{SNR}_{\text{dB}} = 10 \log_{10} \text{SNR} \longrightarrow \text{SNR} = 10^{\text{SNR}_{\text{dB}}/10}$$

Data Rate

- Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as
- Consider the same noiseless channel transmitting a signal with four signal levels. The maximum bit rate can be calculated as
- We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

$$\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

$$\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

$$265{,}000 = 2 \times 20{,}000 \times \log_2 L$$

$$\log_2 L = 6.625$$

$$L = 2^{6.625}$$

$$= 98.7 \text{ levels}$$

Data Rate

- We have a channel with a 1-MHz bandwidth. The SNR for this channel is 63. What are the maximum bit rate?

$$C = B \log_2(1 + \text{SNR})$$

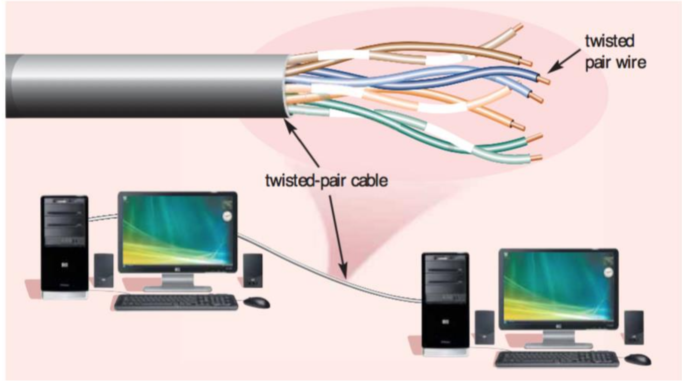
$$= 10^6 \log_2(1 + 63)$$

$$= 10^6 \log_2 64$$

$$= 6 \text{ Mbps}$$

Day 2 (23-07-2020)
ILO

Upon the completion of todays lecture, students will be able to understand the differences between different guided transmission mediums.



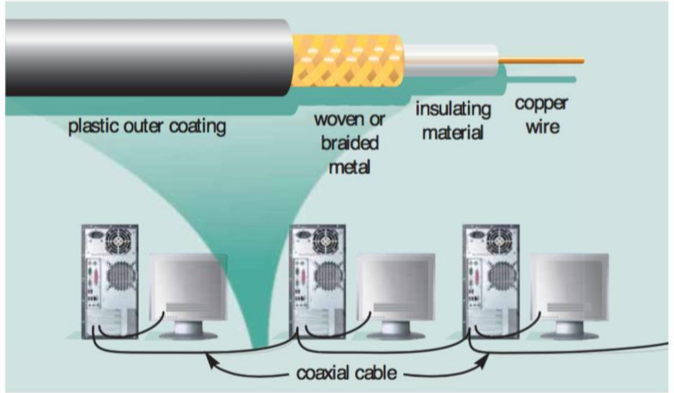
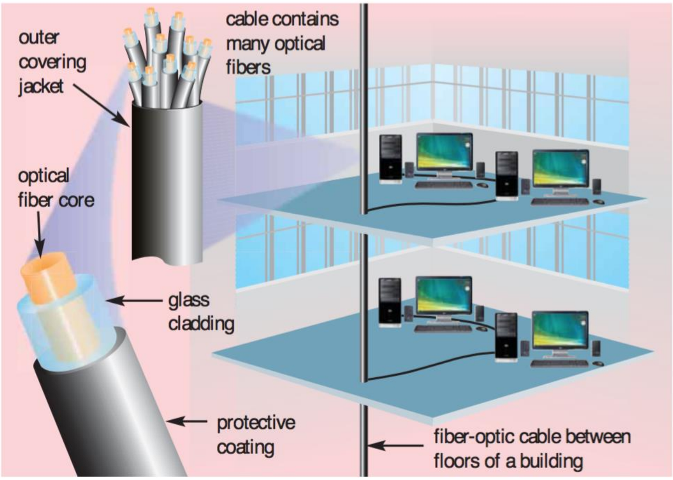
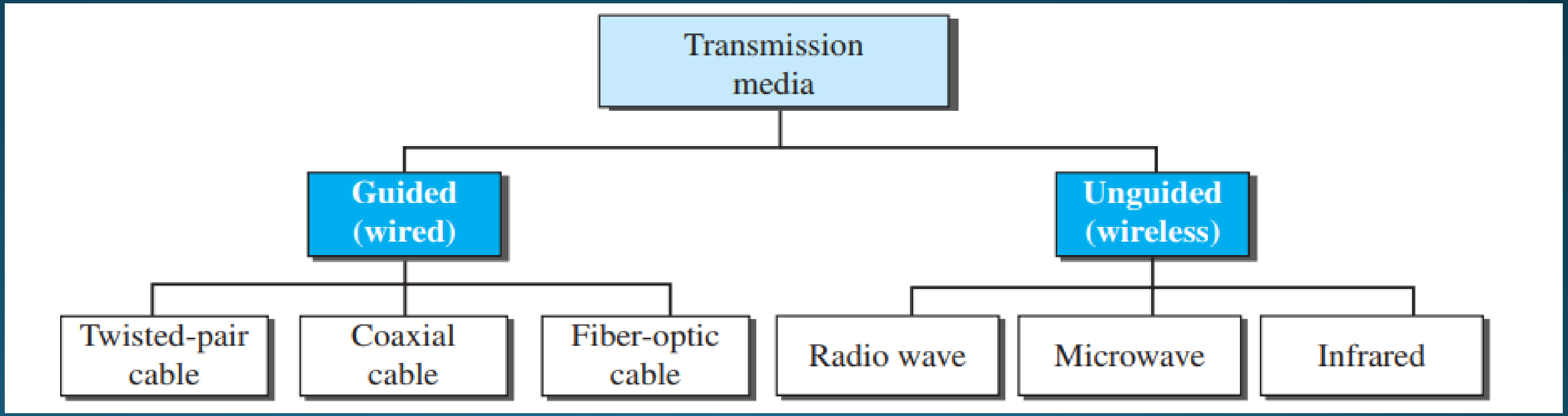


FIGURE 8-25 On a coaxial cable, data travels through a copper wire. This illustration shows computers networked together with coaxial cable.



Transmission Medium

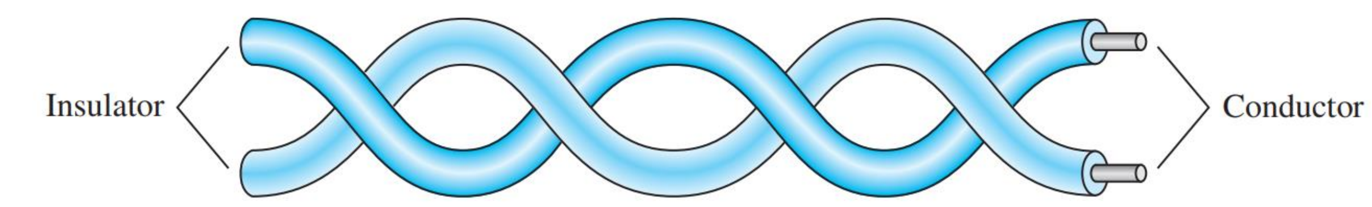
- A **transmission medium** can be broadly defined as anything that can carry information from a source to a destination.



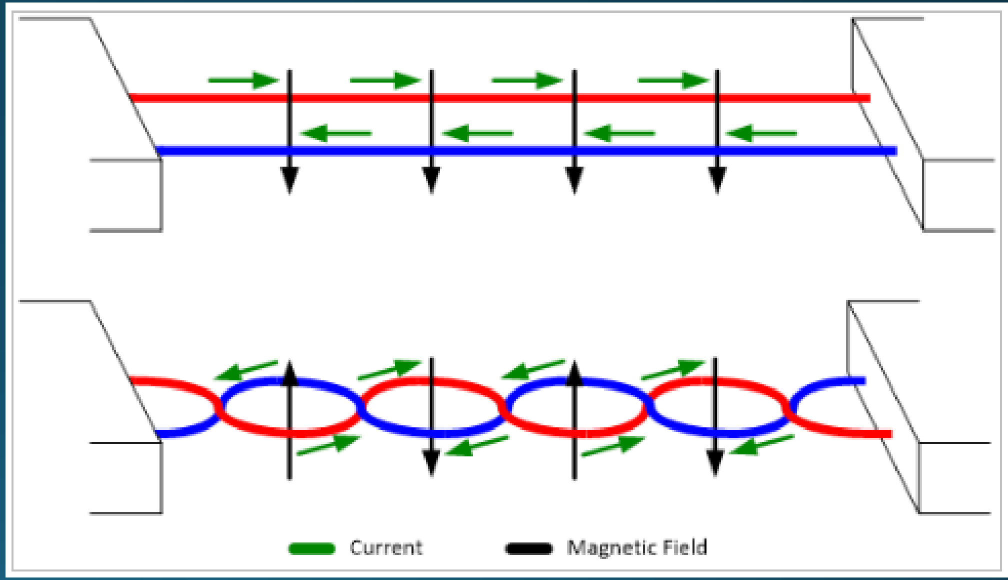
Guided Medium/Media

- A signal traveling along any of these media is directed and contained by the physical limits of the medium.
- It guides signal through solid physical path.
- Three major guided media
  - Twisted-Pair
    - Unshielded Twisted-Pair (UTP)
    - Shielded Twisted-Pair (STP)
  - Coaxial Cables
  - Fiber-Optic Cables

Twisted-Pairs

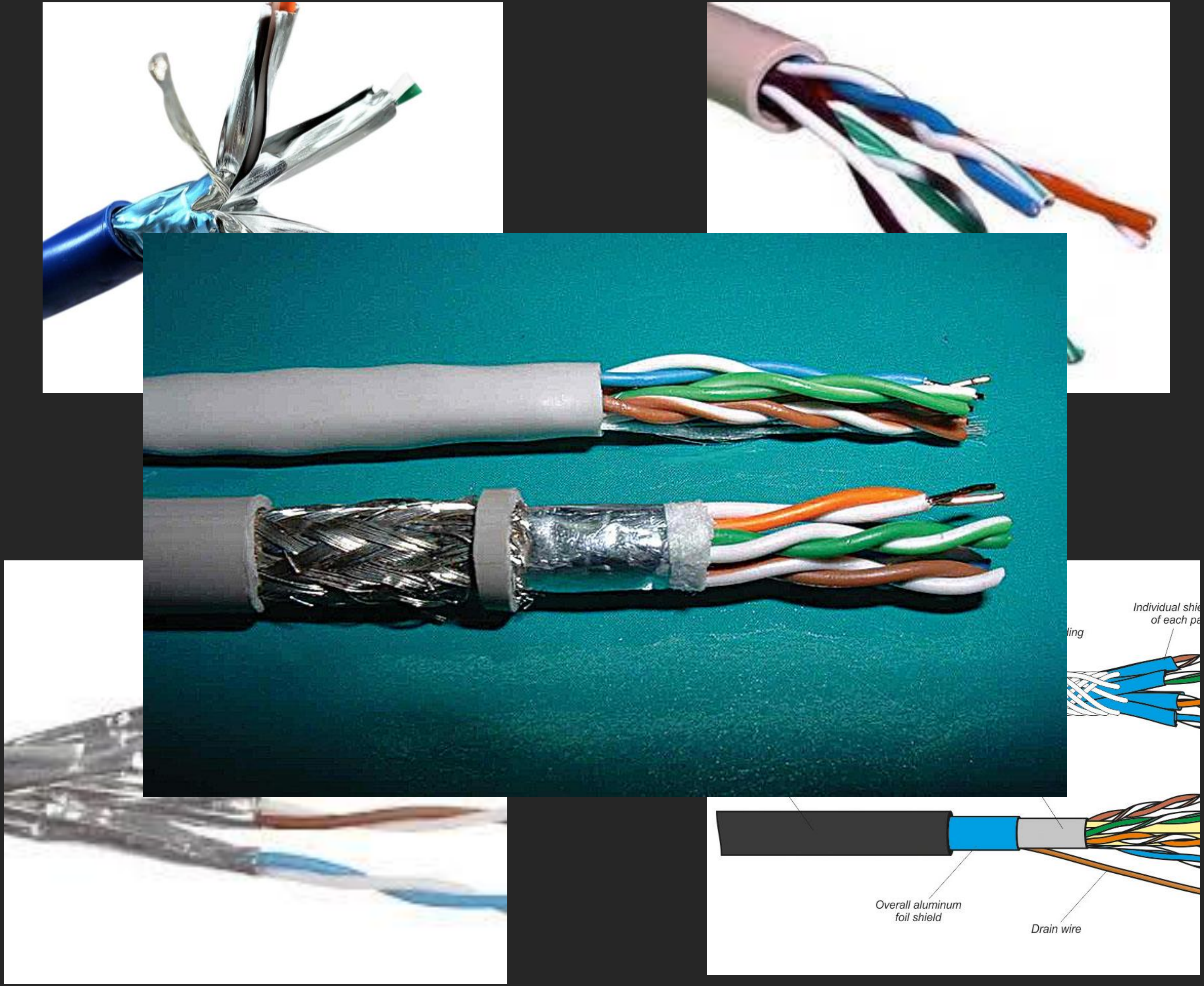


- A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together, as shown in Figure.
- By twisting the pairs, a balance is maintained by nullifying the noise/interference.
- Twisting also nullify the magnetic field generated, so the wire radiates less effectively. Hence reduces cross talks.

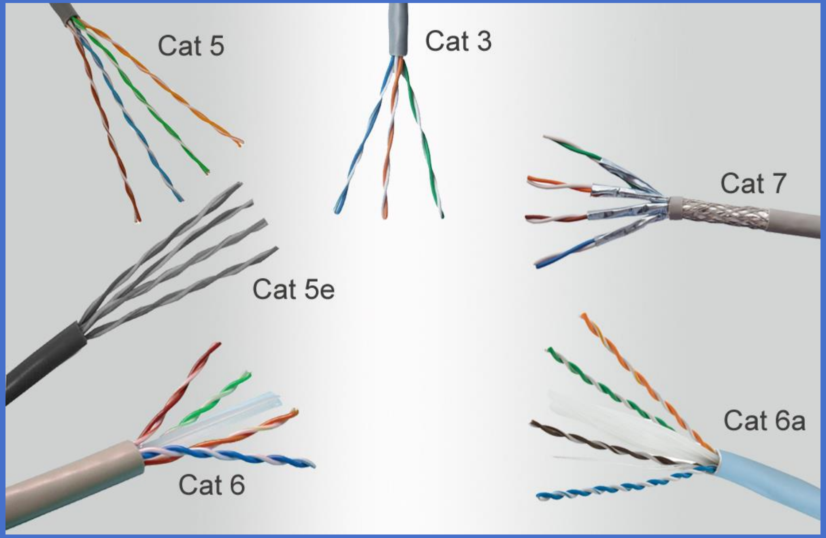


Unshielded vs Shielded

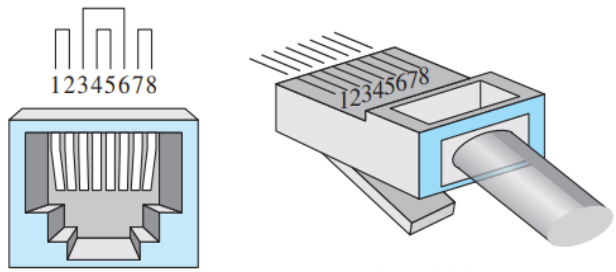
The most common twisted-pair cable used in communications is referred to as ***unshielded twisted-pair* (UTP).** IBM has also produced a version of twisted-pair cable for its use, called ***shielded twisted-pair* (STP).** STP cable has a metal foil or braided mesh covering that encases each pair of insulated conductors.



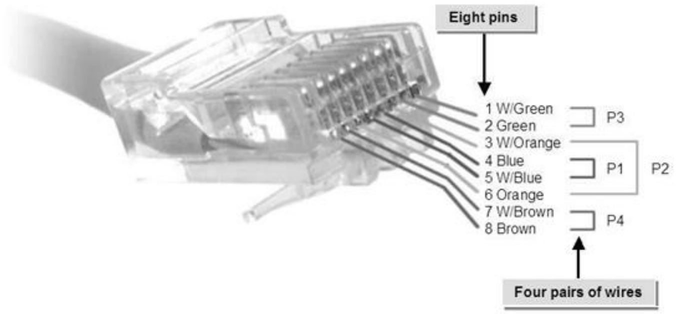
Twisted-Pairs



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



RJ-45 Female RJ-45 Male

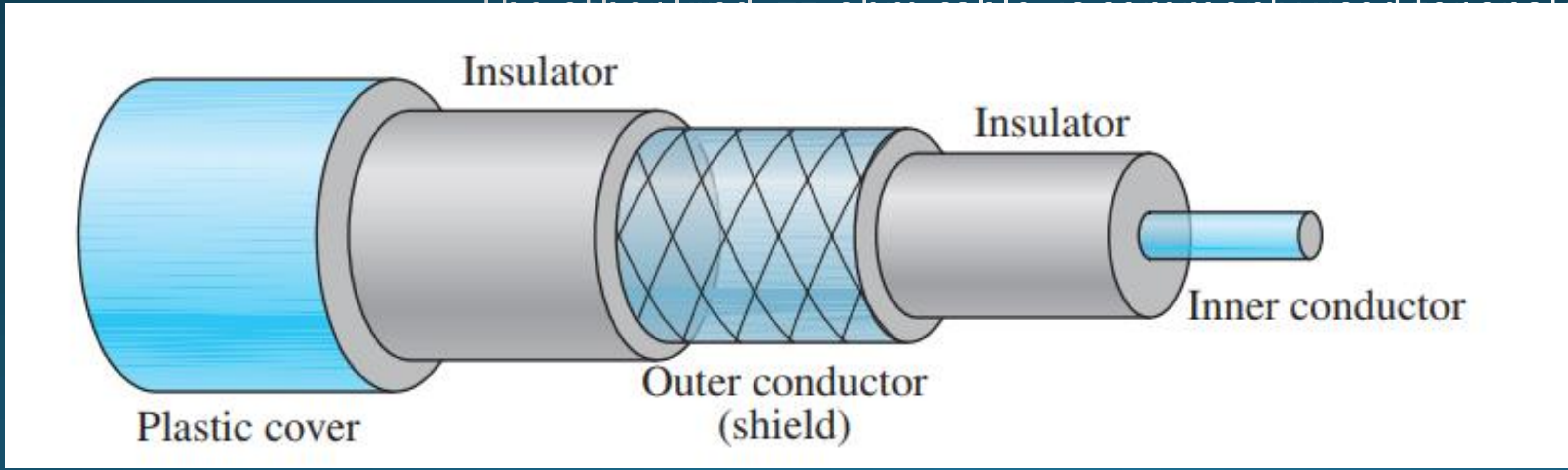


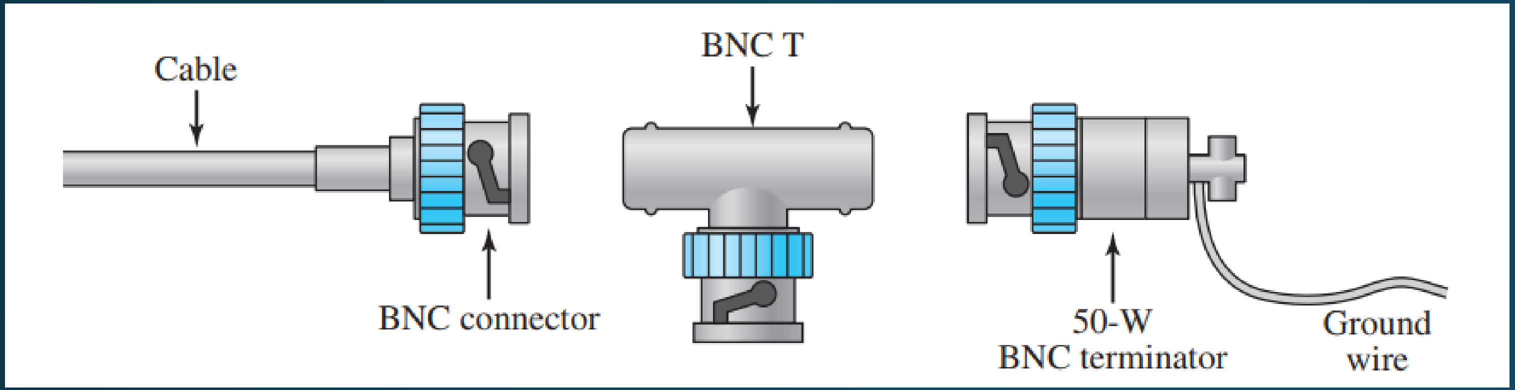
Twisted-Pair Connecters

The RJ45 is a keyed connector, meaning the connector can be inserted in only one way.

