

Computer Networks

Lecture 02

Transmission and Physical Media

By
Dr. Khaled ELMenshawy

Lecture

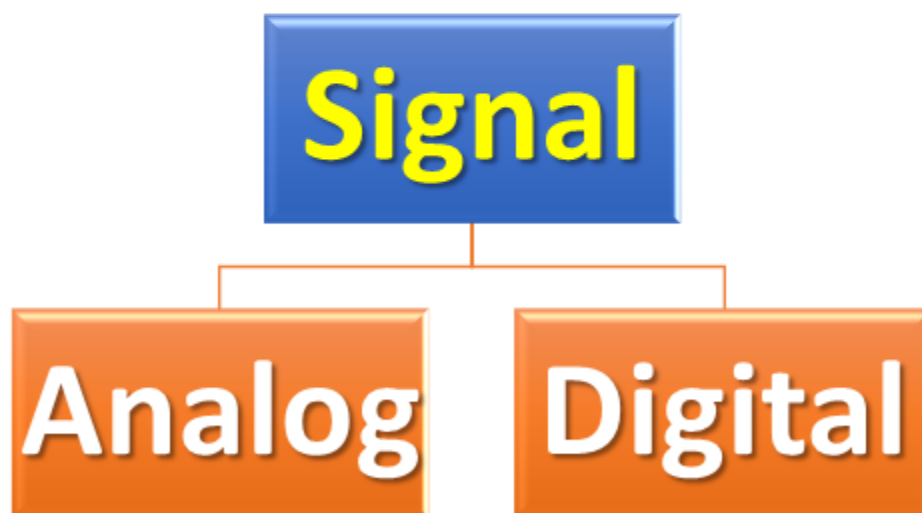
02

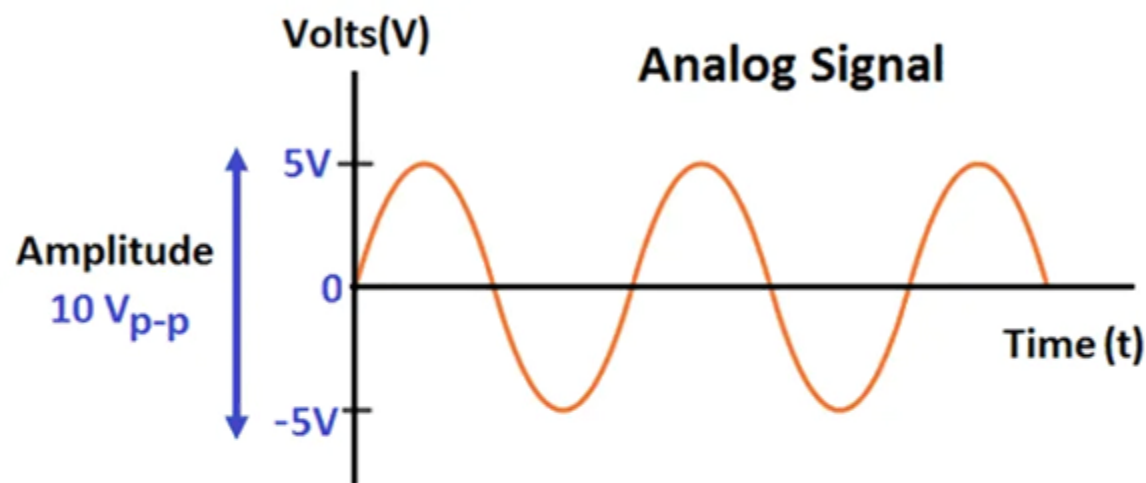
LEARNING OUTCOMES

- Differentiate between analog and digital signals.
- Understand the difference between wavelength, frequency, amplitude, and phase.
- Apply Frequency, bandwidth, throughput, and latency calculations.
- Define different techniques of Digital Modulation.
- Understand network performance.
- Define communication modes.
- Understand the different types of Multiplexing.
- Recognize the network cabling and connectors.
- Understand the different methods for accessing networks.

What is a Signal?

A signal is an electromagnetic wave or electrical current that is used for carrying data through a physical medium from one system or network to another.

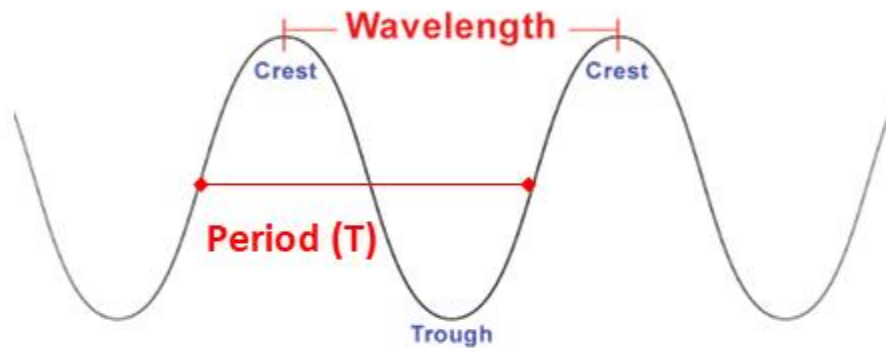




What is an Analog Signal?

Analog signal is a type of signal sent in a **continuous wave as time varying** and has varying frequencies and amplitudes and it is able to move anywhere along the wave and between the minimum and maximum values, this means it can have infinite values between the maximum and minimum wave values (e.g., +5V to -5V). A wave produced from an analog signal is also known as a **sine wave**.

Analog and digital signal

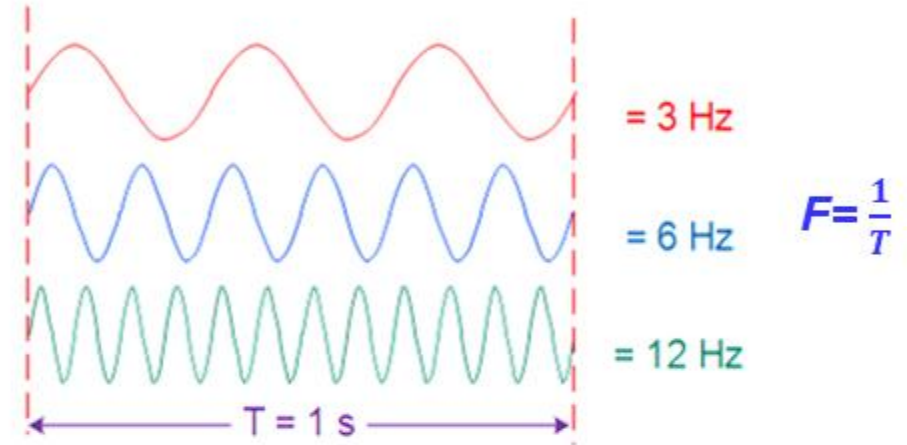


Wavelength:

Wavelength is the distance between two successive crests or troughs of a wave (Full Cycle or Period "T").

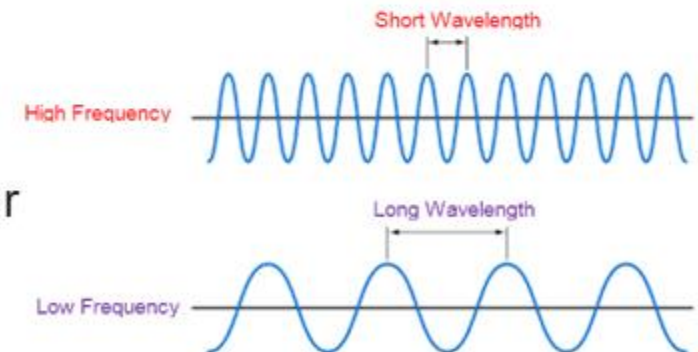
$$\text{Frequency} = 1 / \text{Period}$$

Frequency is inversely proportional to wavelength; the higher the frequency, the shorter the wavelength.