Coaxial Cable

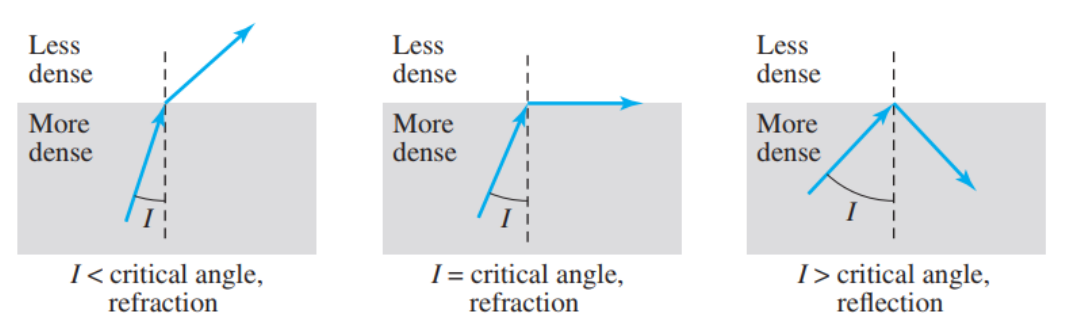
- Coaxial cable (or *coax*) carries signals of higher frequency ranges than those in twisted-pair cable, in part because the two media are constructed quite differently.
- Coax has a central core conductor of solid or stranded wire (usually copper) enclosed in an insulating sheath, which is, in turn, 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.
- Two kinds of coaxial cable are widely used. One kind, 50-ohm cable, is commonly used when it is intended for digital transmission from the start. [illegible]og transmission and





Coaxial Cable

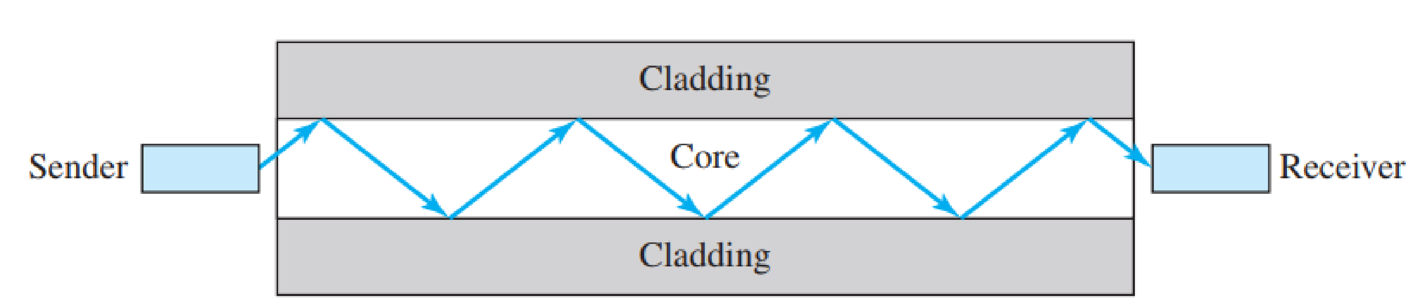
Fiber-Optic Cable



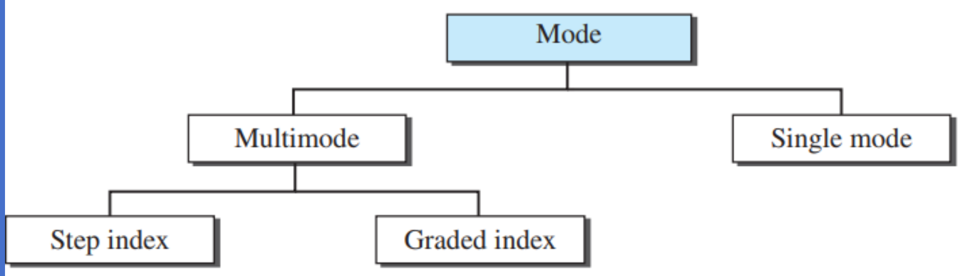
- A fiber-optic cable is made of glass or plastic and transmits signals in the form of light.
- Working Principle:
  - If a ray of light traveling through one substance suddenly enters another substance (of a different density), the ray changes direction. In that case, if the **angle of incidence** *I* 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)

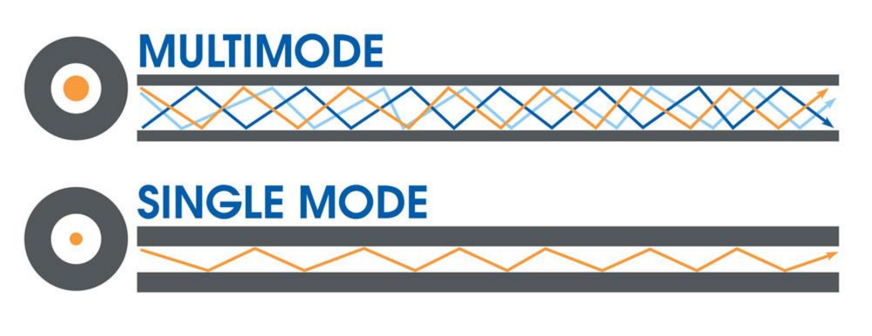
Fiber-Optic Cable

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.



Fiber-Optic Cable

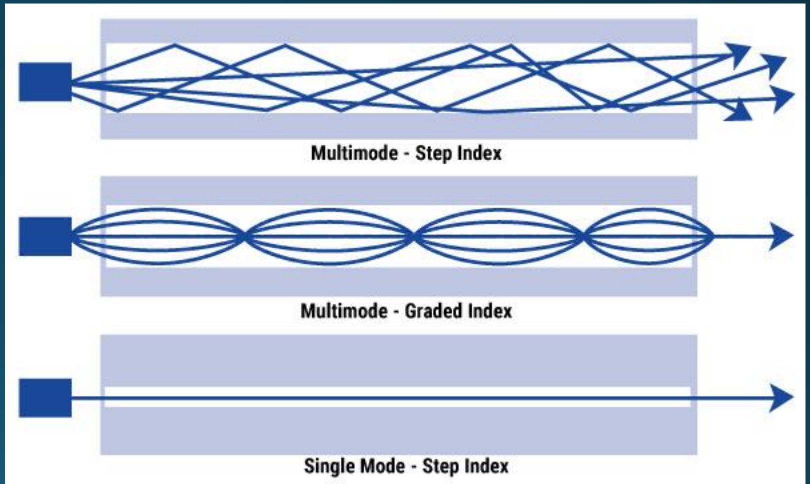




Current technology supports two modes (multimode and single mode) for propagating light along optical channels, each requiring fiber with different physical characteristics. Multimode can be implemented in two forms: step-index or graded-index.

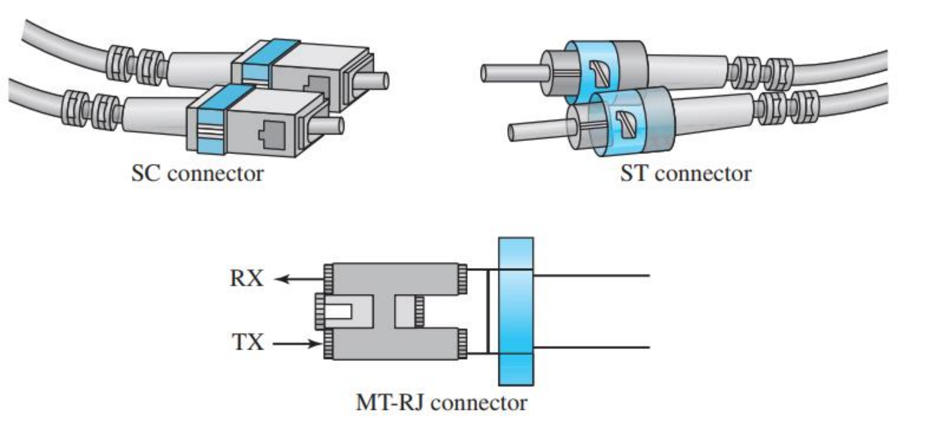
Fiber-Optic Cable

- 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 **multimode step-index fiber,** the density of the core remains constant from the center to the edges.
- **In multimode graded-index fiber,** decreases this distortion of the signal through the cable.



Fiber-Optic Cable

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



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. A Mechanical Transfer Registered **Jack** (**MT**-**RJ**) is a **connector** used for two fibers.

Fiber-Optic Cable

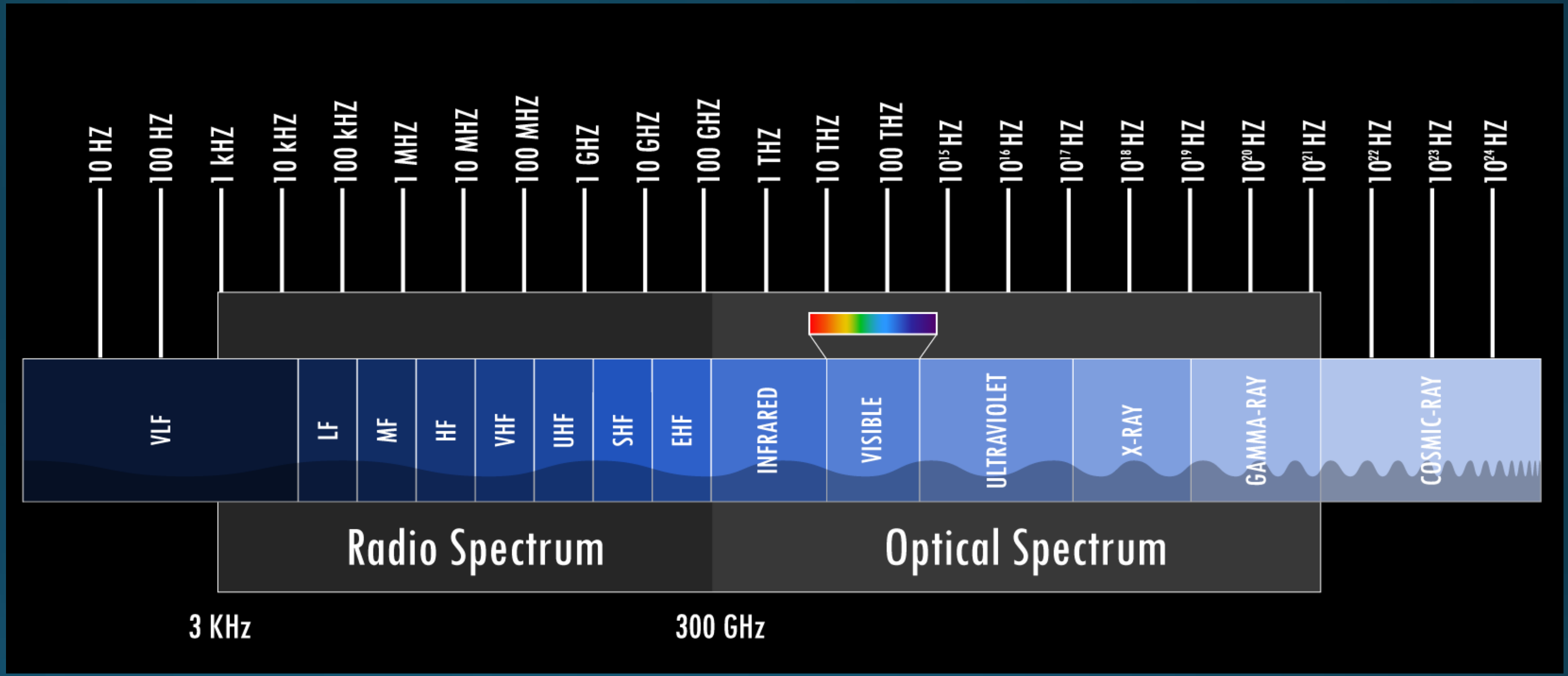
- **Advantages**
  - Higher bandwidth.
  - Less signal attenuation.
  - Resistance to corrosive materials.
  - Light weight.
  - Greater immunity to tapping.
- **Disadvantages**
  - Installation and maintenance.
  - Unidirectional light propagation.
  - Cost.

Applications

- Twisted-Pair
  - 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.
  - Local-area networks, such as 10Base-T and 100Base-T, also use twisted-pair cables.
- Coax
  - 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.
  - Used in traditional Ethernet LANs
  - Now a days mostly used in TV communication.
- Optical-Fibers
  - Used in backbone networks because its wide bandwidth is cost-effective.
  - In some TV communications.

Day 3 (27-07-2020)
ILO

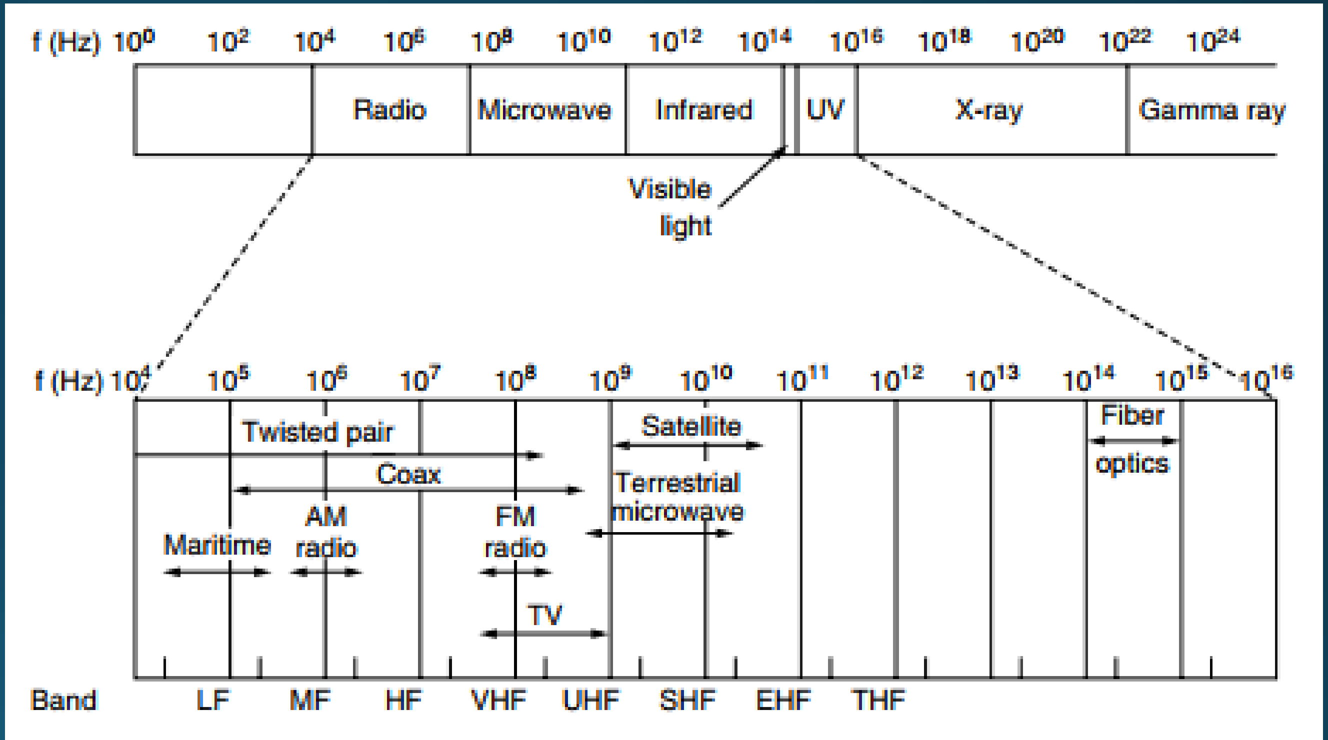
Upon the completion of todays lecture, students will be able to understand the differences between different unguided transmission mediums.



Unguided Medium(Wireless)

- **Unguided medium** transport electromagnetic waves without using a physical conductor. This type of communication is often referred to as ***wireless communication*.**
- Unlike guided transmission medium, in unguided, signals are normally broadcast through free space and thus are available to anyone who has a device capable of receiving them.