Frequency:

Frequency is the number of cycles per second.



Units of period and frequency

Time		Frequency	
Unit	Equivalent	Unit	Equivalent
Seconds (s)	1 s	Hertz (Hz)	1 Hz
Milliseconds (ms)	10^{-3} s	Kilohertz (kHz)	10^{-3} Hz
Microseconds (μ s)	10^{-6} s	Megahertz (MHz)	10^{-6} Hz
Nanoseconds (ns)	10^{-9} s	Gigahertz (GHz)	10^{-9} Hz

Example:

The period of a signal is 100 ms. What is its frequency in Kilohertz?

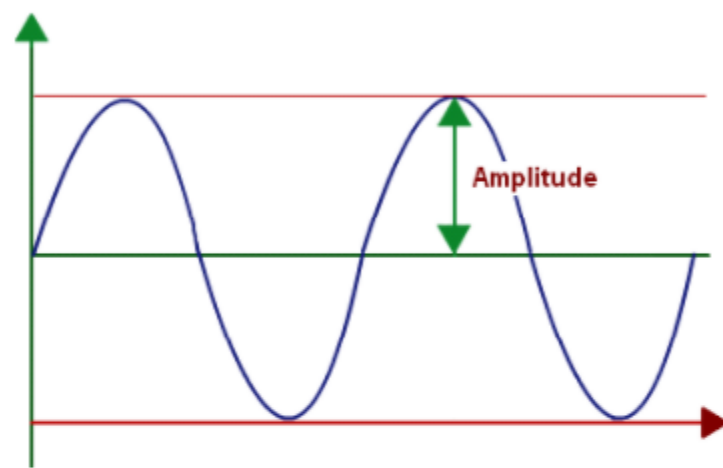
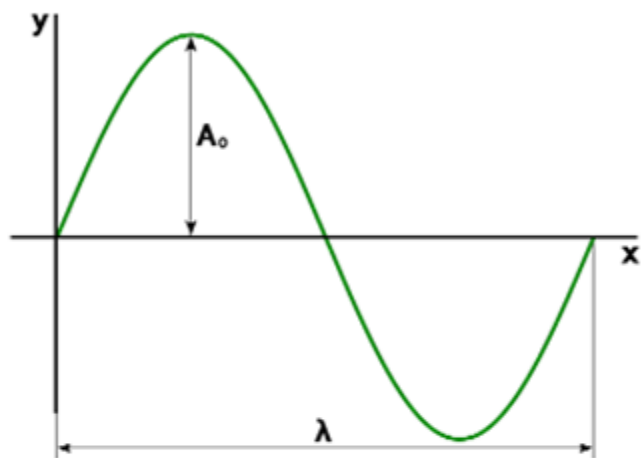
Answer:

First, we change 100 ms to seconds, and then we calculate the frequency from the period ($1 \text{ Hz} = 10^{-3} \text{ kHz}$).

$$100 \text{ ms} = 100 \times 10^{-3} = 10^{-1} \text{ s}$$

$$F = \frac{1}{T} = \frac{1}{10^{-1}} = 10 \text{ Hz} = 10 \times 10^{-3} = 10^{-2} \text{ kHz}$$

Analog and digital signal



Amplitude:

Amplitude is the maximum displacement of points on a wave from the equilibrium position. The equilibrium position is the straight line represented by the x-axis. For electric signals, peak amplitude is normally measured in volts.

Phase:

The phase describes the position of the waveform relative to time 0. The wave can be shifted backward or forward along the time axis. It indicates the status of the first cycle.

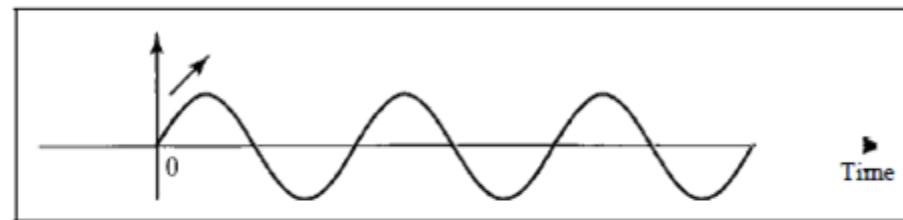
- A signal with a phase of 0° is not shifted.
- A signal with a phase of 90° is shifted to the left by $\frac{1}{4}$ cycle.

However, note that the signal does not really exist before time 0.

- A signal with a phase of 180° is shifted to the left by $\frac{1}{2}$ cycle.

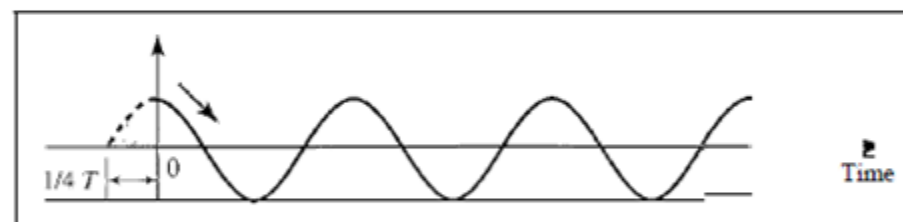
However, note that the signal does not really exist before time 0.

A signal with a phase 0° starts at time 0 with a zero amplitude. The amplitude is increasing.



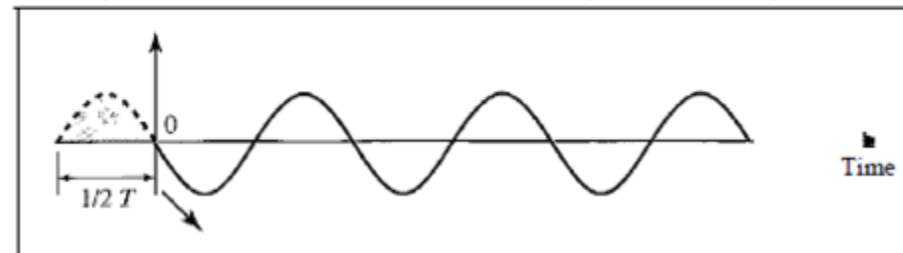
a. 0° degrees

A signal with a phase 90° starts at time 0 with a zero amplitude. The amplitude is decreasing.