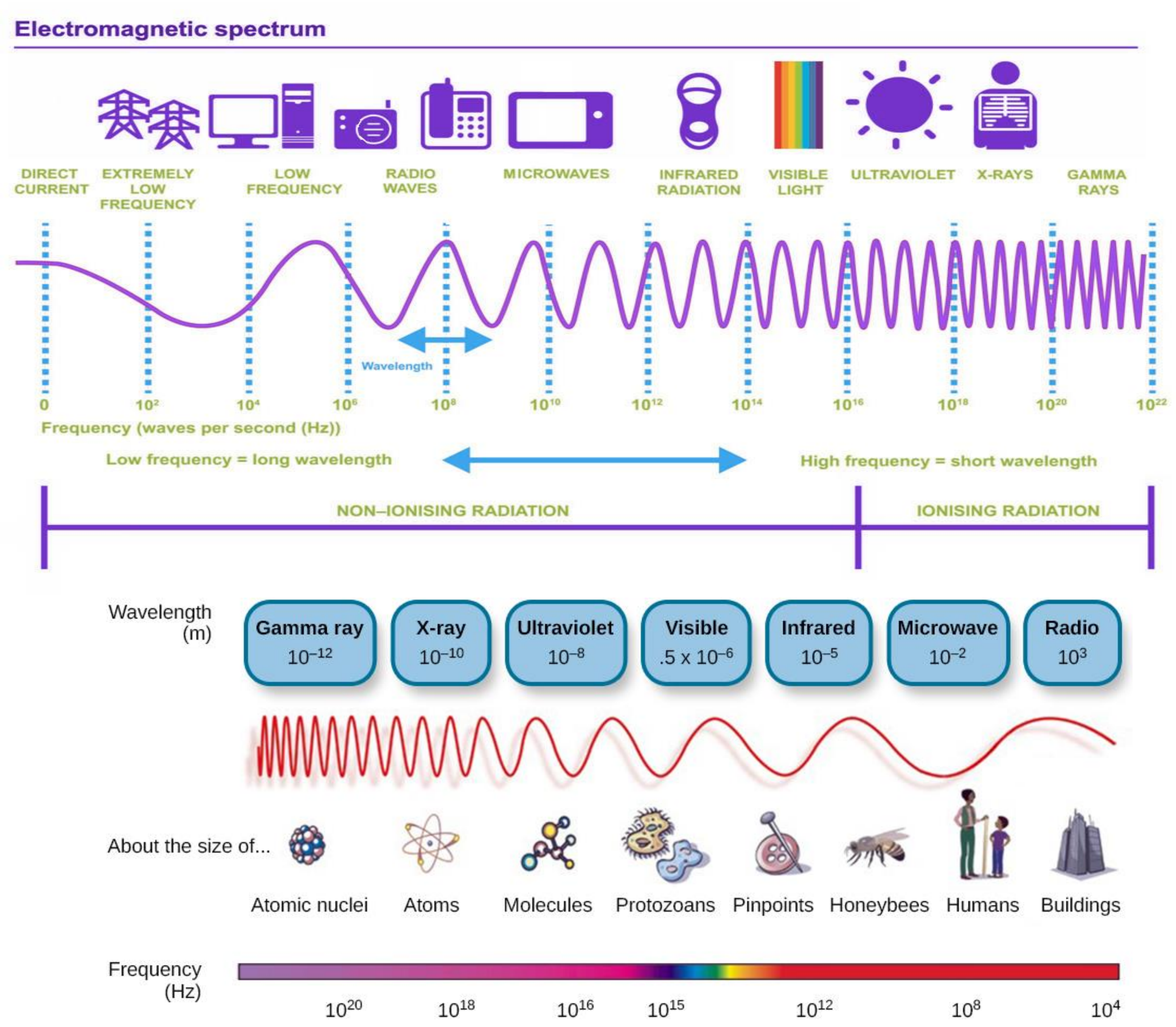
Background



f (Hz) 10^0 10^2 10^4 10^6 10^8 10^{10} 10^{12} 10^{14} 10^{16} 10^{18} 10^{20} 10^{22} 10^{24}
Radio
Microwave
Infrared
UV
X-ray
Gamma ray
Visible light
f (Hz) 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16}
Twisted pair
Coax
Satellite
Terrestrial microwave
Fiber optics
Maritime
AM radio
FM radio
TV
Band LF MF HF VHF UHF SHF EHF THF

Background

An **antenna** – usually 1/2 **wavelength** long

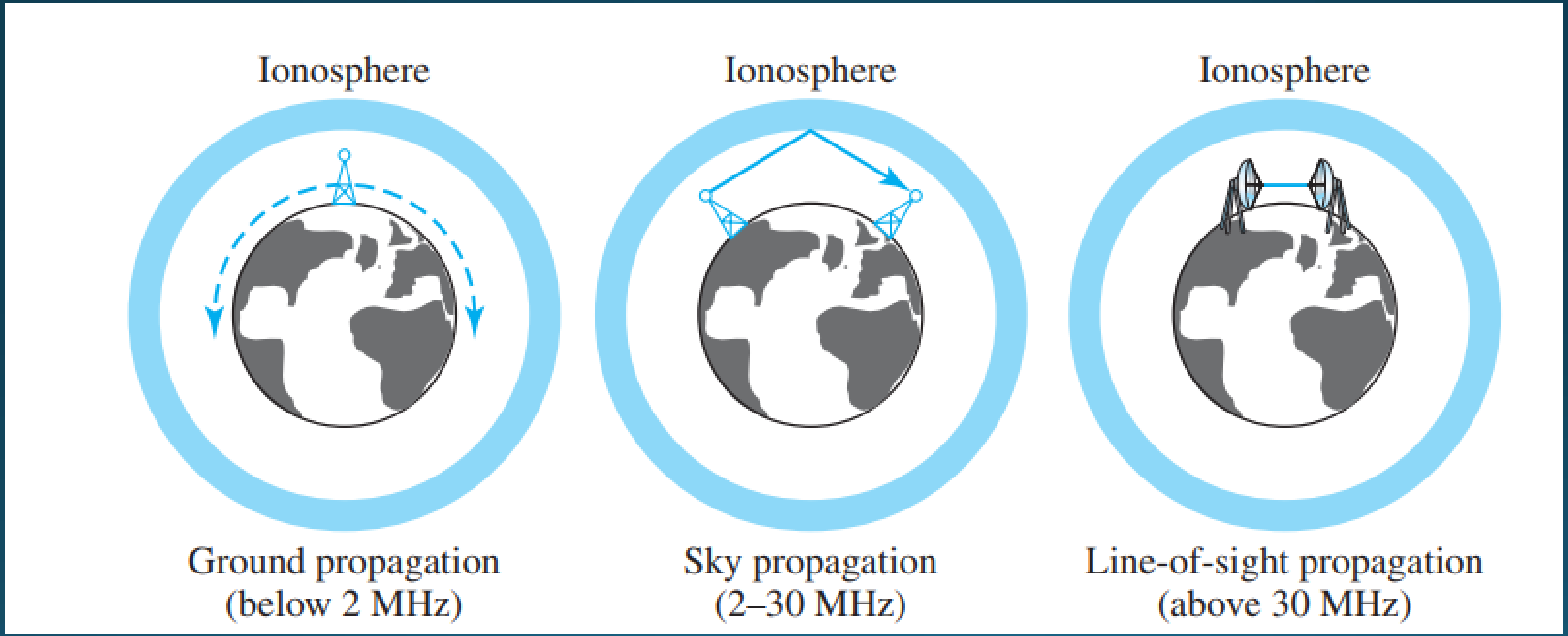


Background

- We can divide wireless transmission into three broad groups: radio waves, microwaves, and infrared waves.
- The section of the electromagnetic spectrum defined as radio waves and microwaves is divided into eight ranges, called *bands*, each regulated by government authorities. These bands are rated from *very low frequency* (VLF) to *extremely high frequency* (EHF).

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

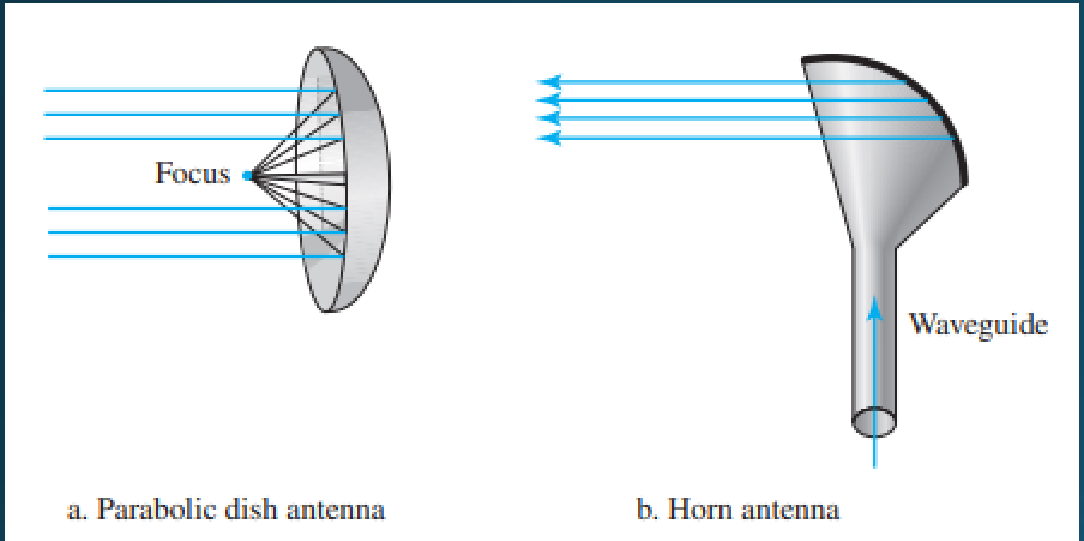
Wireless Propagation



Radio Waves (3kHz-1GHz)

- Although there is no clear-cut demarcation between radio waves and microwaves, however, the behavior of the waves, rather than the frequencies, is a better criterion for classification.
  - Adv: Radio waves, for the most part, are omnidirectional. When an antenna transmits radio waves, they are propagated in all directions.
  - Disadv: 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, particularly those waves that propagate in the sky mode, can travel long distances. This makes radio waves a good candidate for long-distance broadcasting such as AM radio.
- Radio waves, particularly those of low and medium frequencies, can penetrate walls.
- The radio wave band is relatively narrow, just under 1 GHz.

Microwaves(1GHz-300Ghz)



- Microwaves are unidirectional.
- Microwave propagation is line-of-sight.
- Use of certain portions of the band requires permission from authorities.
- Disadv: Very high-frequency microwaves cannot penetrate walls.
- Adv: The microwave band is relatively wide, almost 299 GHz. Therefore wider sub-bands can be assigned, and a high data rate is possible.

Infrared(300Ghz-400Thz)

- Used for short-range communication, can’t penetrate through walls.
- Not suitable for outside communication as the sun’s rays contain infrared waves that can interfere with the communication.

Applications

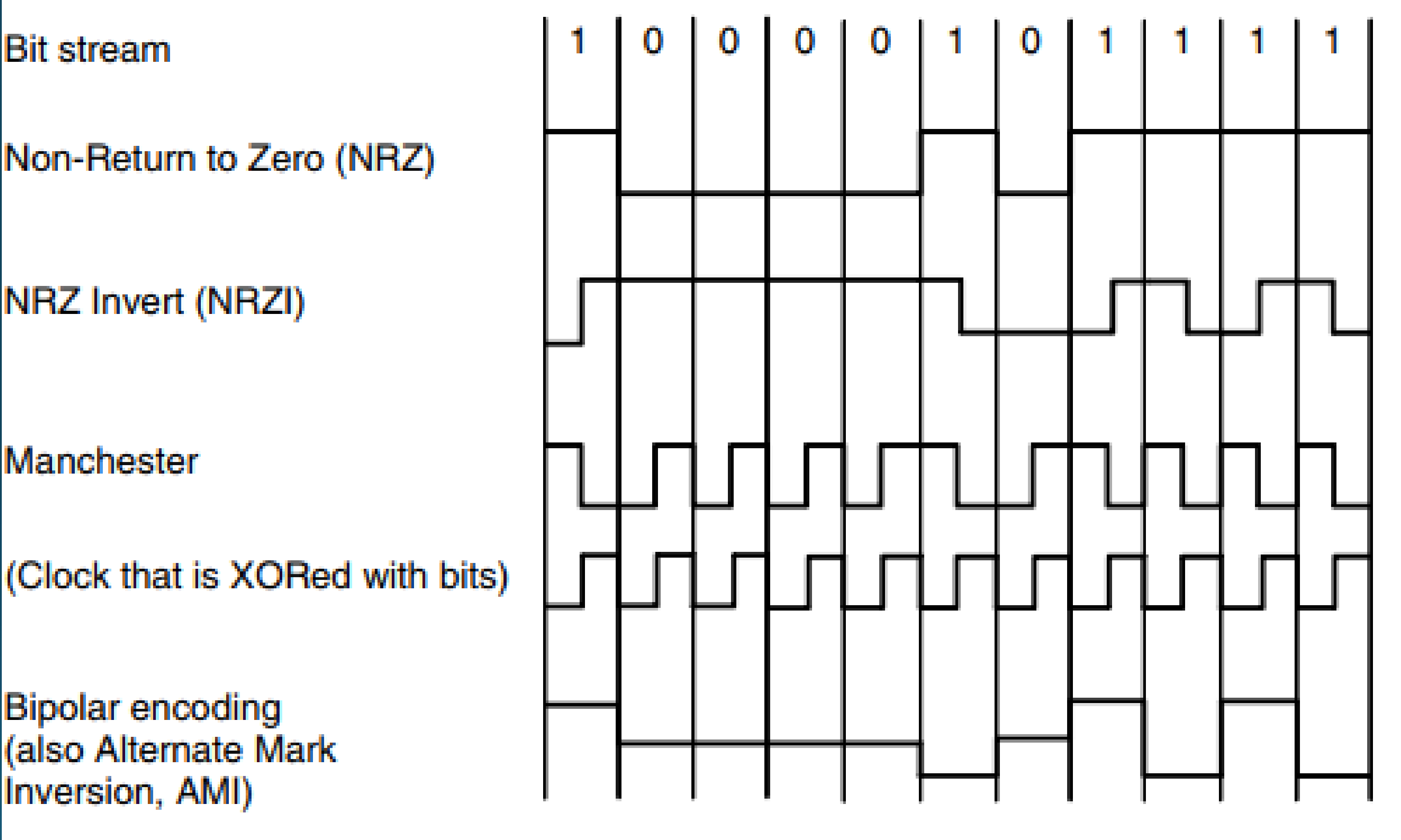
- Radio Waves:
  - The omnidirectional characteristics of radio waves make them useful for multicasting, in which there is one sender but many receivers.
  - Ex: AM and FM radio, television, maritime radio, cordless phones, and paging.
- Microwaves
  - Microwaves, due to their unidirectional properties, are very useful when unicast (one-to-one) communication is needed between the sender and the receiver.
  - Ex: Cellular phones, satellite networks, and wireless LANs.
- Infrared
  - The infrared band, almost 400 THz, has an excellent potential for data transmission.
  - Ex: Communication between devices such as keyboards, mice, PCs, printers, Mobiles using special ports.
  - One widely used application is in Remote Controllers.

Digital Modulation

- Wires and wireless channels carry analog signals such as continuously varying voltage, light intensity, or sound intensity. The process of converting between bits and signals that represent them is called **digital modulation.**
- **Two Schemes:**
  - **Baseband Transmission:** Directly convert bits into a signal.
  - **Passband Transmission:** Regulate the amplitude, phase, or frequency of a carrier signal to convey bits.

Baseband Transmission

The most straightforward form of digital modulation is to use a positive voltage to represent a 1 and a negative voltage to represent a 0. For an optical fiber, the presence of light might represent a 1 and the absence of light might represent a 0. This scheme is called **NRZ** (**Non-Return-to-Zero**).

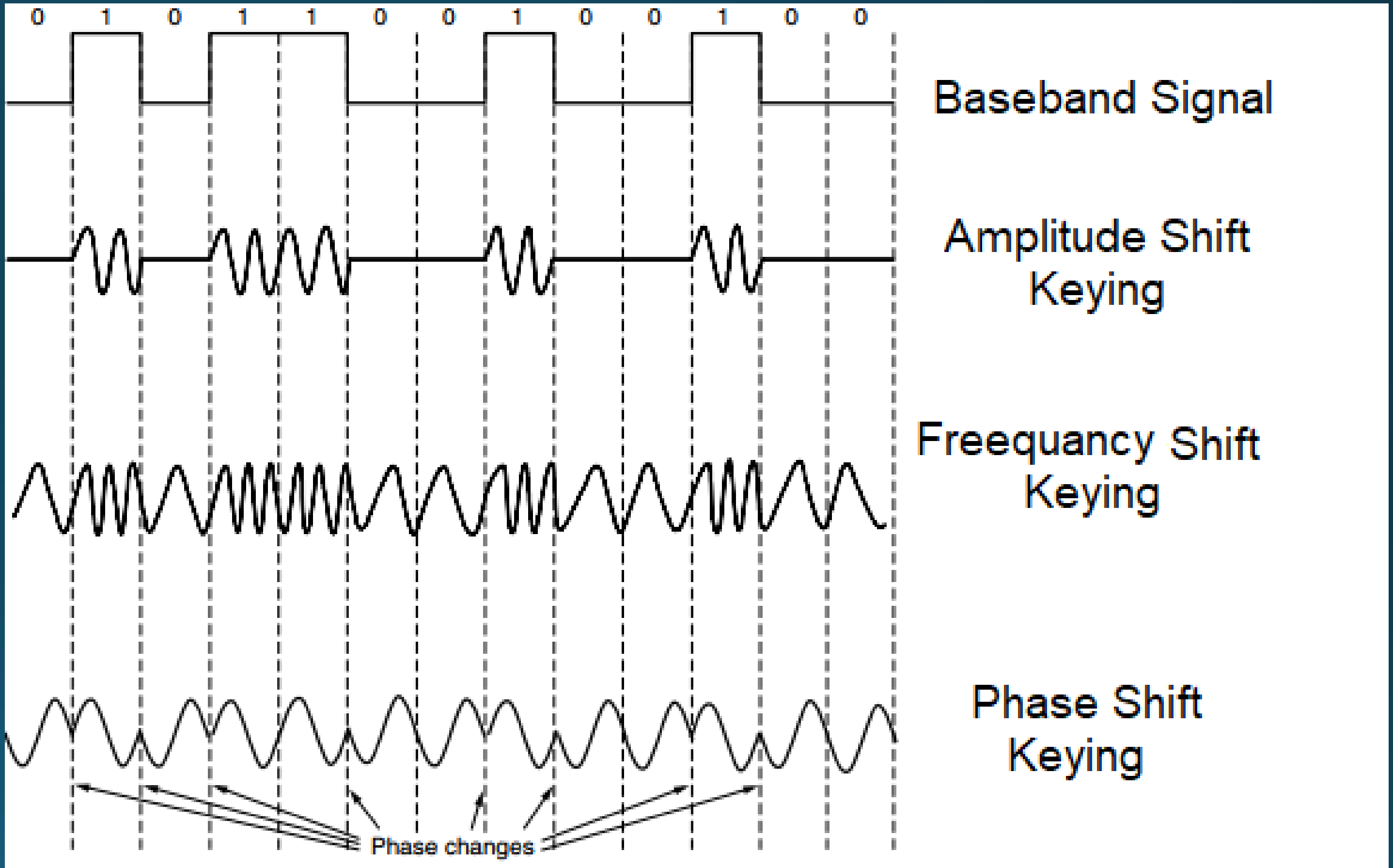


Baseband Transmission

- Clock Recovery: For all schemes that encode bits into symbols, the receiver must know when one symbol ends and the next symbol begins to correctly decode the bits. With NRZ, in which the symbols are simply voltage levels, a long run of 0s or 1s leaves the signal unchanged.
- Solution:
  - Sending a Separate Clock Signal.
  - Using encoding mechanisms that send clock along with data by mixing them together like Manchester encoding.
- Balanced Signal: Signals that have as much positive voltage as negative voltage even over short periods of time are called **balanced signals**.
  - Provide transitions for clock recovery.
  - Provides a simple way to calibrate receivers.

Passband Transmission

- Often, we want to use a range of frequencies that does not start at zero to send information across a channel. For wireless channels, it is not practical to send very low frequency signals because the size of the antenna needs to be a fraction of the signal wavelength, which becomes large.
- That we can take a **baseband** signal that occupies 0 to *B* Hz and shift it up to occupy a **passband** of *S* to *S* +*B* Hz without changing the amount of information that it can carry.
- When the receiver gives importance to carrier as major factor for detection then it is called as coherent detection otherwise non coherent detection.

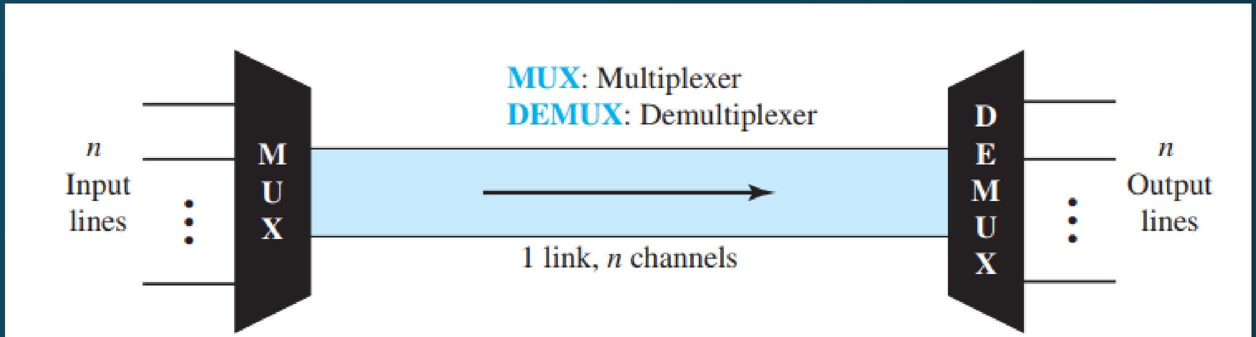


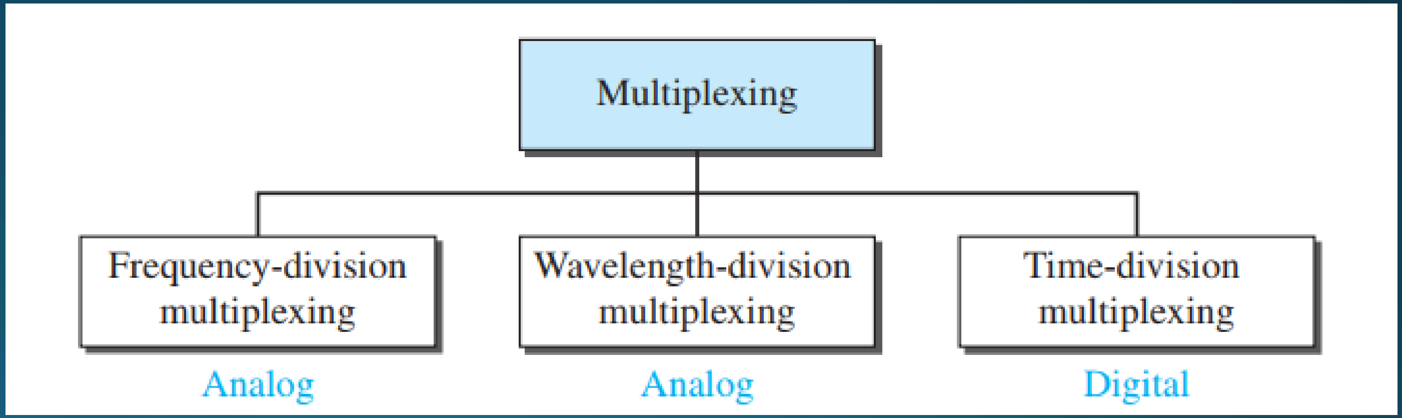
Day 4 & Day 5 (29-07-2020 & 06-08-2020) :ILO

Upon the completion of lecture, students will be able to understand the differences between different multiplexing techniques.