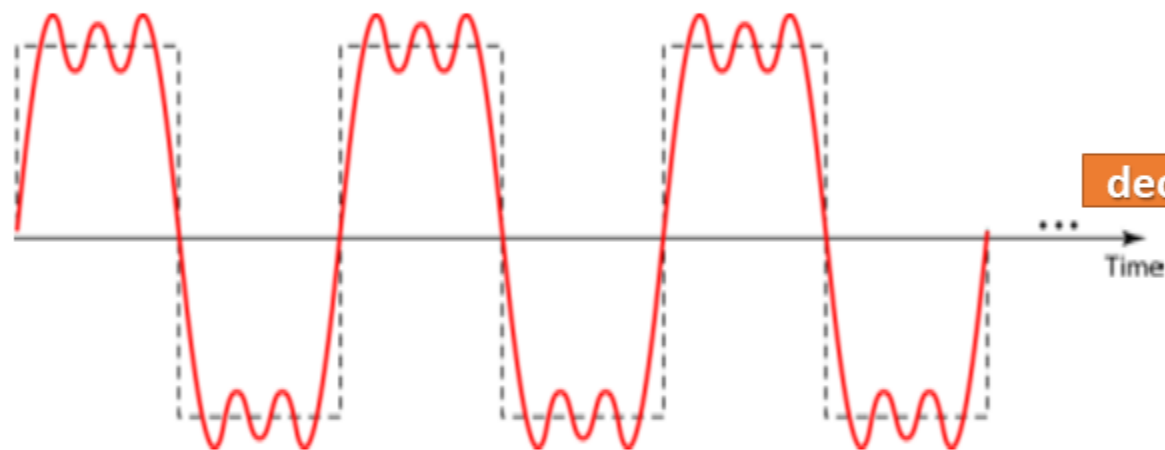


b. 90° degrees

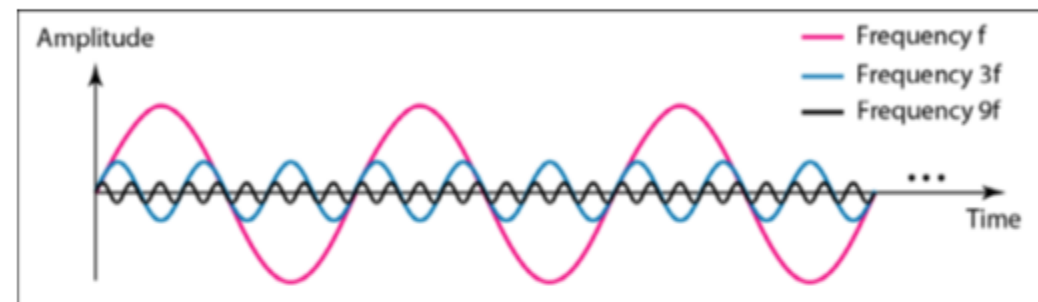
A signal with a phase 180° starts at time 0 with a zero amplitude. The amplitude is decreasing.



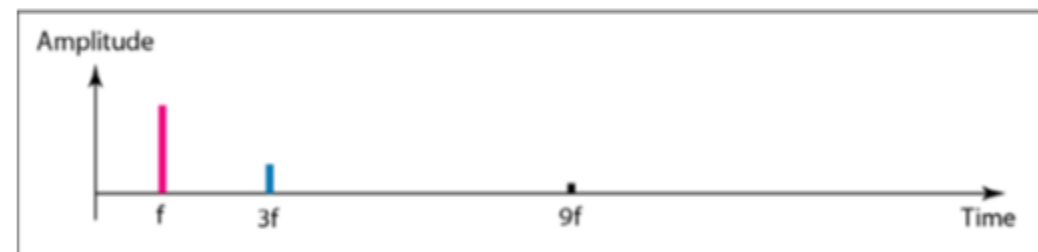
c. 180° degrees



decompose



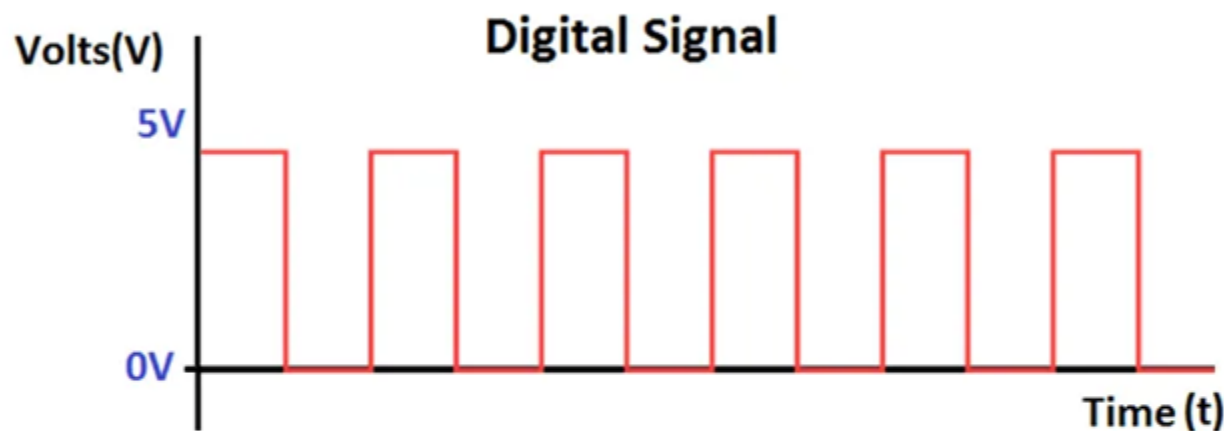
a. Time-domain decomposition of a composite signal



b. Frequency-domain decomposition of the composite signal

Composite signal:

A composite signal is made of many simple sine waves (signal) with different frequencies, amplitudes, and phases.



What is a Digital Signal?

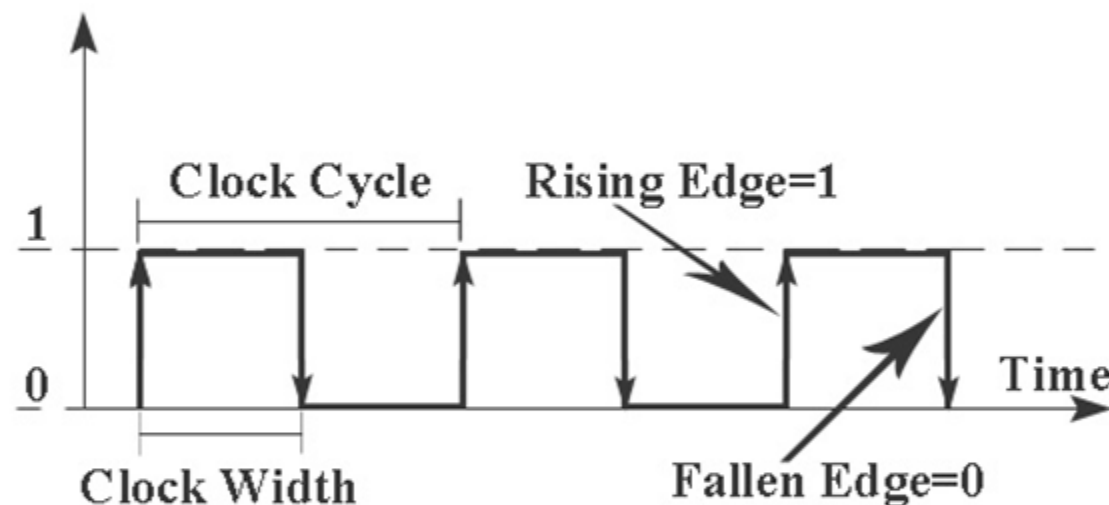
Digital signals are signals that are represented in **discrete values**. This means there is a finite number of values that the signal can be converted into. Typically, digital signals are given in binary code, where an 'up value' of 1 means "on" and a 'down value' of 0 means "off".

What is a Clock?

A **clock** is a square wave used to synchronize all the various computer components.

What is a Cycle?

A **Cycle** is the amount of time between two clocks. A **Clock Speed** or **Clock Rate** is the number of cycles that occur each second and is measured in Hertz (Hz).



What is a bit rate?

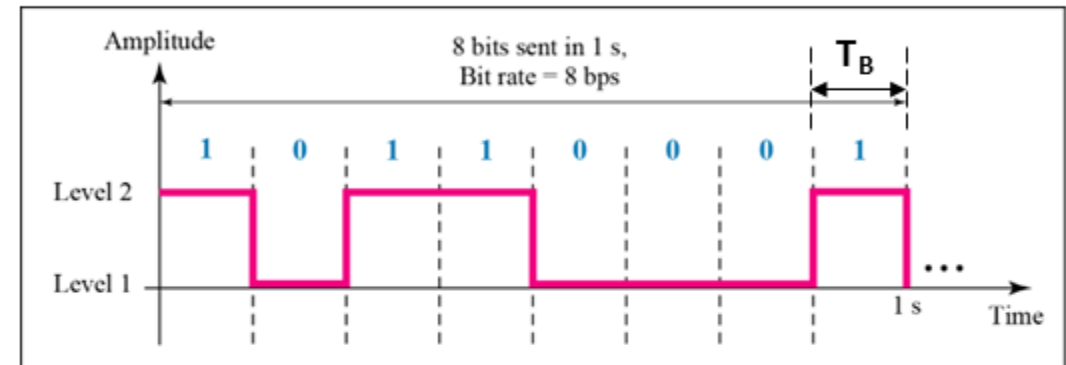
The **bit rate** is the number of bits sent in 1s, expressed in bits per second (bps). The bit rate R is a function of the duration of the bit time (T_B) where $R = 1/T_B$

A digital signal can have **more than two levels**. In this case, we can send more than 1 bit for each level. *Number*

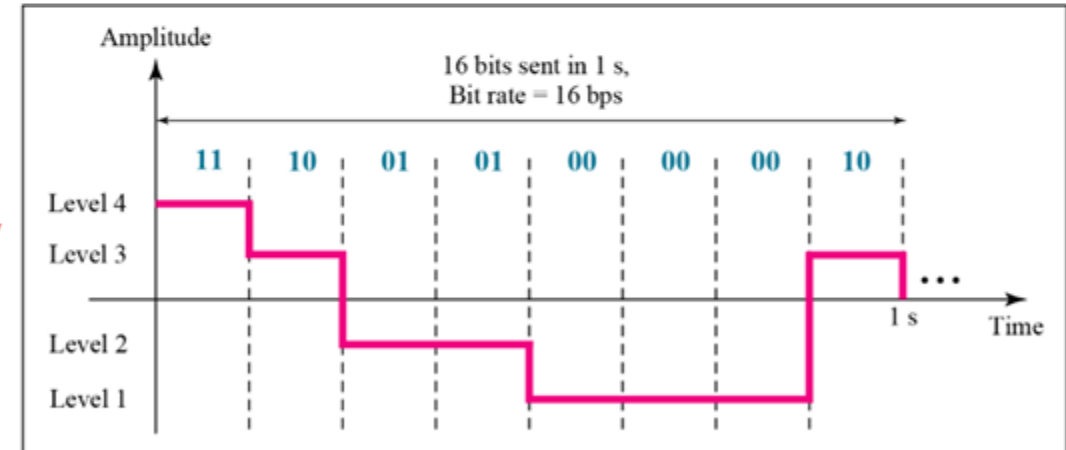
of bits for each level (L) = $\log_2(L)$

For example; A digital signal has **eight levels**. **How many bits are needed per level?**

Number of bits for each level (L) = $\log_2(L) = \log_2 8 = 3$ bits



a. A digital signal with two levels



b. A digital signal with four levels

Difference between Analog and Digital Signals.

Analog Signal	Digital Signal
Continuous and time varying.	Represented in discrete values.
Analog Signal works on continuous data.	Digital signals are time separated signals.
An analog signal is usually in the form of sine wave.	A digital signal is usually in the form of square wave.
Accuracy of the analog signals may be affected by noise.	Accuracy of the digital signals are immune from the noise.
It is suited for audio and video transmission.	It is suited for Computing and digital electronics.

What is modulation?

Simply, modulation is the process of **imposing data signal wave into a high frequency carrier wave**. We need modulation for the following reasons:

- The Data signal is a low frequency signal which is easily exposed to interference rather than high frequency wave (carrier wave).
- Separate different types of data signal by using different frequencies of carrier wave to avoid data waves interference or sending different data waves using multiple channels.
- High frequency wave (carrier wave) have more bandwidth and thus carrying more data.
- **The data signal is hidden inside the carrier wave, which is more immune to some form of noise.**

Baseband signal:

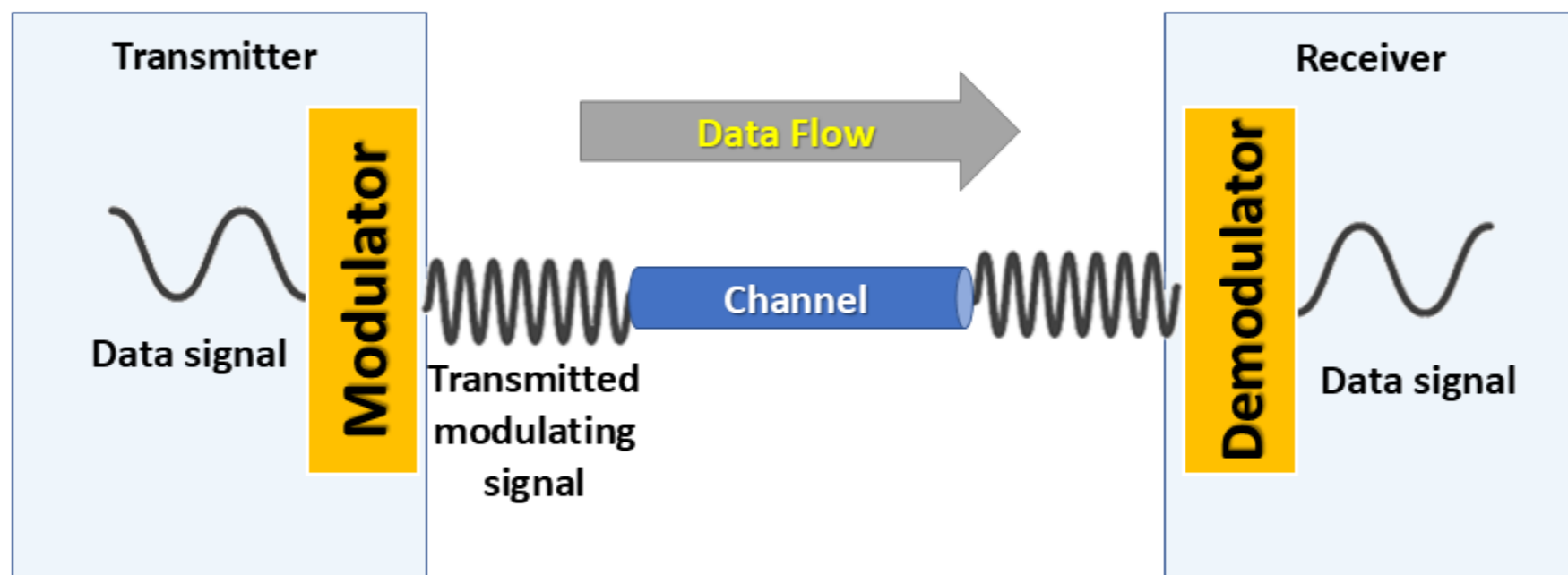
The baseband signal is the signal before modulation which has frequency much lower than that of carrier or signal after modulation.