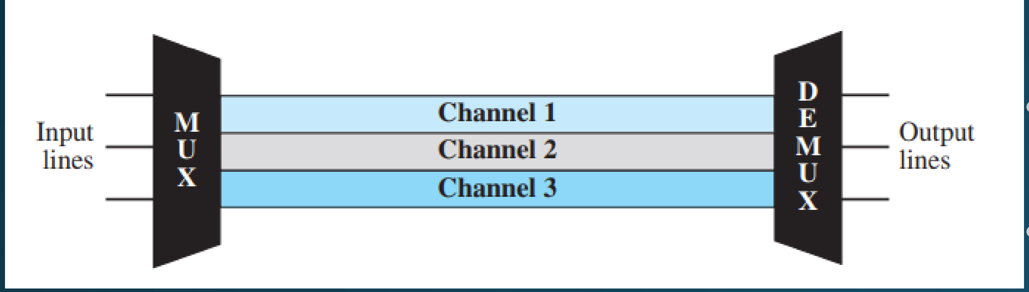
Multiplexing

- **Multiplexing** is the set of techniques that allow the simultaneous transmission of multiple signals across a single data link.
- In a multiplexed system, *n* lines share the bandwidth of one link.

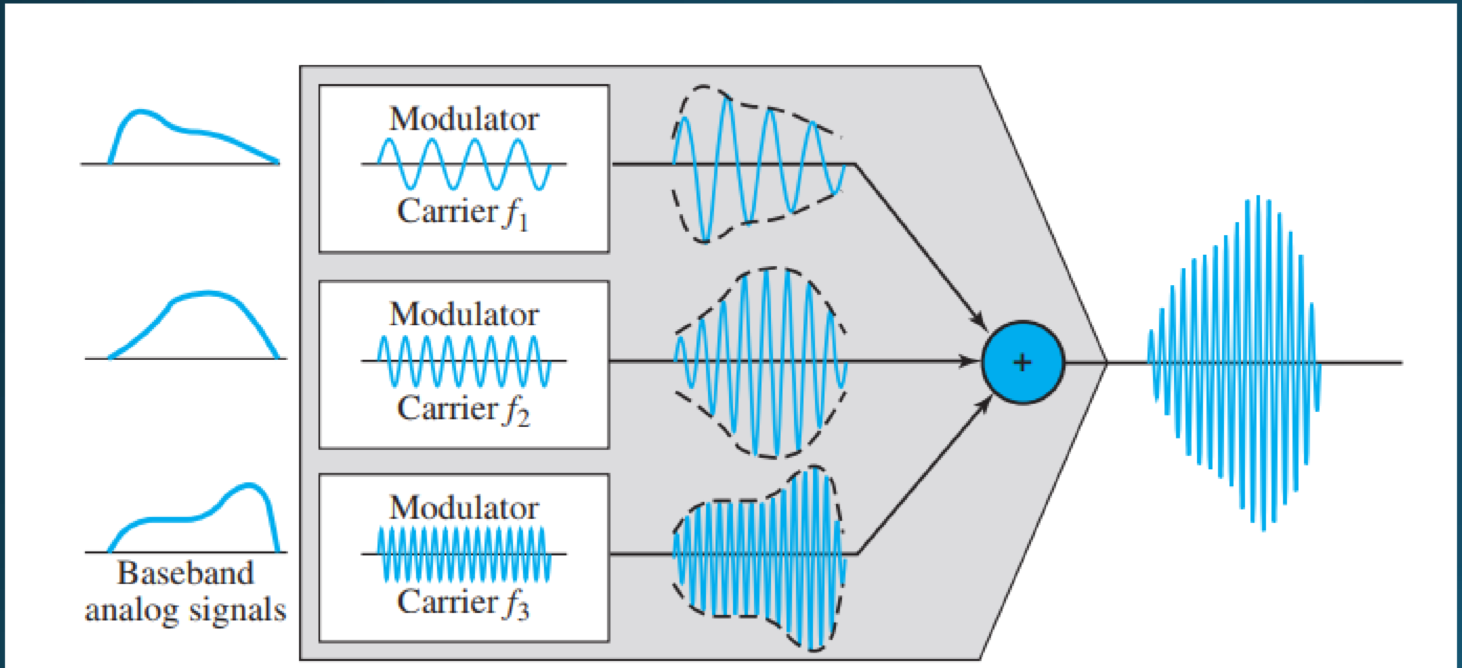




Frequency-Division Multiplexing

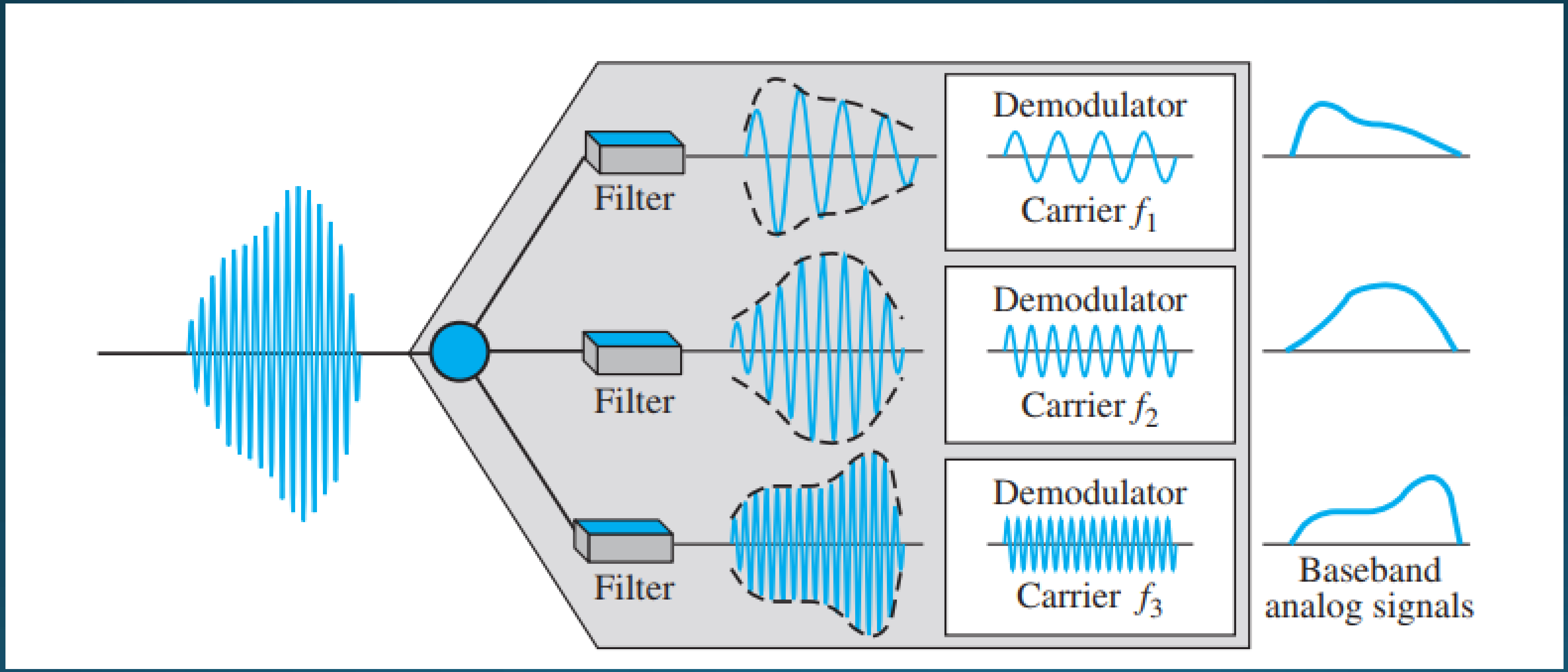


- **Frequency-division multiplexing (FDM)** is an analog technique that can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted.
- In FDM, signals generated by each sending device modulate different carrier frequencies and combined into single composite signal.
- Carrier frequencies are separated by sufficient bandwidth to accommodate the modulated signal.
- Channels can be separated by strips of unused bandwidth—**guard bands**—to prevent signals from overlapping.



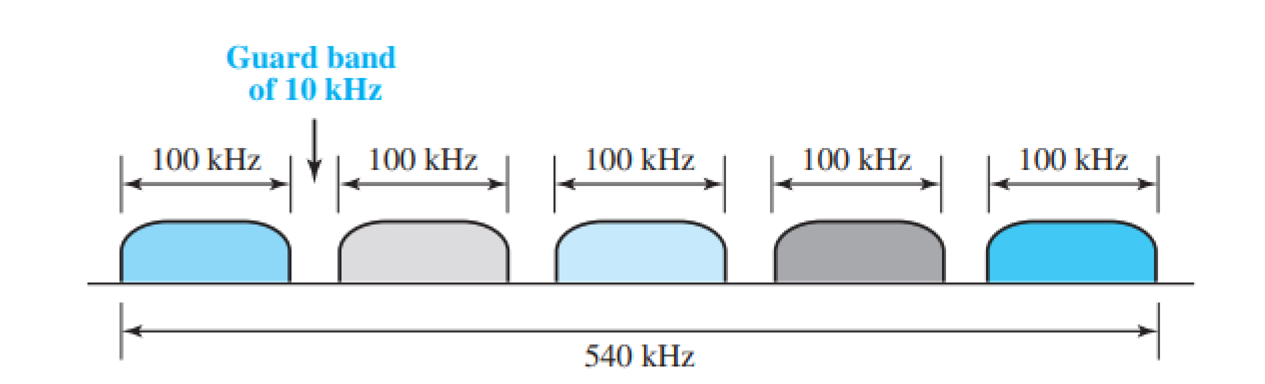
FDM Multiplexing

FDM Demultiplexing



Problems

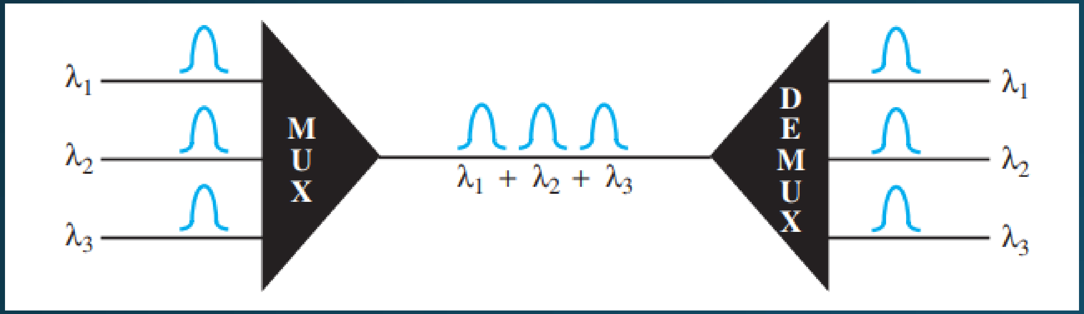
- Q: Five channels, each with a 100-kHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10 kHz between the channels to prevent interference?
- Sol: For five channels, we need at least four guard bands. This means that the required bandwidth is at least $5 \times 100 + 4 \times 10 = 540$ kHz.



Problems

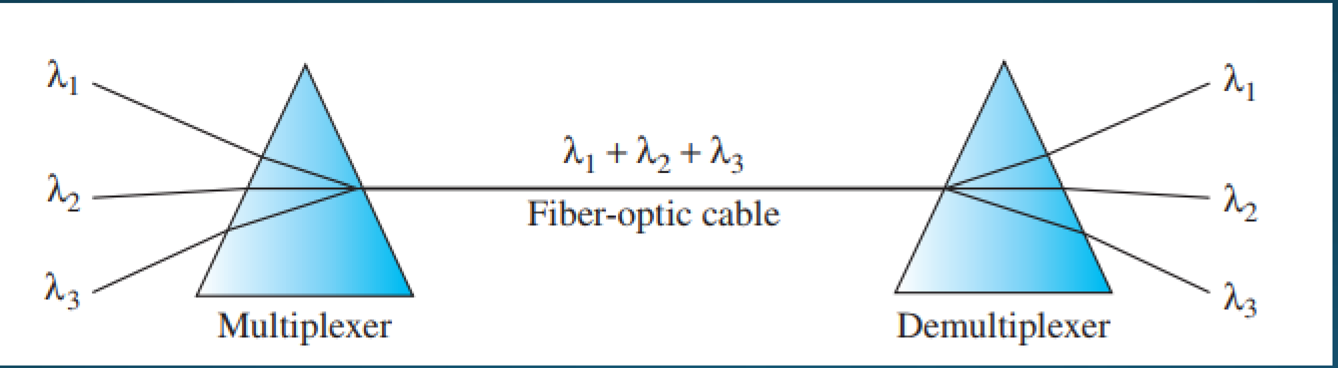
- Q: Four data channels (digital), each transmitting at 1 Mbps, use a satellite channel of 1 MHz. Design an appropriate configuration, using FDM.
- Sol:
  - The satellite channel is analog of 1MHz.
  - We need four channels so each channel haves a 250-kHz bandwidth.
  - B=250 kHz, max data rate=1 Mbps
  - So Data rate=2*B*$\log_2$ (L)

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 idea is the same: We are combining different signals of different frequencies. The difference is that the frequencies are very high.

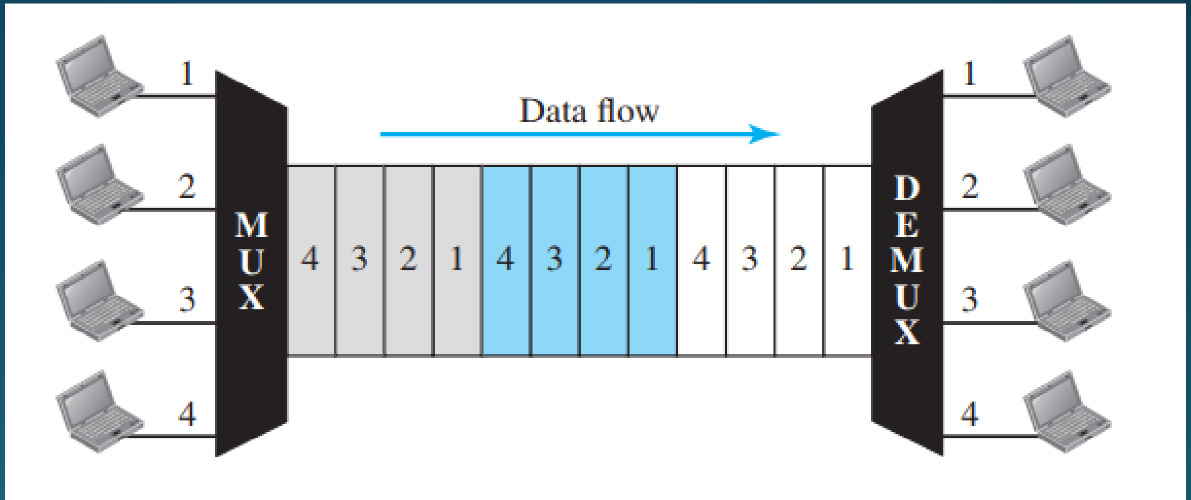
Wavelength-Division Multiplexing



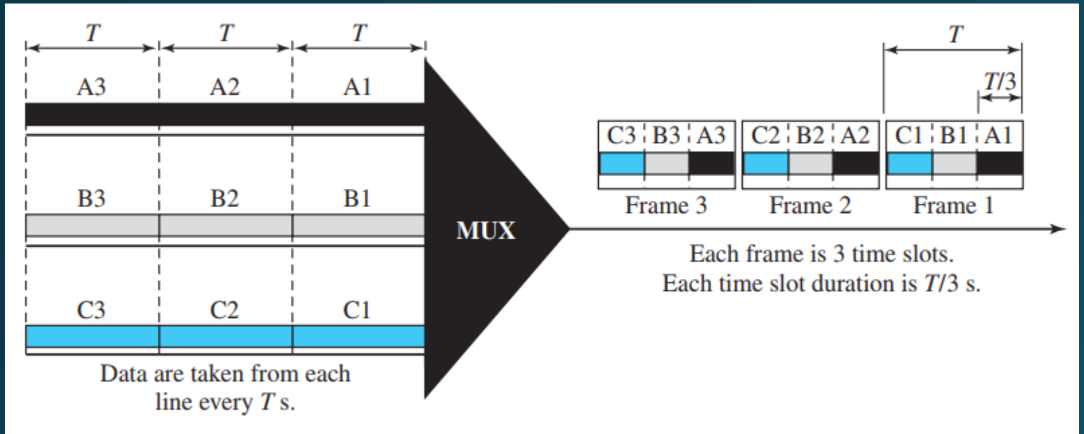
Time-Division Multiplexing

Two different schemes:
Synchronous TDM
Statistical/Asynchronous TDM

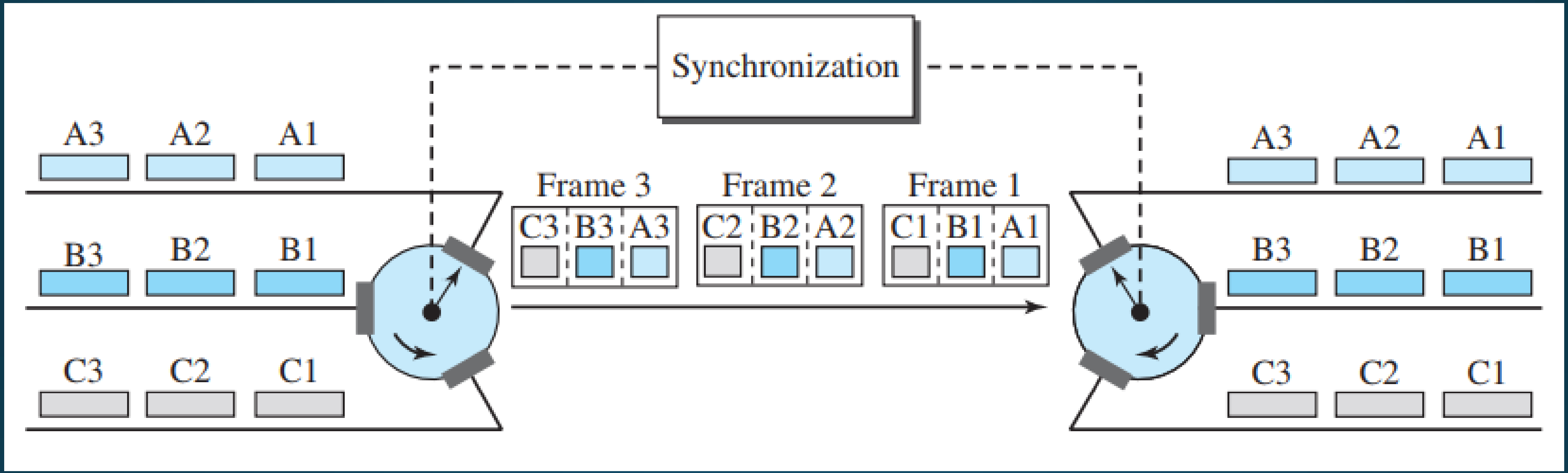
- **Time-division multiplexing (TDM)** is a digital process that allows several connections to share the high bandwidth of a link.
- Instead of sharing a portion of the bandwidth as in FDM, time is shared. Each connection occupies a portion of time in the link.