Passband signal:

The passband signal is the signal after modulation (transmitted signal) which has frequency around carrier frequency.

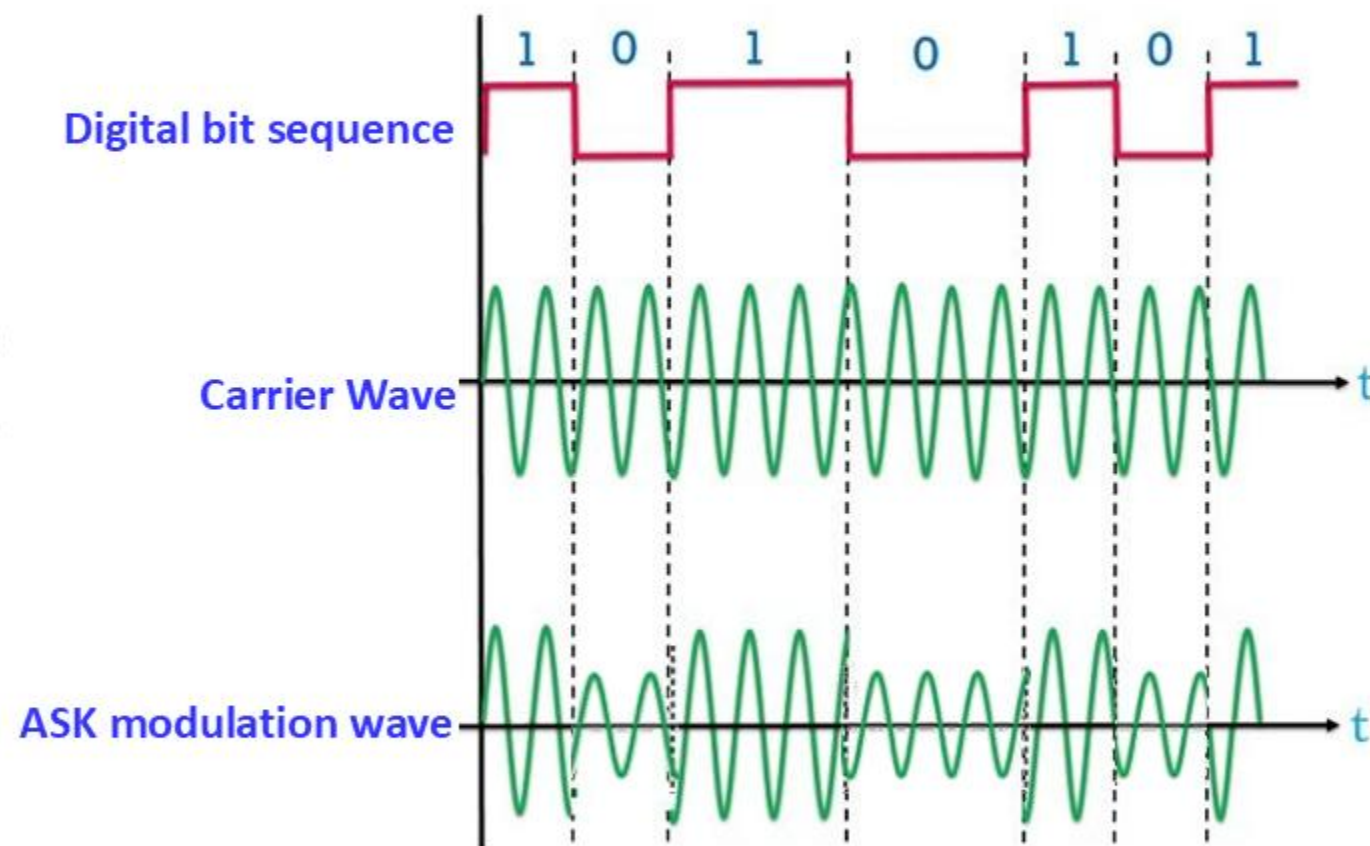
Demodulation:

It is the reverse modulation process; It extracts the data signal from the carrier signal and passes it to the receiver.

Generic communication system

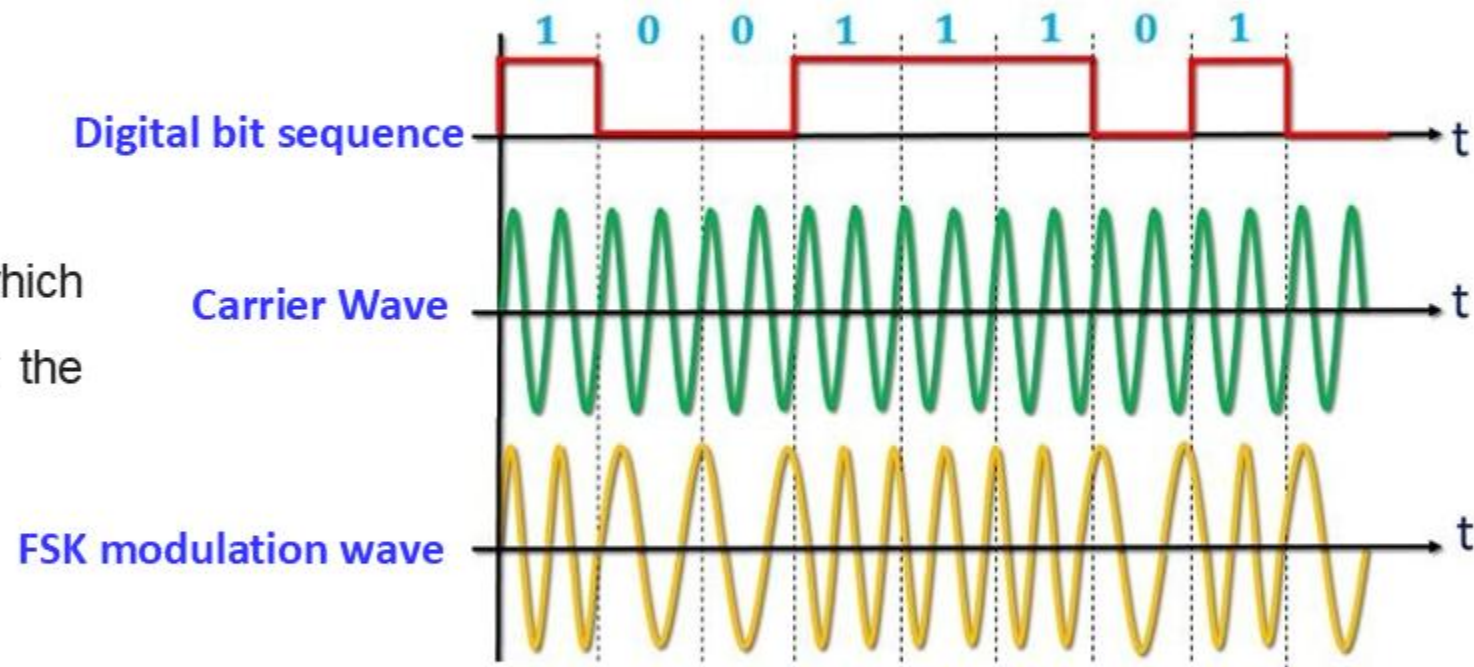
Amplitude Shift Keying (ASK):

ASK is a digital modulation technique in which the digital signals change the amplitude of the carrying wave



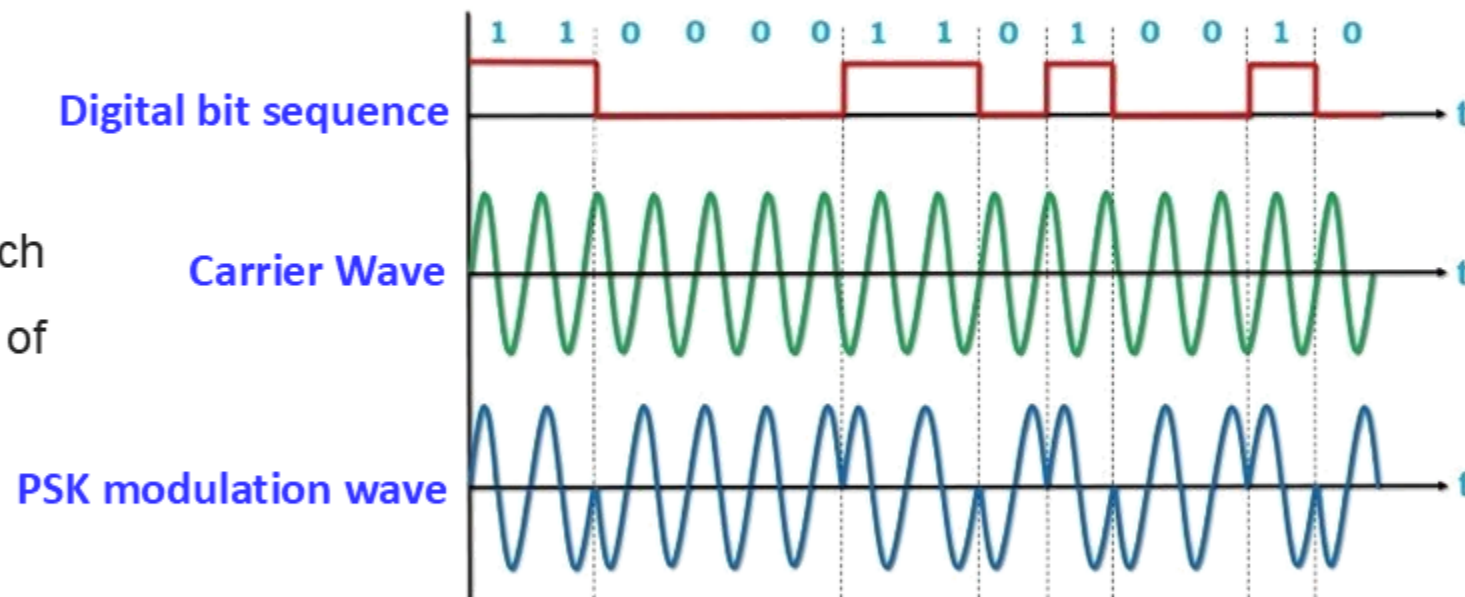
Frequency Shift Keying (FSK):

FSK is a digital modulation technique in which the carrier wave frequency changes with the digital signals.



Phase Shift Keying (PSK):

PSK is digital modulation technique in which changing the phase of a constant frequency of the carrier wave with the digital signals.



Bandwidth (in Hz):

The range of frequencies contained in a composite signal is its bandwidth. It is the difference between the highest and the lowest frequencies contained in that signal. For example, if a composite signal contains frequencies between 1000 Hz and 5000 Hz, its bandwidth is $5000 - 1000 = 4000$ Hz.

Example:

If a signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? assuming all components have a maximum amplitude of 10 V.

Answer:

$$\text{Bandwidth (B)} = \text{Highest frequency (F}_h\text{)} - \text{Lowest frequency (F}_l\text{)} = 900 - 100 = 800 \text{ Hz}$$

Bandwidth (in bits / second):

Bandwidth is measured as the amount of data that can be transferred from one point to another within a network in a specific amount of time. Typically, bandwidth is expressed as a bitrate and measured in bits per second (bps).

For example, one can say the bandwidth of a Fast Ethernet network (or the links in this network) is a maximum of 100 Mbps. This means that this network can send 100 Mbps.

There is a relationship between the bandwidth in hertz and bandwidth in bits per seconds. Basically, an increase in bandwidth in hertz means an increase in bandwidth in bits per second.

Example:

The bandwidth of a subscriber line is 4 kHz for voice or data. The bandwidth of this line for data transmission can be up to 56,000 bps using a modem to change the digital signal to analog.

Throughput:

The throughput is a measure of how fast we can actually send data through a network.

Although, bandwidth in bits per second and throughput is the same, they are different. A link may have a bandwidth of B bps, but we can only send T bps through this link with T always less than B . In other words, the bandwidth is a potential measurement of a link; the throughput is an actual measurement of how fast we can send data.

Example:

we may have a link with a bandwidth of 1 Mbps, but the devices connected to the end of the link may handle only 200 kbps. This means that we cannot send more than 200 kbps through this link.

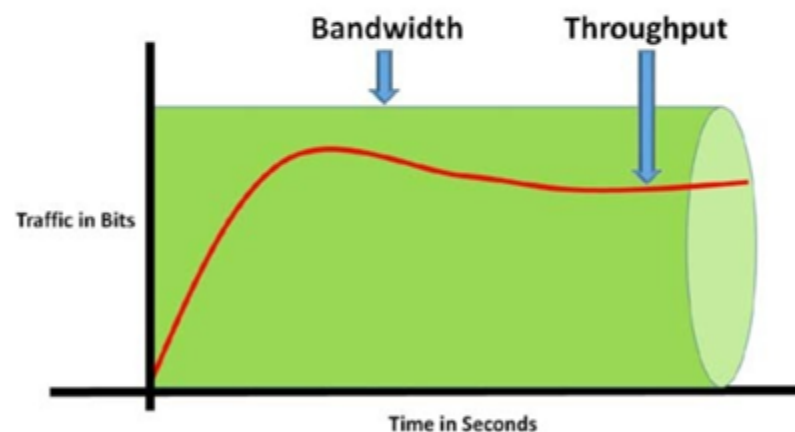
Question:

A network with *bandwidth of 10 Mbps* can pass only an average of *12,000 frames per minute* with *each frame carrying an average of 10,000 bits*. What is the throughput of this network?.

Answer:

$$\text{Throughput} = \frac{\text{data successfully transmitted}}{\text{total time taken to transmit data}} = \frac{(12000 \times 10000)}{(1 \times 60)} = 2 \text{ Mbps}$$

The throughput is almost one-fifth of the bandwidth in this case.



Latency (Delay):

Latency is how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source. Latency is made of four components: propagation time, transmission time, queuing time and processing delay. ($Latency = T_{Propagation} + T_{transmission} + T_{queuing} + T_{processing}$)

Propagation time; It is the time required for a bit to travel from the source to the destination. The propagation time is calculated by dividing the distance by the propagation speed.

$$The\ propagation\ time = \frac{Distance\ (m)}{Propagation\ speed\ (m/s)}$$

The propagation speed of electromagnetic signals depends on the medium and on the frequency of the signal.

Question:

What is the **propagation time** if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4×10^8 m/s in cable.

$$\begin{aligned} \text{The propagation time} &= \frac{\text{Distance (m)}}{\text{Propagation speed (m/s)}} \\ &= \frac{(12000 \times 1000) \text{ m}}{2.4 \times 10^8 \text{ m/s}} \\ &= 50 \text{ ms} \end{aligned}$$

The question shows that a bit can go over the Atlantic Ocean in only 50 ms if there is a direct cable between the source and the destination.