Synchronous TDM



- In synchronous TDM, each input connection has an allotment in the output even if it is not sending data.
- The data flow of each input connection is divided into units, where each input occupies one input time slot.
- Each input unit becomes one output unit and occupies one output time slot. However, the duration of an output time slot is n times shorter than the duration of an input time slot.
- If an input time slot is T s, the output time slot is T/n s, where n is the number of connections.
- The data rate of the output link must be n times the data rate of a connection to guarantee the flow of data.
- In synchronous TDM, a round of data units from each input connection is collected into a frame.



Synchronous TDM-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.

Ex Problems

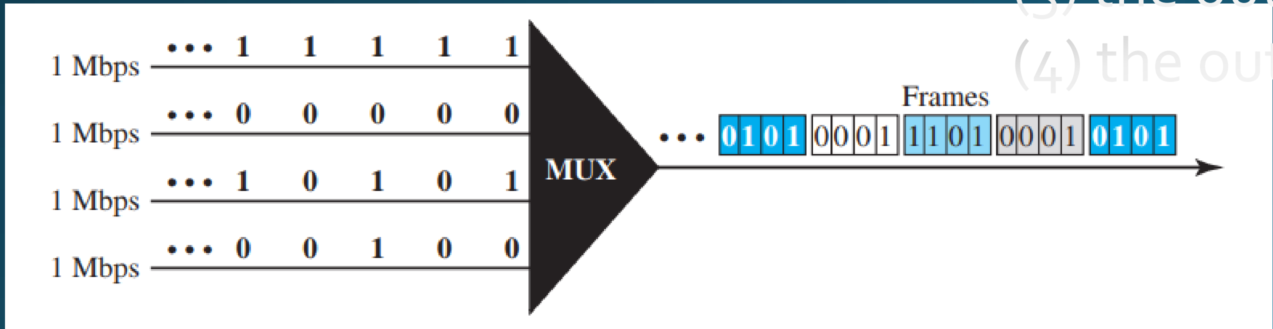
- Figure shows synchronous TDM with a data stream for each input and one data stream for the output. The unit of data is 1 bit. Find

(1) the input bit duration

(2) the output bit duration

(3) the output bit rate

(4) the output frame rate.

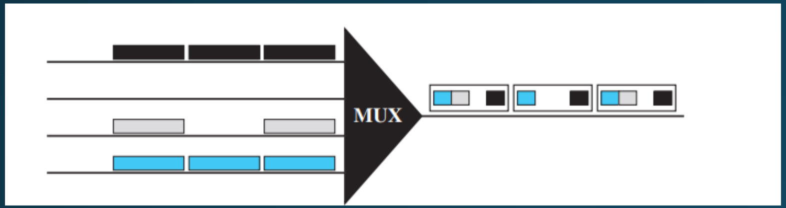


Problems

Q. Four channels are multiplexed using TDM. If each channel sends 100 bytes/s and we multiplex 1 byte per channel, show the frame traveling on the link, the size of the frame, the duration of a frame, the frame rate, and the bit rate for the link.

Q. 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?

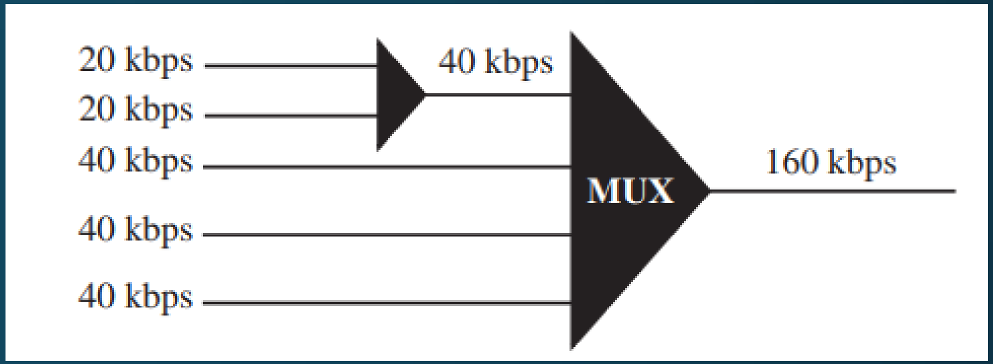
Synchronous TDM

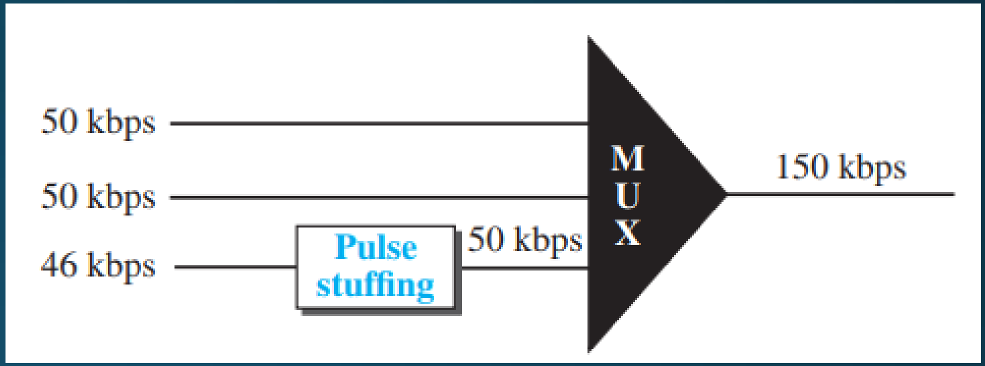


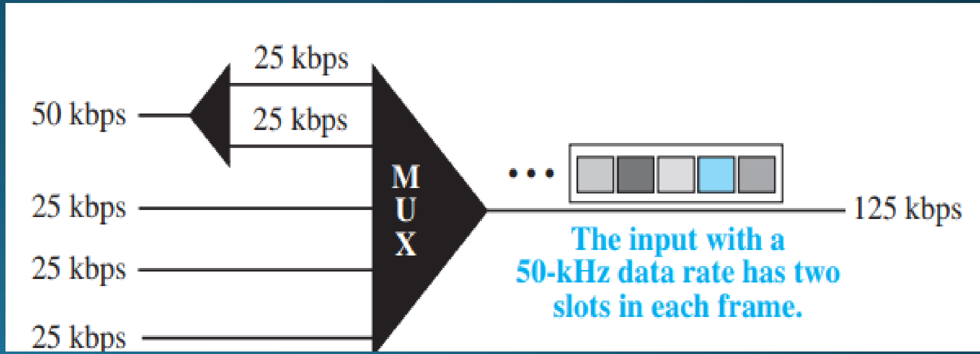
- Disadvantages:
  - If a source does not have data to send, the corresponding slot in the output frame is empty.
  - Disparity is input data rates

Synchronous TDM

- If data rates are not the same, three strategies, or a combination of them, can be used. We call these three strategies:
  - **Multilevel multiplexing**
  - **Multiple-slot allocation**
  - **Pulse stuffing.**
- The implementation of TDM is not as simple as that of FDM. Synchronization between the multiplexer and demultiplexer is a major issue. For this reason, one or more synchronization bits are usually added to the beginning of each frame.

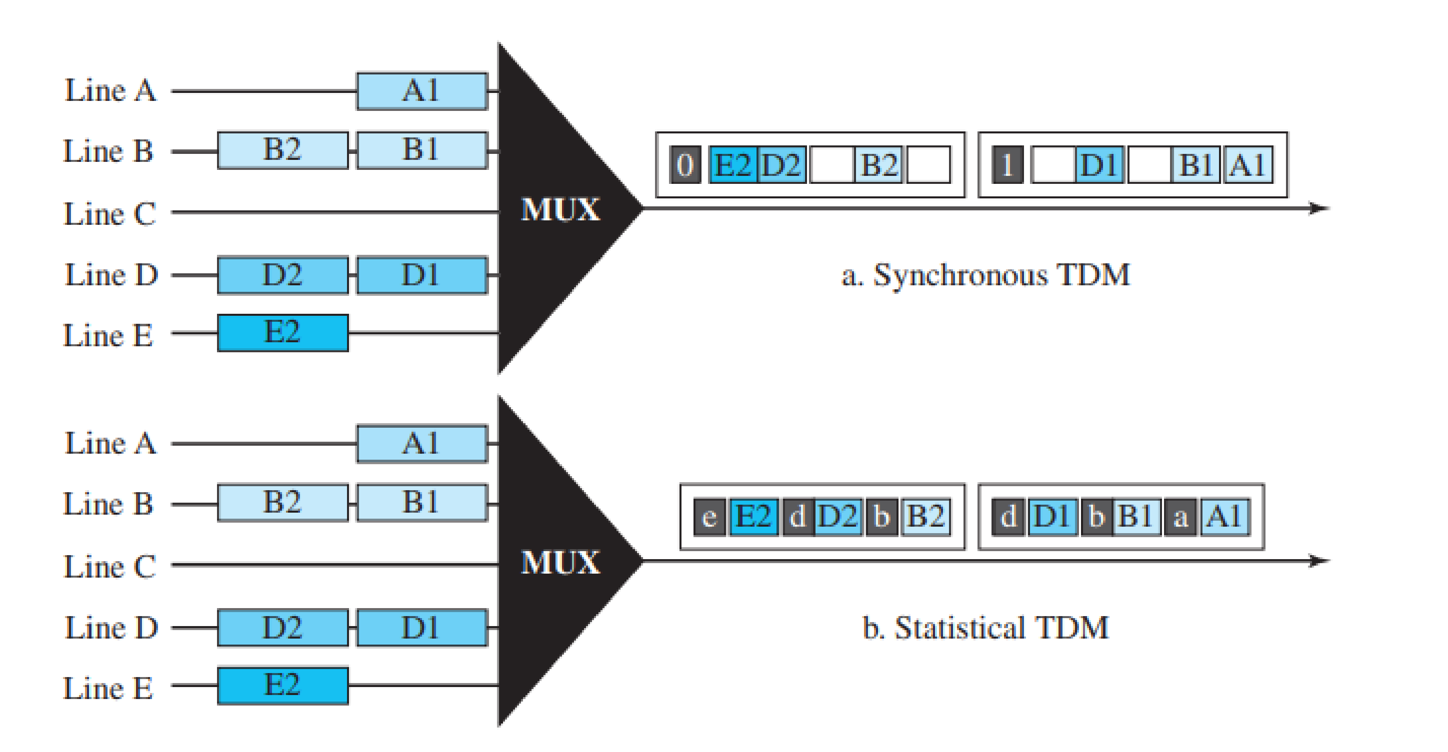






Statistical TDM

In statistical time-division multiplexing, slots are dynamically allocated to improve bandwidth efficiency.



Statistical TDM

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.

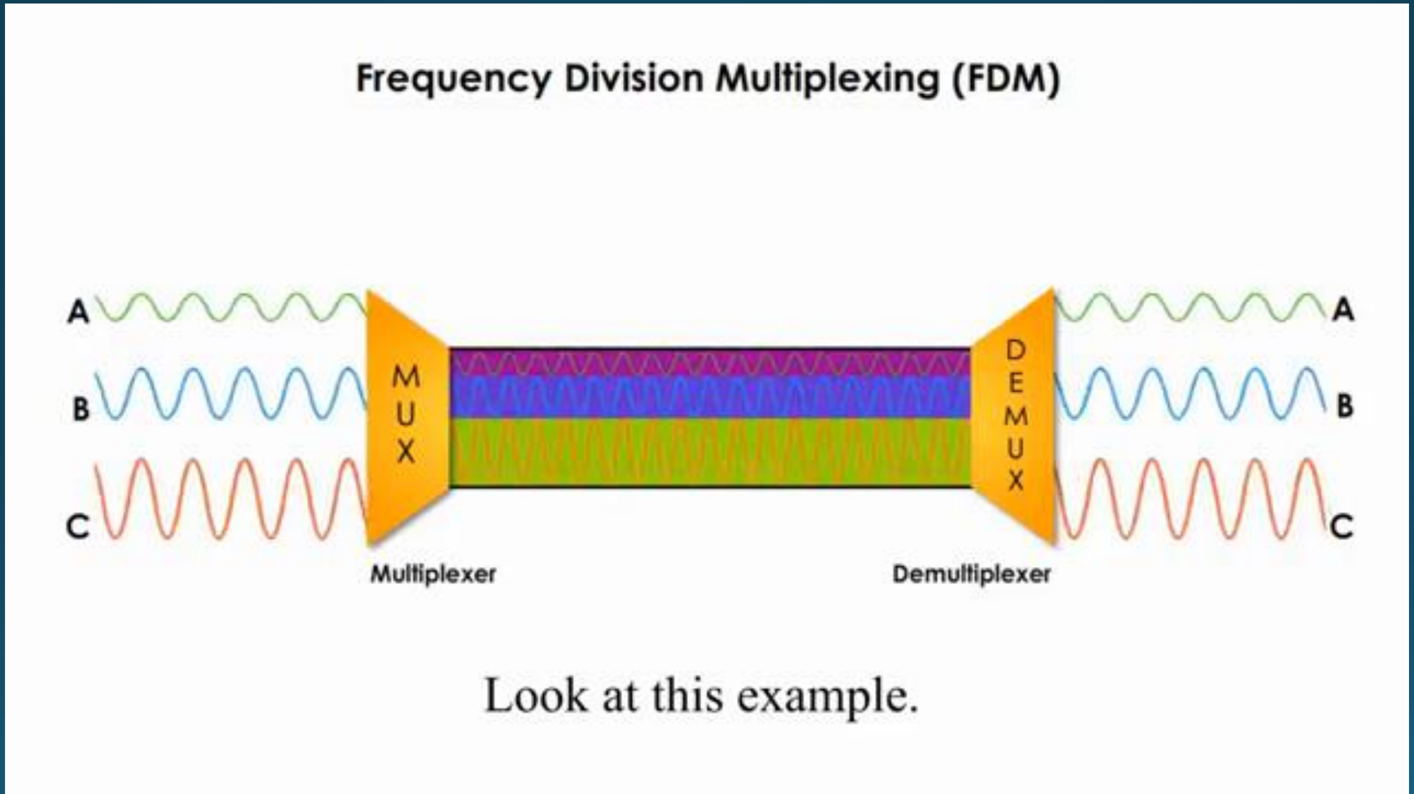
It allocates a slot for an input line if the line has data to send, otherwise, it skips the line and checks the next line.

Statistical TDM

- ***Addressing:*** In statistical TDM, a slot needs to carry data as well as the address of the destination.
- ***Slot Size:*** Since a slot carries both data and an address in statistical TDM, the ratio of the data size to address size must be reasonable to make transmission efficient.
- ***No Synchronization Bit***
- ***Bandwidth:*** the capacity of the link is normally less than the sum of the capacities of each channel.

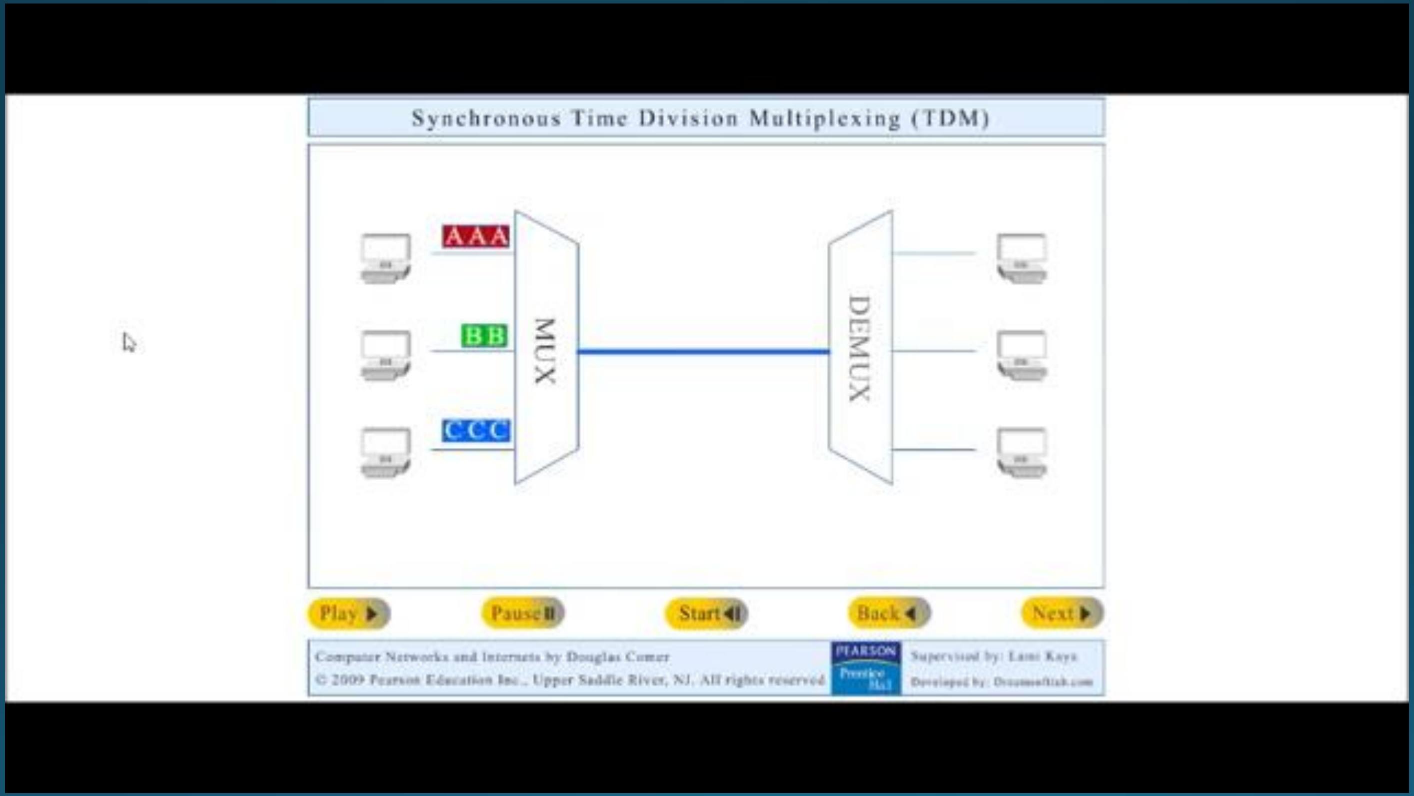
FDM

FDM

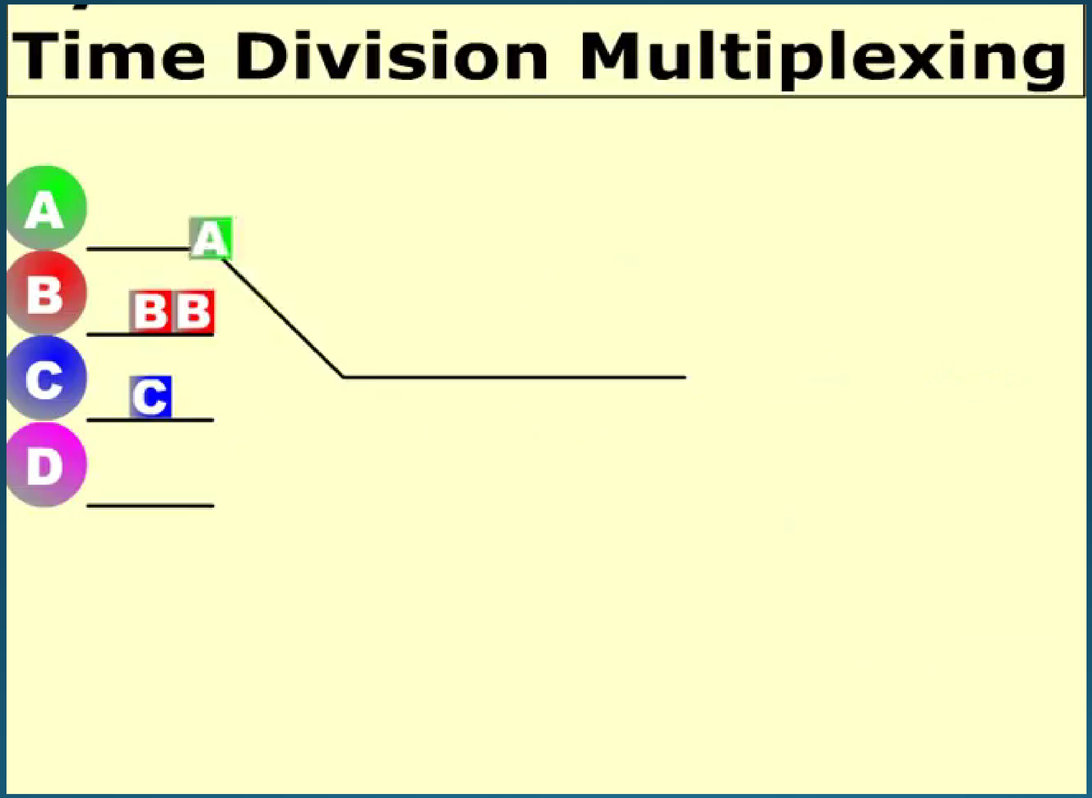


Frequency Division Multiplexing (FDM)
A
B
C
MUX
DEMUX
A
B
C
Multiplexer
Demultiplexer
Look at this example.