Transmission time:

In data communications we don't send just 1 bit, we send a message. The first bit may take a time equal to the propagation time to reach its destination; the last bit also may take the same amount of time. However, there is a **time between the first bit leaving the sender and the last bit arriving at the receiver**. The first bit leaves earlier and arrives earlier; the last bit leaves later and arrives later. The time required for transmission of a message depends on the size of the message and the bandwidth of the channel.

$$\text{Transmission time} = \frac{\text{message size (bit)}}{\text{Bandwidth (bps)}}$$

Question:

What are the propagation time and the transmission time for a 2.5 Kbyte message (an e-mail) if the bandwidth of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4×10^8 m/s.

$$\text{The propagation time} = \frac{\text{Distance (m)}}{\text{Propagation speed (m/s)}} = \frac{(12000 \times 1000)m}{2.4 \times 10^8 \text{ m/s}} = 0.05 \text{ s} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{\text{message size (bit)}}{\text{Bandwidth(bps)}} = \frac{(2.5 \times 1000 \times 8)\text{bit}}{1 \times 10^9 \text{ bps}} = 0.0000020 \text{ s} = 0.0020 \text{ ms}$$

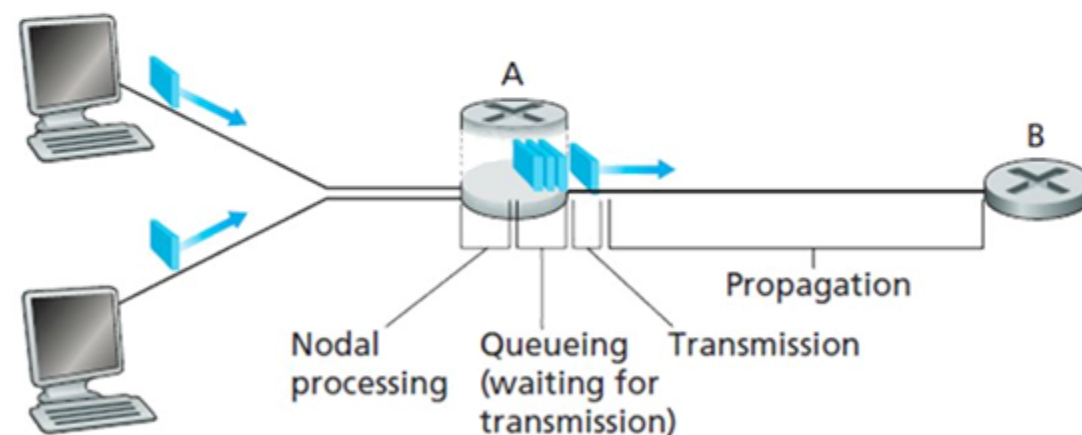
Queuing time:

It is time needed for an end device (e.g., router) to hold the message before it can be processed. The queuing time is not a fixed factor; it changes with the load imposed on the network. When there is heavy traffic on the network, the queuing time increases. An end device, *such as a router*, queues the arrived messages and processes them one by one. If there are many messages, each message will have to wait.



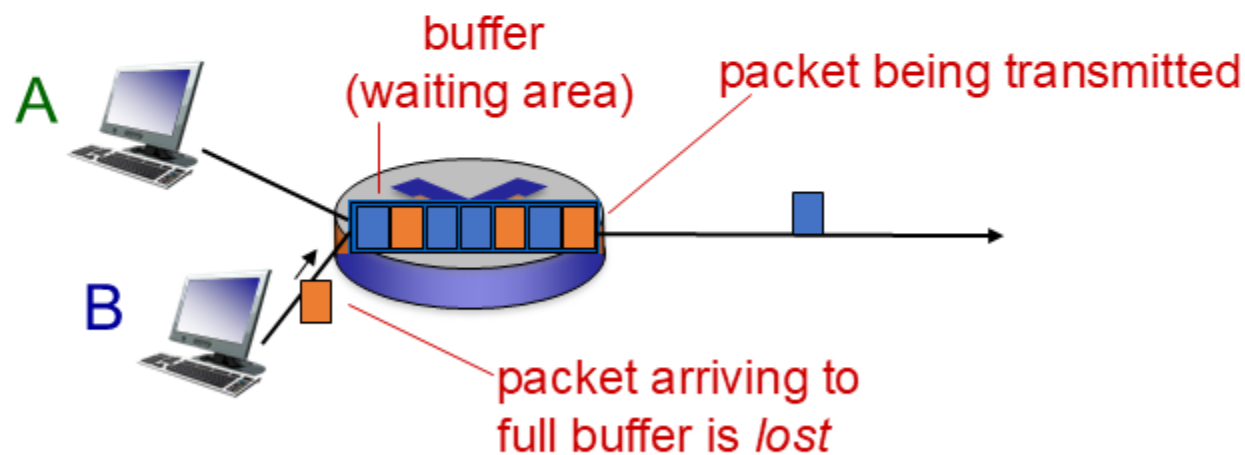
Processing delay :

Processing delay is the time it takes routers to process the packet header. Time is taken to process the data packet by the processor that is the time required by intermediate routers to decide **where to forward the packet**, **update TTL**, perform **header checksum calculations**. (few Microseconds)



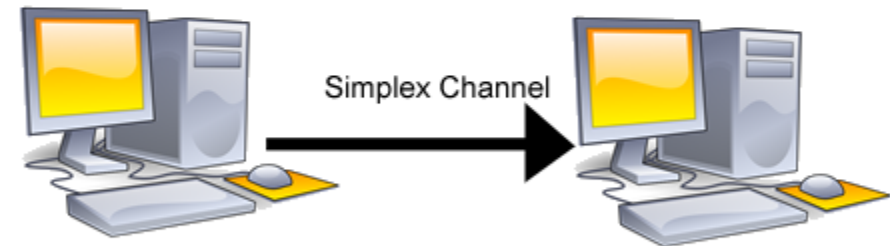
Packet loss:

Queue (buffer) has finite capacity. Thus, packet arriving to full queue dropped (lost) and it may be retransmitted by previous node, by source end system, or not at all.

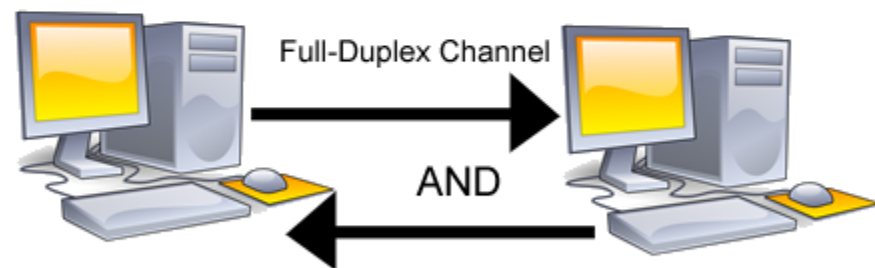
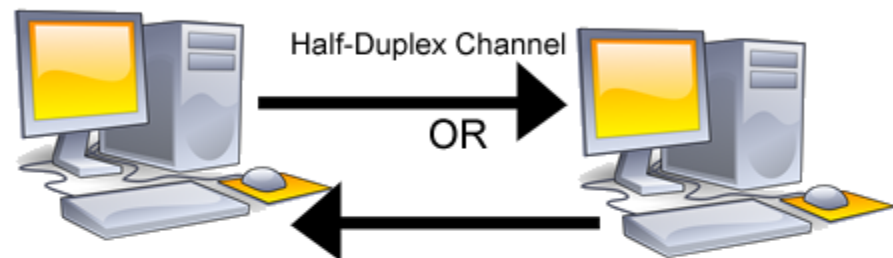