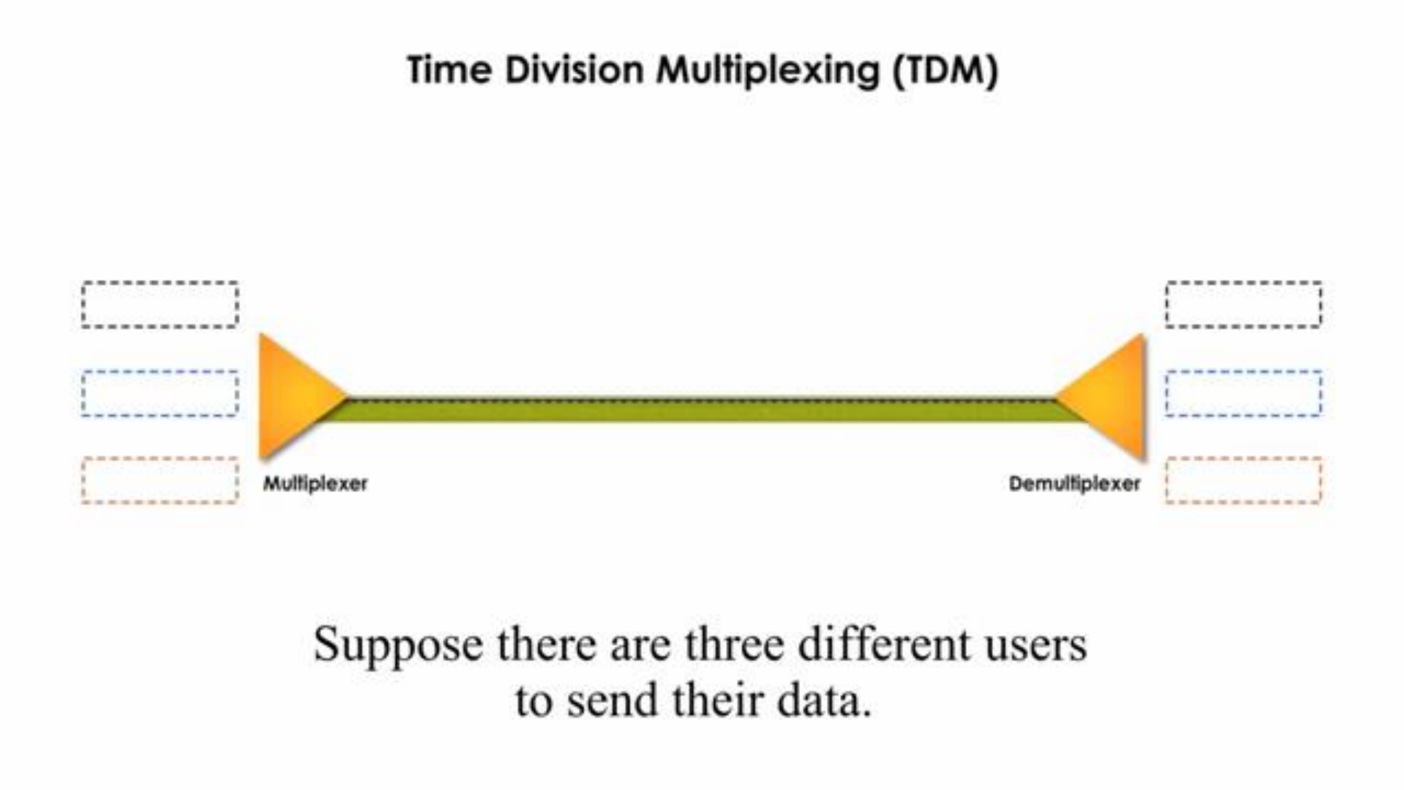
Synchronous TDM



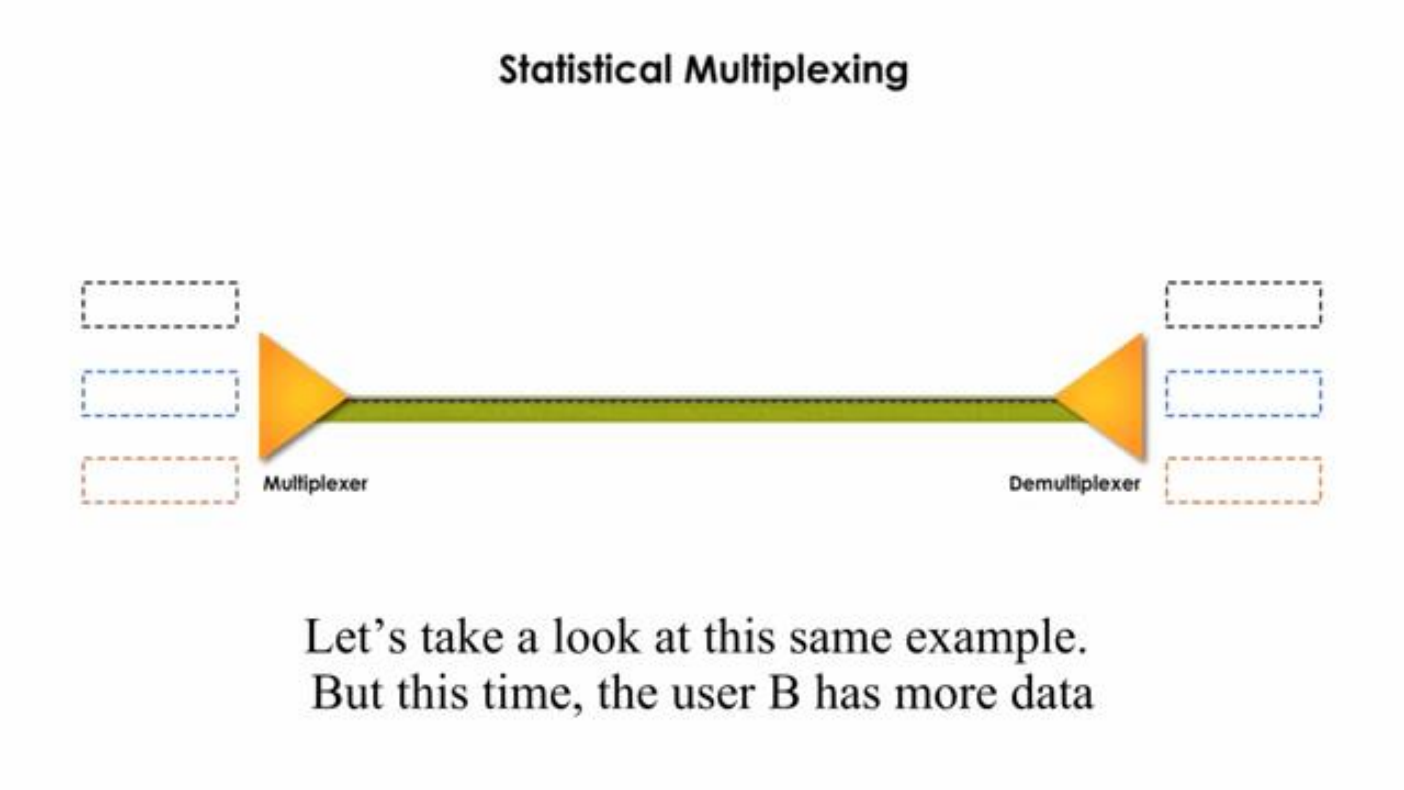
Synchronous TDM



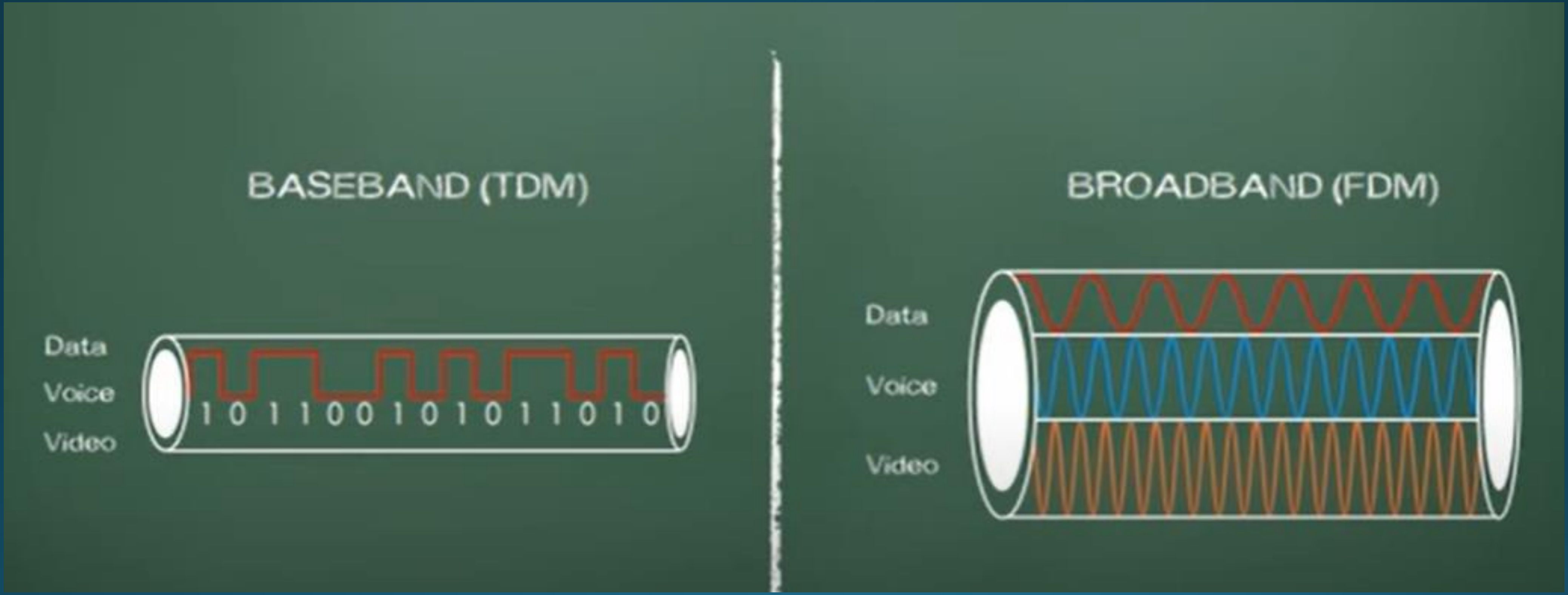
Synchronous TDM



Asynchronous TDM



TDM vs FDM


BASEBAND (TDM)
Data
Voice
Video
1 0 1 1 0 0 1 0 1 0 1 1 0 1 0
BROADBAND (FDM)
Data
Voice
Video

FDM Problems

- Assume that a voice channel occupies a bandwidth of 4 kHz. We need to multiplex 10 voice channels with guard bands of 500 Hz using FDM. Calculate the required bandwidth.
- Ten signals, each requiring 4000 Hz, are multiplexed onto a single channel using FDM. What is the minimum bandwidth required for the multiplexed channel? Assume that the guard bands are 400 Hz wide.
- Four data channels (digital), each transmitting at 1 Mbps, use a satellite channel of 1 MHz. Design an appropriate configuration, using FDM.

TDM Problems

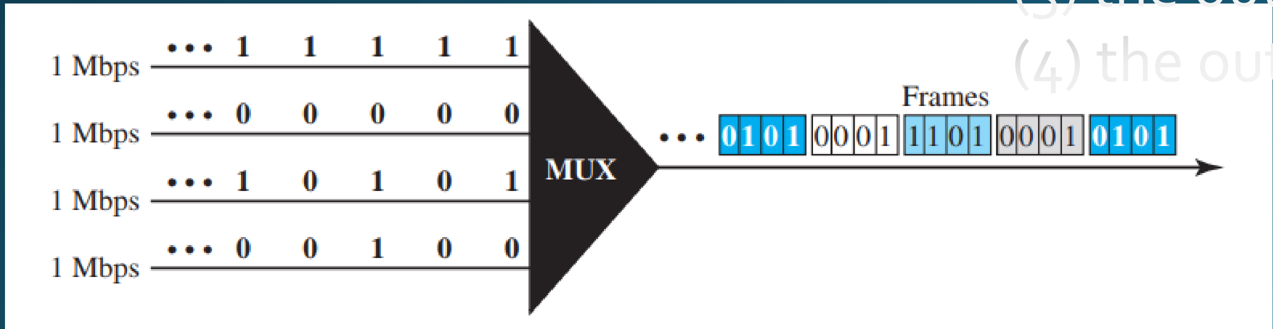
- Figure shows synchronous TDM with a data stream for each input and one data stream for the output. The unit of data is 1 bit. Find

(1) the input bit duration

(2) the output bit duration

(3) the output bit rate

(4) the output frame rate.



Syn TDM Problems

- We need to use synchronous TDM and combine 20 digital sources, each of 100 Kbps. Each output slot carries 1 bit from each digital source, but one extra bit is added to each frame for synchronization. Answer the following questions:
  - a. What is the size of an output frame in bits?
  - b. What is the output frame rate?
  - c. What is the duration of an output frame?
  - d. What is the output data rate?
  - e. What is the efficiency of the system (ratio of useful bits to the total bits)
- We need to use synchronous TDM and combine 20 digital sources, each of 100 Kbps. Each output slot carries 2 bit from each digital source. Answer the following questions:
  - a. What is the size of an output frame in bits?
  - b. What is the output frame rate?
  - c. What is the duration of an output frame?
  - d. What is the output data rate?
  - e. What is the efficiency of the system (ratio of useful bits to the total bits)

Syn TDM Problems

- Four channels are multiplexed using TDM. If each channel sends 100 bytes/s and we multiplex 1 byte per channel, show the frame traveling on the link, the size of the frame, the duration of a frame, the frame rate, and the bit rate for the link.
- A multiplexer combines four 100-kbps channels using a time slot of 2 bits. What is the frame rate? What is the frame duration? What is the bit rate? What is the bit duration?

Asyn TDM Problems

- We have 14 sources, each creating 500 8-bit characters per second. Since only some of these sources are active at any moment, we use statistical TDM to combine these sources using character interleaving. Each frame carries 6 slots at a time, but we need to add 4-bit addresses to each slot. Answer the following questions:
    - a. What is the size of an output frame in bits?
    - b. What is the output frame rate?
    - c. What is the duration of an output frame?
    - d. What is the output data rate?

More Problems on TDM

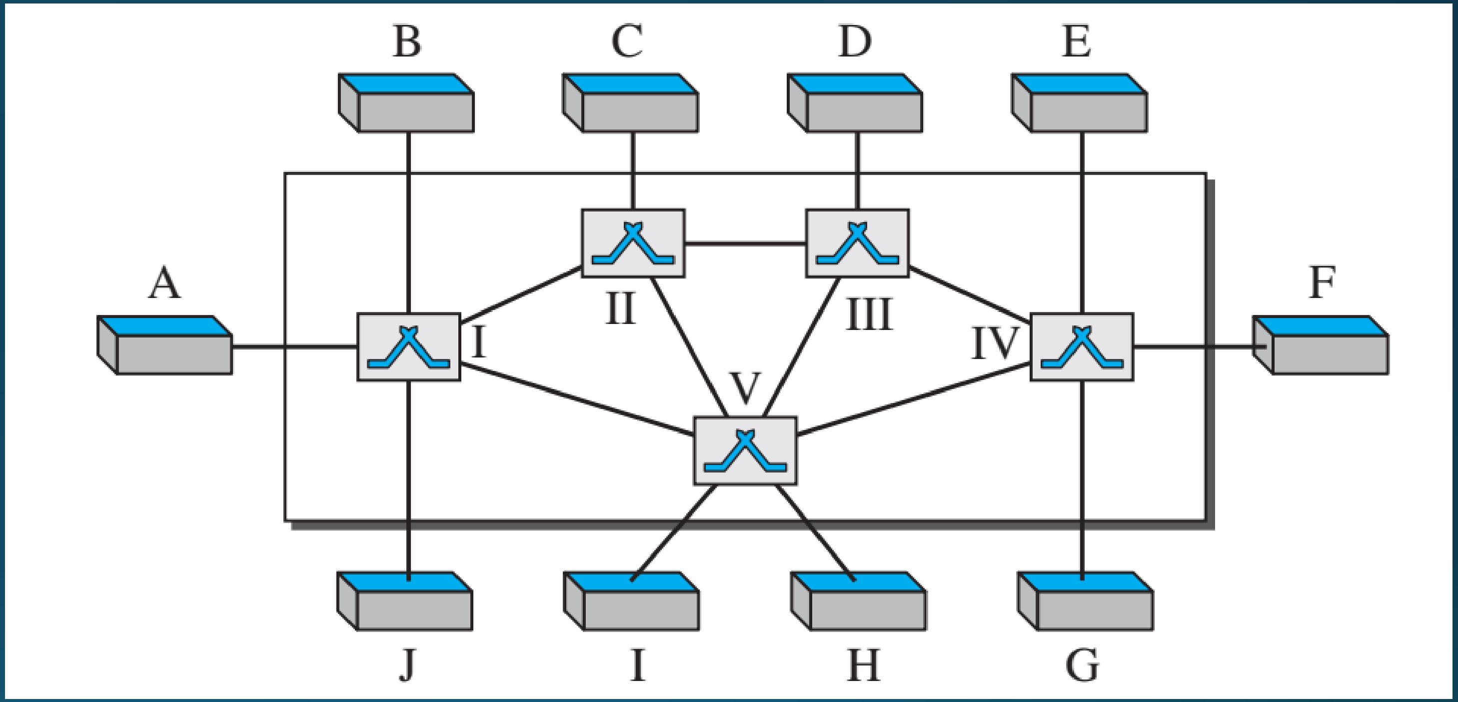
- Ten sources, six with a bit rate of 200 kbps and four with a bit rate of 400 kbps, are to be combined using multilevel TDM with no synchronizing bits. Answer the following questions about the final stage of the multiplexing:
  - a. What is the size of a frame in bits?
  - b. What is the frame rate?
  - c. What is the duration of a frame?
  - d. What is the data rate?

More Problems on TDM

- Four channels, two with a bit rate of 200 kbps and two with a bit rate of 150 kbps, are to be multiplexed using multiple-slot TDM with no synchronization bits. Answer the following questions:
  - a. What is the size of a frame in bits?
  - b. What is the frame rate?
  - c. What is the duration of a frame?
  - d. What is the data rate?

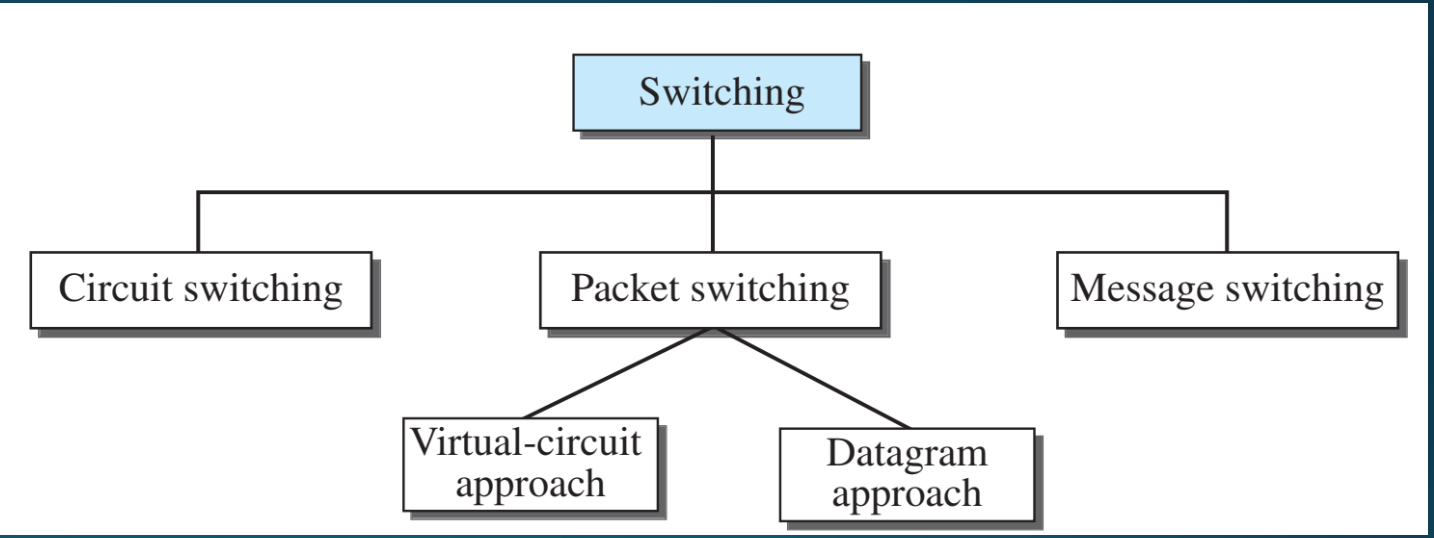
Switching

- A network is a set of connected devices. Whenever we have multiple devices, we have the problem of how to connect them to make one-to-one communication possible.
- A better solution is **switching.** A switched network consists of a series of interlinked nodes, called ***switches*.** Switches are devices capable of creating temporary connections between two or more devices linked to the switch.

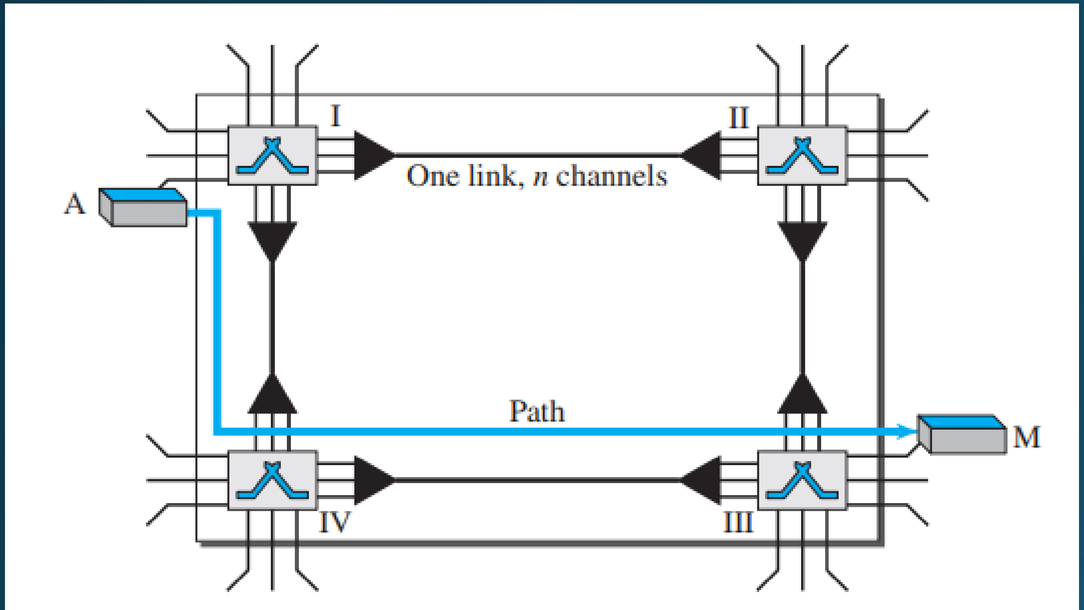


Switching

- ***Switching at Physical Layer-***At the physical layer, we can have only circuit switching.
- ***Switching at Data-Link Layer-*** At the data-link layer, we can have packet switching. However, the term *packet* in this case means *frames* or *cells*.
- ***Switching at Data-Link Layer-***At the data-link layer, we can have packet switching. However, the term *packet* in this case means *frames* or *cells*.
- ***Switching at Application Layer-***At the application layer, we can have only message switching.



Circuit-switched Networks



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

Circuit-switched Networks

- 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.
- Data transferred between the two stations are not packetized, it is a continuous flow.
- There is no addressing involved during data transfer.
- Circuit-switched network normally implemented in the physical layer

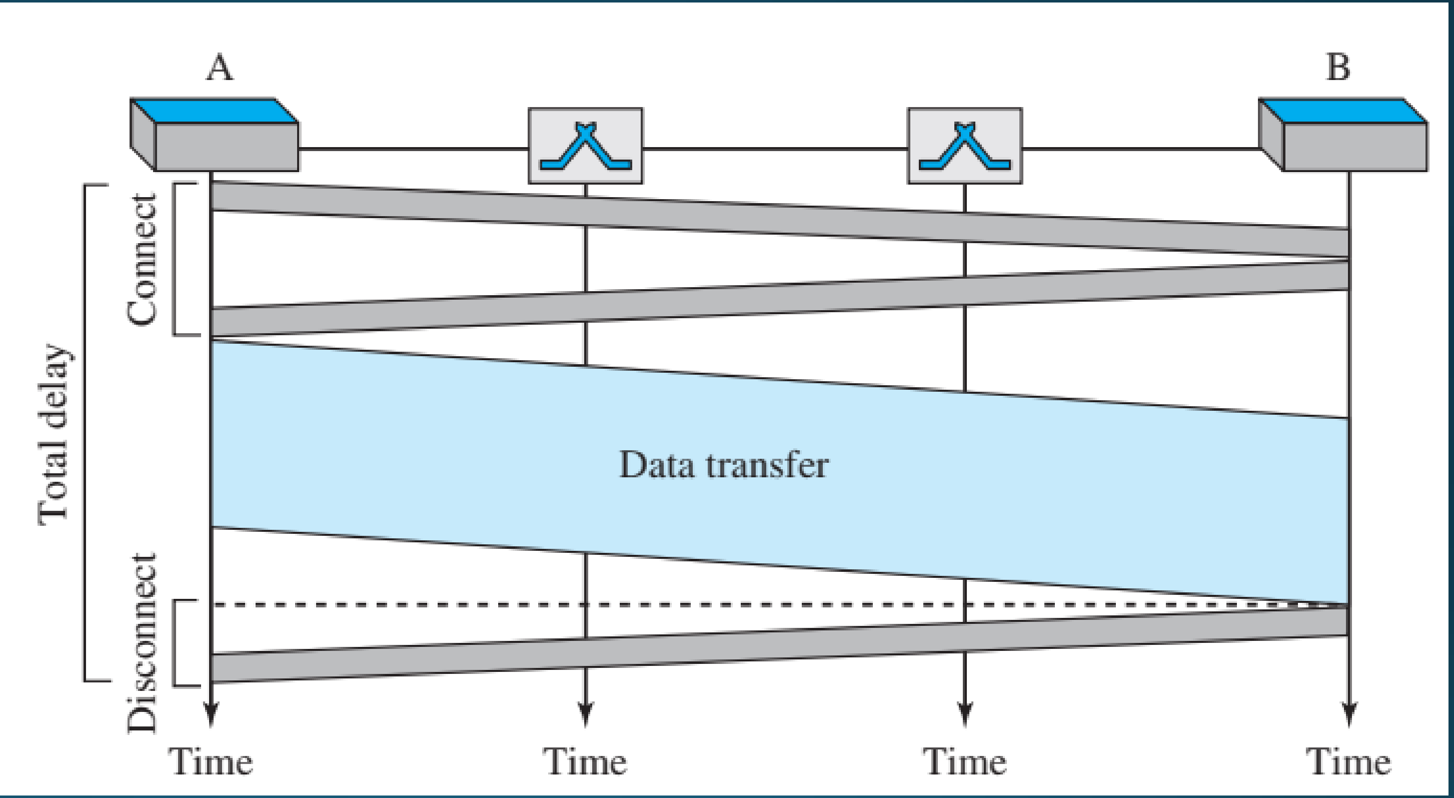
Circuit-switched Networks

- Three phases:
  - Setup Phase
  - Data Transfer Phase
  - Teardown Phase

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

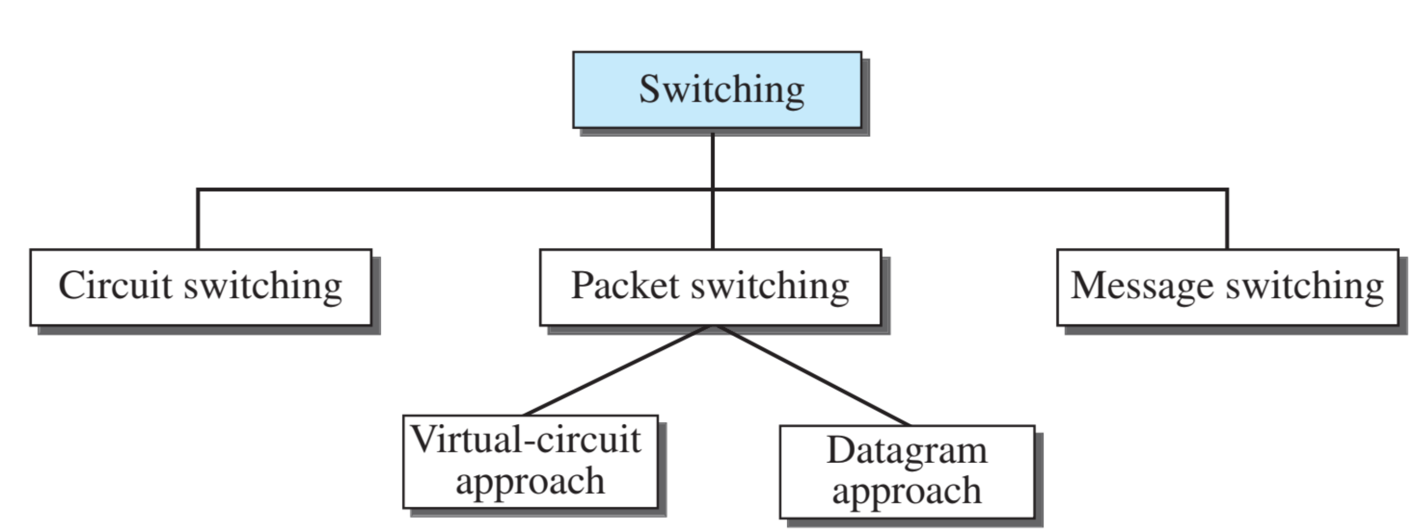
Circuit-switched Networks

- Efficiency: not as efficient as the other two types of networks because resources are allocated during the entire duration of the connection.
- 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.



Day-15 (13-08-2020)

- Datagram Switching and VC Switching

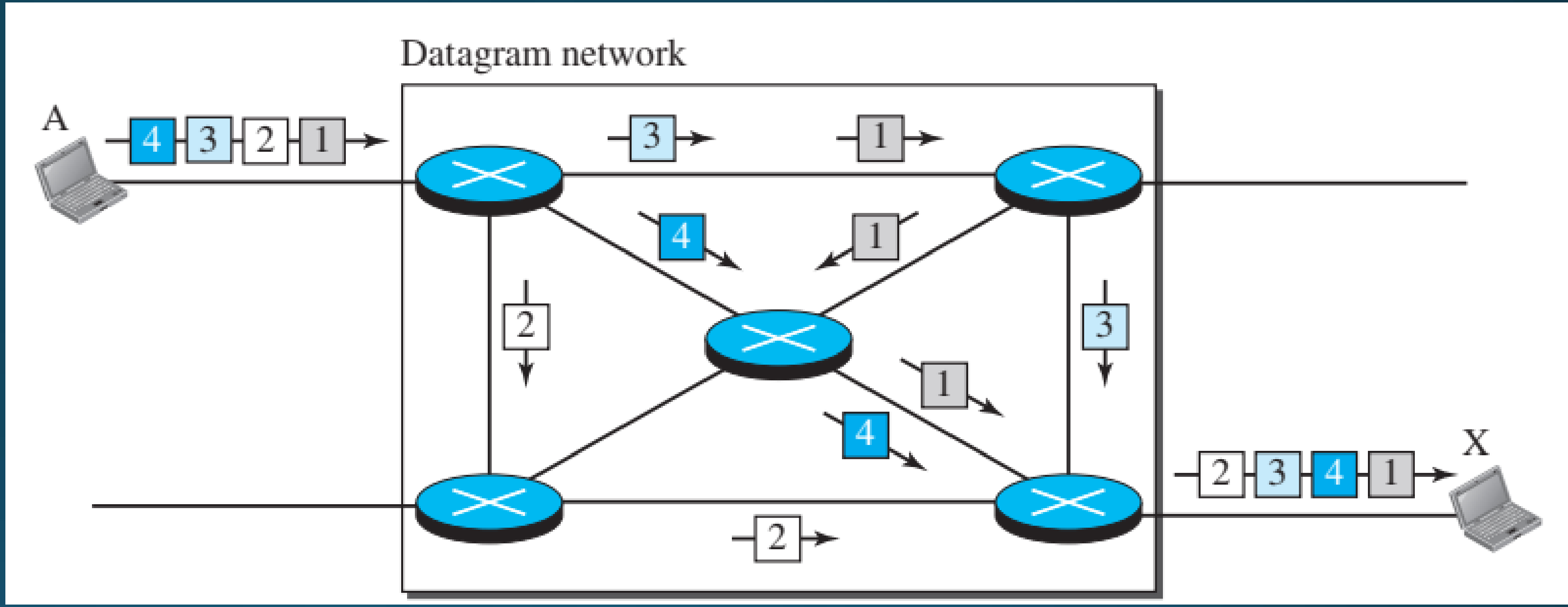


Packet Switching

- In a packet-switched network, there is no resource reservation; resources are allocated on demand.
- If the message is going to pass through a packet-switched network, it needs to be divided into packets of fixed or variable size.
- Two Types:
  - Datagram Networks
  - Virtual Circuit Networks

Datagram Networks

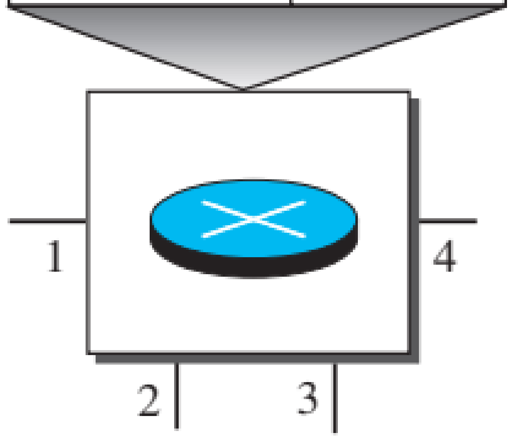
- In a datagram network, each packet is treated independently of all others. Even if a packet is part of a multipacket transmission, the network treats it as though it existed alone. Packets in this approach are referred to as datagrams.
- Datagram switching is normally done at the network layer.
- The datagram networks are sometimes referred to as connectionless networks.
- Datagram networks normally implemented in the network layer



Datagram Networks

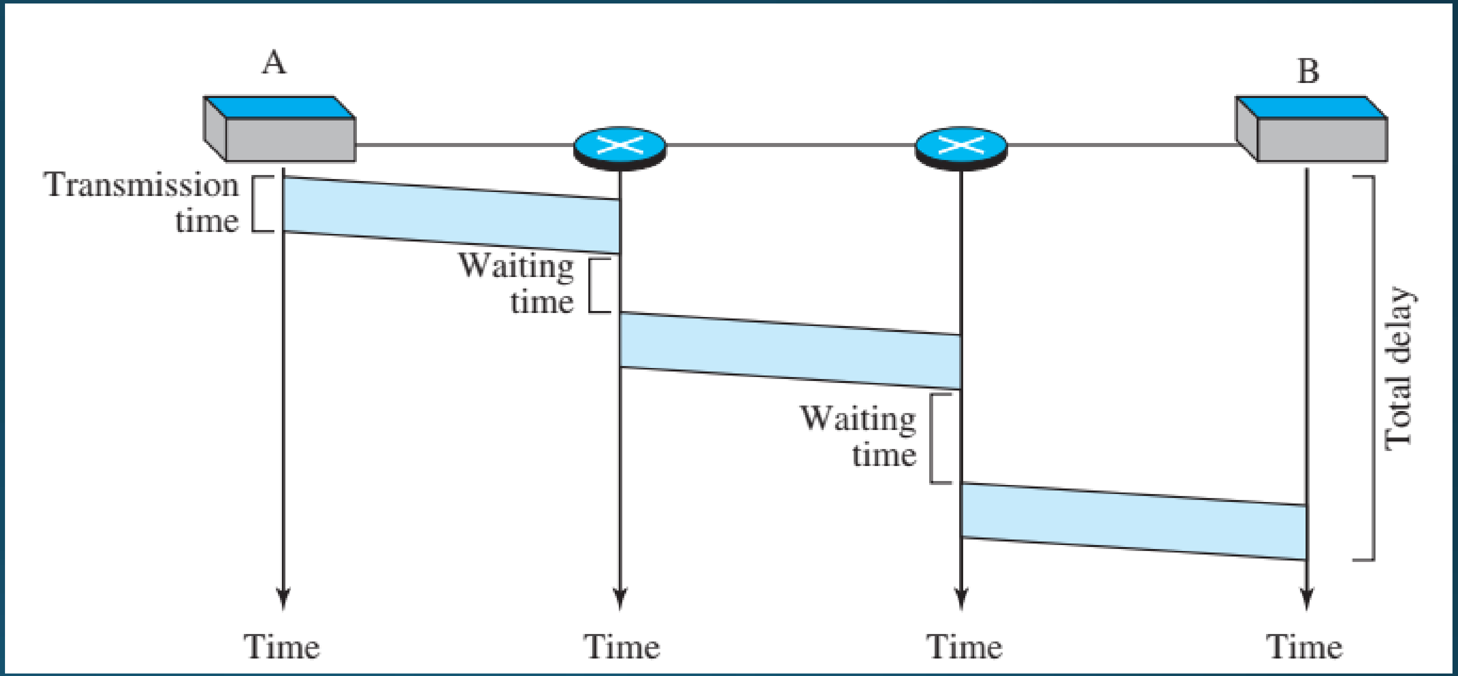
- Routing Table
  - If there are no setup or teardown phases, how are the packets routed to their destinations in a datagram network? In this type of network, each switch (or packet switch) has a routing table which is based on the destination address.
  - The destination address in the header of a packet in a datagram network remains the same during the entire journey of the packet.

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



Datagram Networks

- 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.
- Delay: There may be greater delay in a datagram network.



Total delay = $3T + 3\tau + w_1 + w_2$

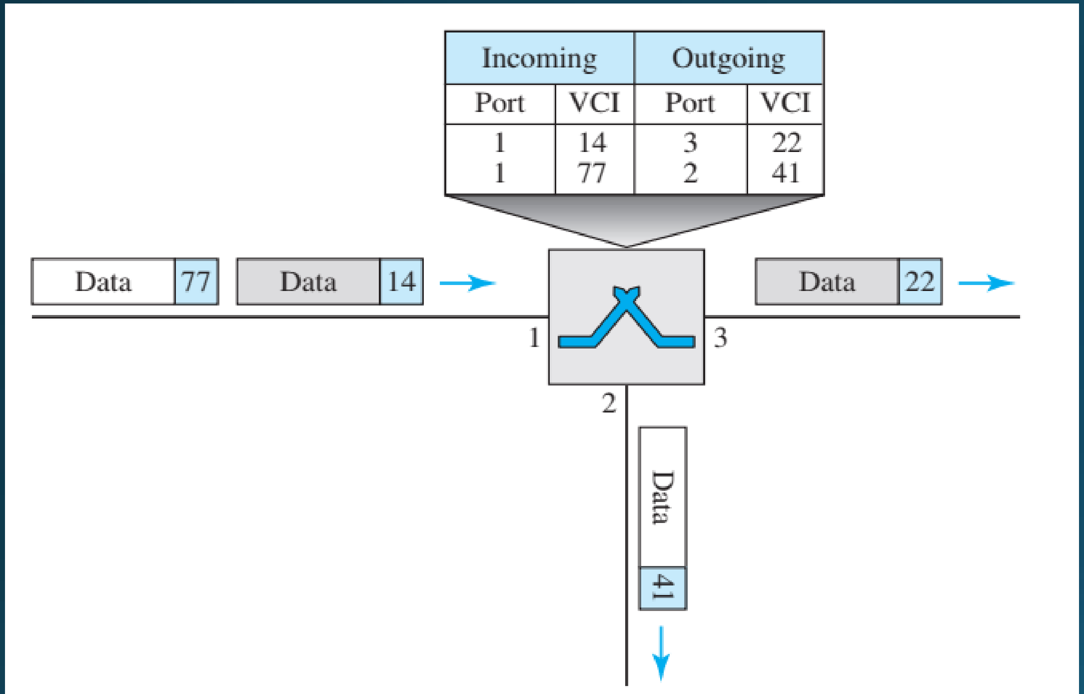
Virtual Circuit Networks

- A virtual-circuit network is a cross between a circuit-switched network and a datagram network. It has some characteristics of both.
  - As in a circuit-switched network, there are setup and teardown phases in addition to the data transfer phase.
  - Resources can be allocated during the setup phase, as in a circuit-switched network, or on demand, as in a datagram network.
  - As in a datagram network, data are packetized and each packet carries an address in the header. However, the address in the header has local jurisdiction.
  - As in a circuit-switched network, all packets follow the same path established during the connection.
- A virtual-circuit network is normally implemented in the data-link layer.

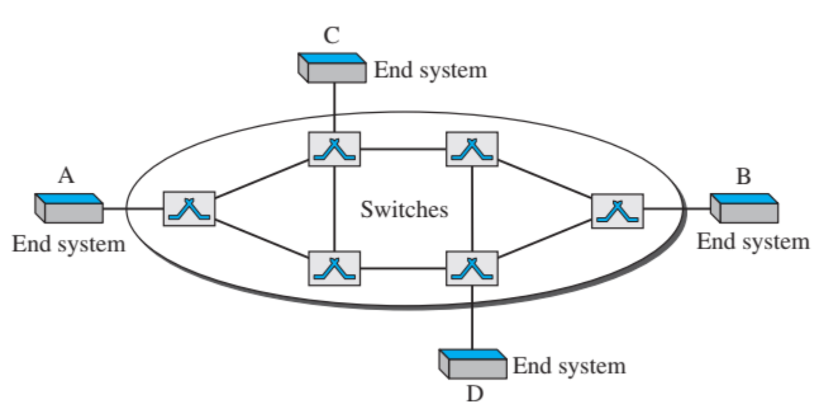
Virtual Circuit Networks

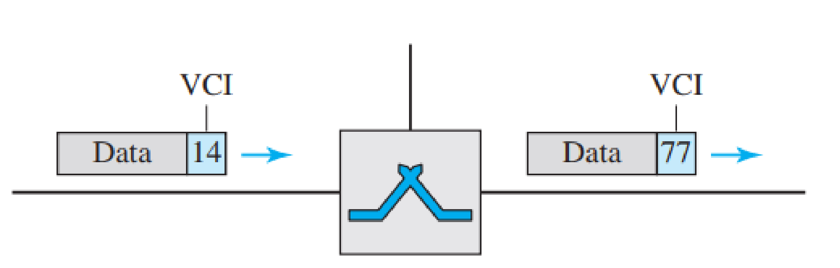
- Three Phases
  - Setup Phase
  - Data Transfer Phase
  - Teardown Phase

Data-Transfer Phase



- To transfer a frame from a source to its destination, all switches need to have a table entry for this virtual circuit. The table, in its simplest form, has four columns. This means that the switch holds four pieces of information for each virtual circuit that is already set up.
- The data-transfer phase is active until the source sends all its frames to the destination. The procedure at the switch is the same for each frame of a message. The process creates a virtual circuit, not a real circuit, between the source and destination.





Virtual Circuit Networks

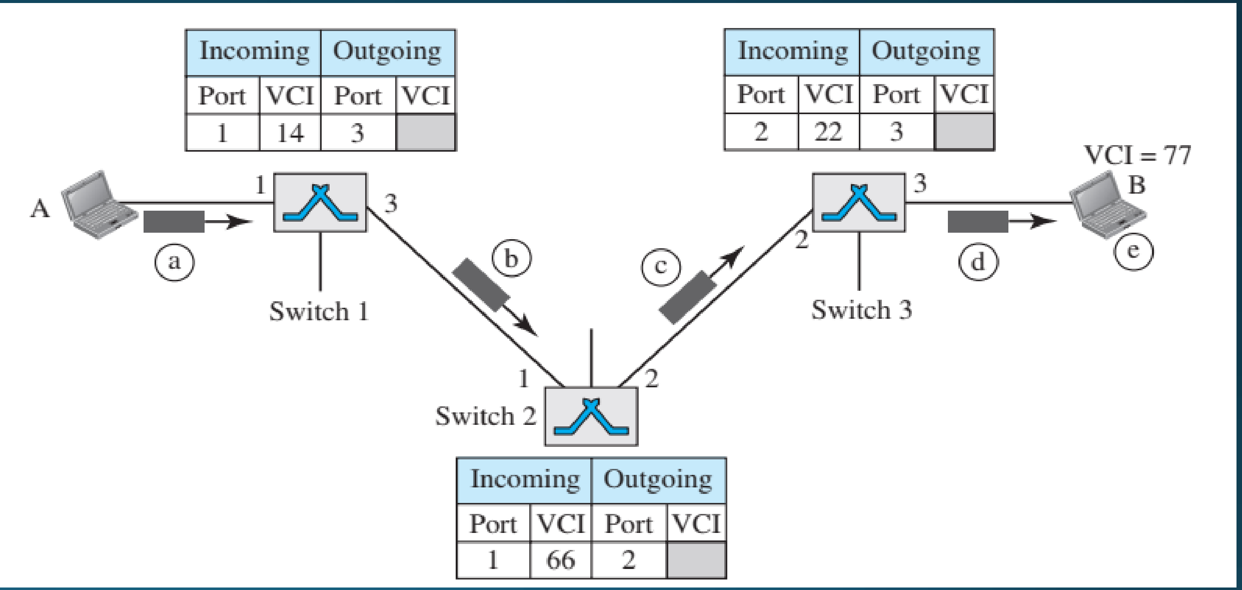
- Addressing
  - Global Addressing: a global address in virtual-circuit networks is used only to create a local address, i.e., a virtual-circuit identifier.
  - Virtual-Circuit Identifier (VCI): used for data transfer, unlike a global address, is a small number that has only switch scope.

VC Networks – Setup Phase

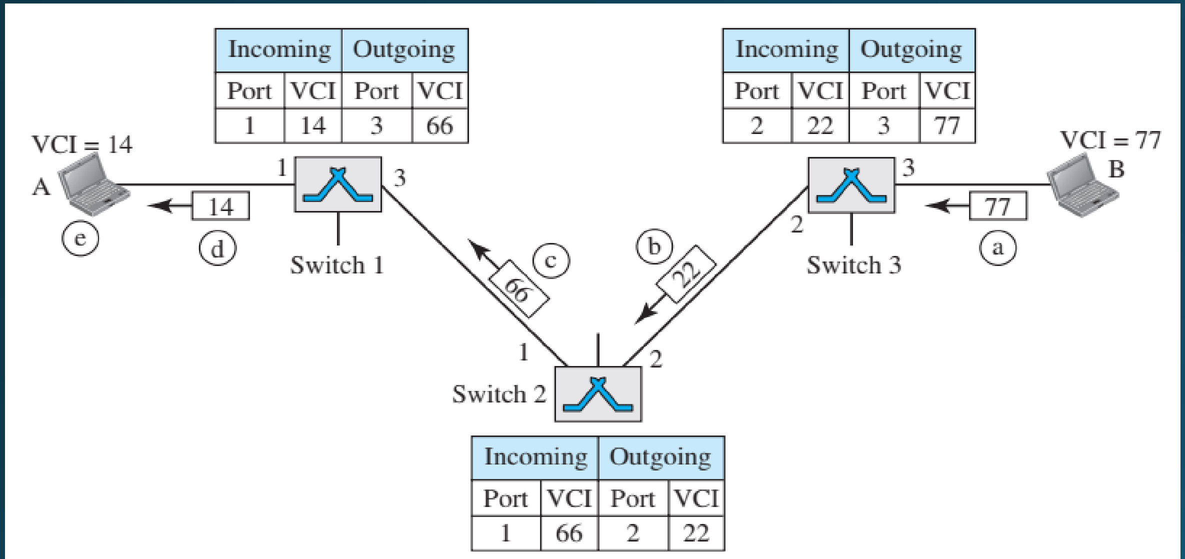
- In the setup phase, a switch creates an entry for a virtual circuit.
- Two steps are required: the setup request and the acknowledgment.
- A setup request frame is sent from the source to the destination.
- A special frame, called the acknowledgment frame will be sent from destination to source in response.
- To transfer a frame from a source to its destination, all switches need to have a table entry for this virtual circuit. The table, in its simplest form, has four columns. This means that the switch holds four pieces of information for each virtual circuit that is already set up.

Setup Request

- A setup request frame is sent from the source to the destination.
- Switch 1 receives the setup request frame. It knows that a frame going from A to B goes out through port 3.
- 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).
- Switch 2 receives the setup request frame. The same events happen here as at switch 1; three columns of the table are completed: in this case, incoming port (1), incoming VCI (66), and outgoing port (2).
- Switch 3 receives the setup request frame. Again, three columns are completed: incoming port (2), incoming VCI (22), and outgoing port (3).
- 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.

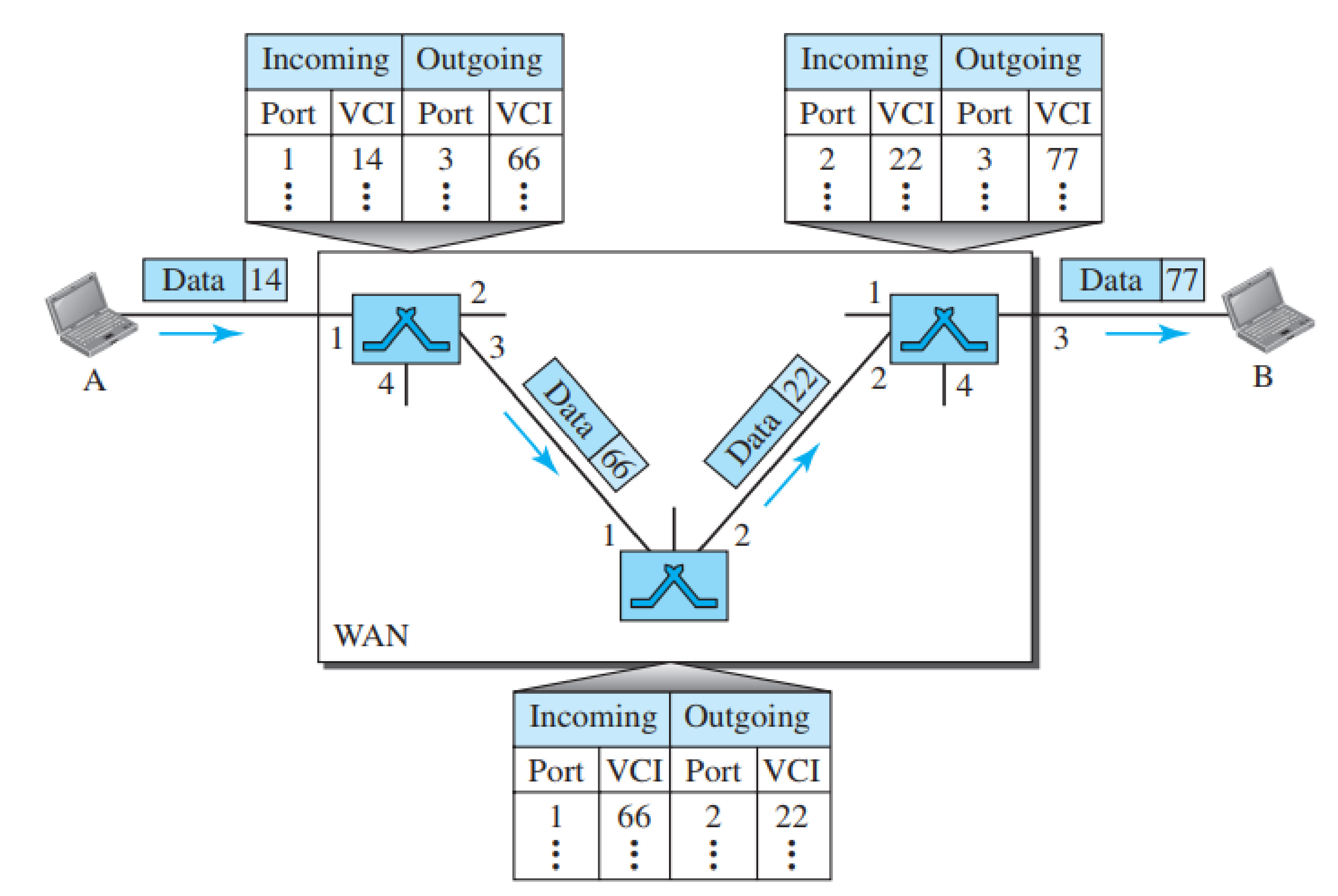


Acknowledgment

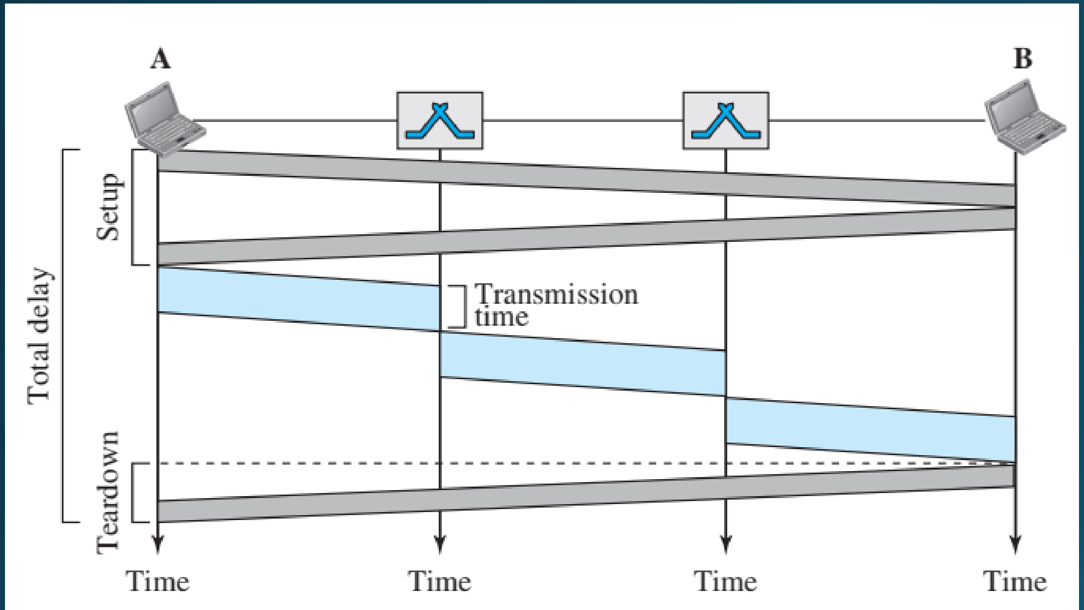


- The destination sends an acknowledgment to switch 3. The acknowledgment carries the global source and destination addresses so the switch knows which entry in the table is to be completed. The frame also carries VCI 77, chosen by the destination as the incoming VCI for frames from A. Switch 3 uses this VCI to complete the outgoing VCI column for this entry. Note that 77 is the incoming VCI for destination B, but the outgoing VCI for switch 3.
- Switch 3 sends an acknowledgment to switch 2 that contains its incoming VCI in the table, chosen in the previous step. Switch 2 uses this as the outgoing VCI in the table.
- Switch 2 sends an acknowledgment to switch 1 that contains its incoming VCI in the table, chosen in the previous step. Switch 1 uses this as the outgoing VCI in the table.
- Finally switch 1 sends an acknowledgment to source A that contains its incoming VCI in the table, chosen in the previous step.
- The source uses this as the outgoing VCI for the data frames to be sent to destination B.

Data-Transfer Phase



Teardown Phase



Total delay + $3T$ + 3τ + setup delay + teardown delay

- 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: As we said before, resource reservation in a virtual-circuit network can be made during the setup or can be on demand during the data-transfer phase. In the first case, the delay for each packet is the same; in the second case, each packet may encounter different delays.
- Delay: In a virtual-circuit network, there is a one-time delay for setup and a one-time delay for teardown. If resources are allocated during the setup phase, there is no wait time for individual packets.