A network is a collection of nodes integrated together using media that can be wired or wireless. It's comprised of two addresses: the source address and the destination address. [The communication mode or mode of transmission of data can be of three types.](#)

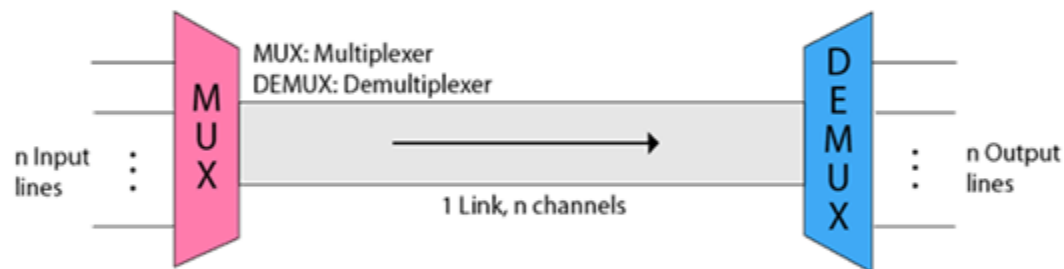
- **Simplex**; there is one transmitter and one receiver. They are always unidirectional, that is, communication can take place in only one direction. The receiver cannot send back data.



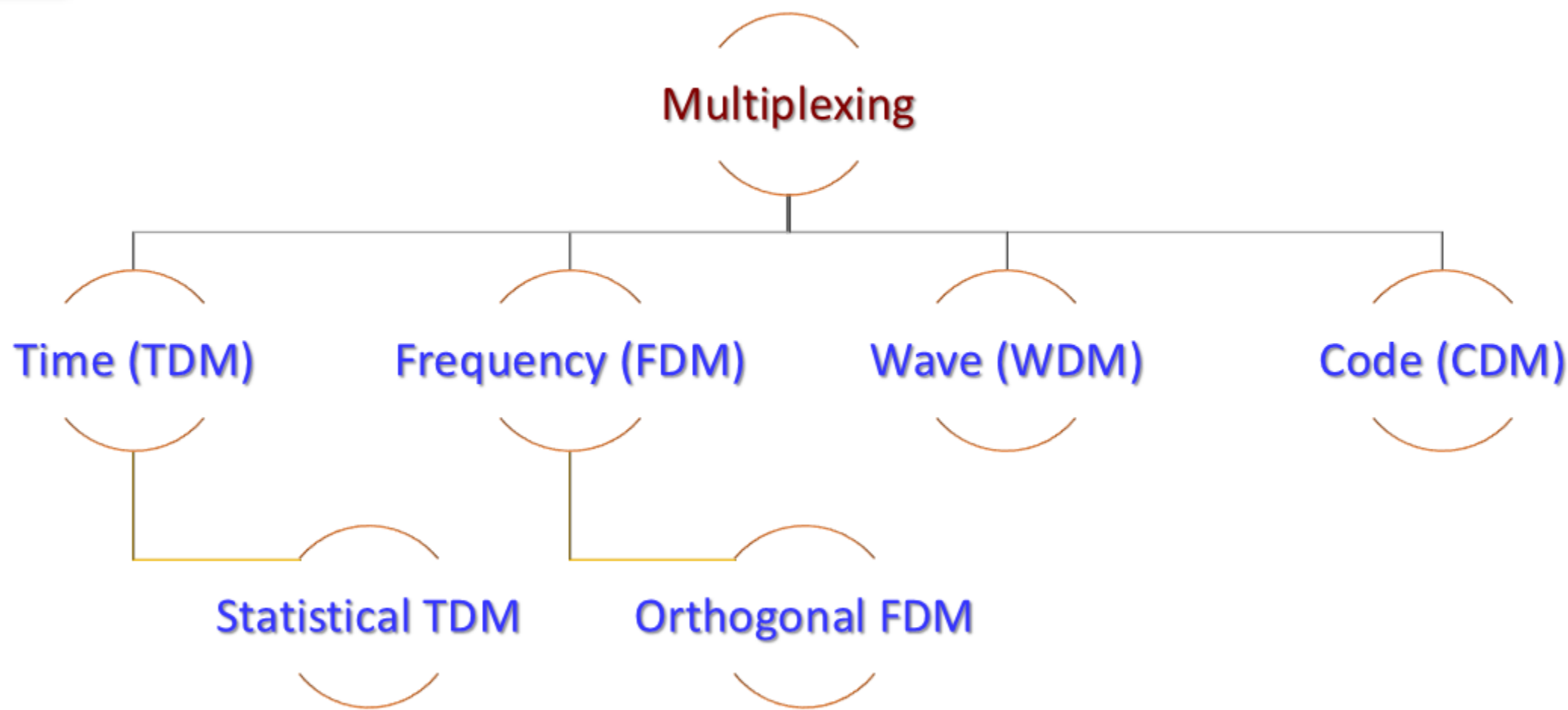
- **Half duplex**; This mode of communication is bidirectional, that is, communication can take place along both sides of the channel, one at a time. Either of the one nodes can act as sender or receiver and transmit data but not at the same time.
- **Full duplex**; This mode of communication is also bidirectional, which means that communication can take place along both sides of the channel simultaneously.



- **Multiplexing**; is the process of combining various digital signals into one signal over a shared medium. This process is done at the sender's end where the signals are combined to form a **composite signal** using the **multiplexer**. Multiplexer is a digital electronic device that is used to combine signals at the sender's end.

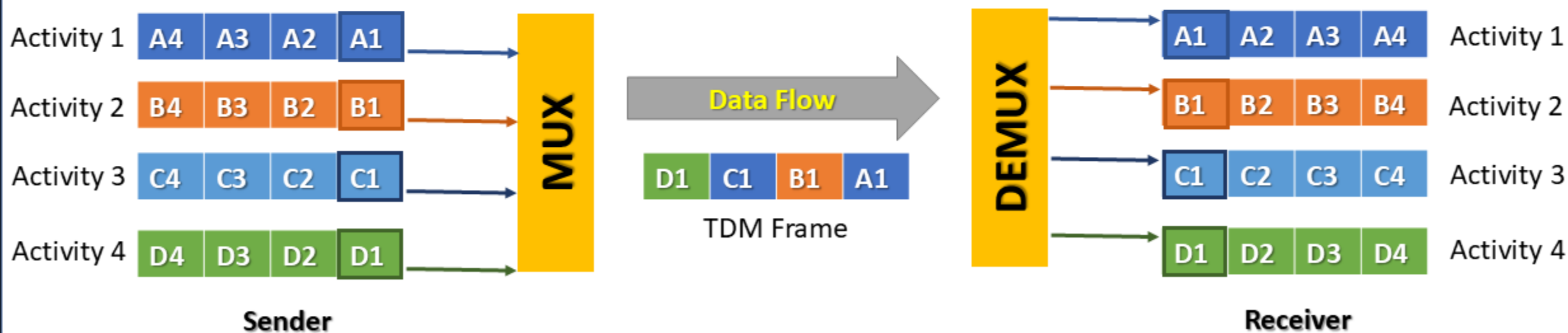


- **De-multiplexing**; is the reverse process done at receiver's end, and thus, extracting the original signal at the receiver's end.



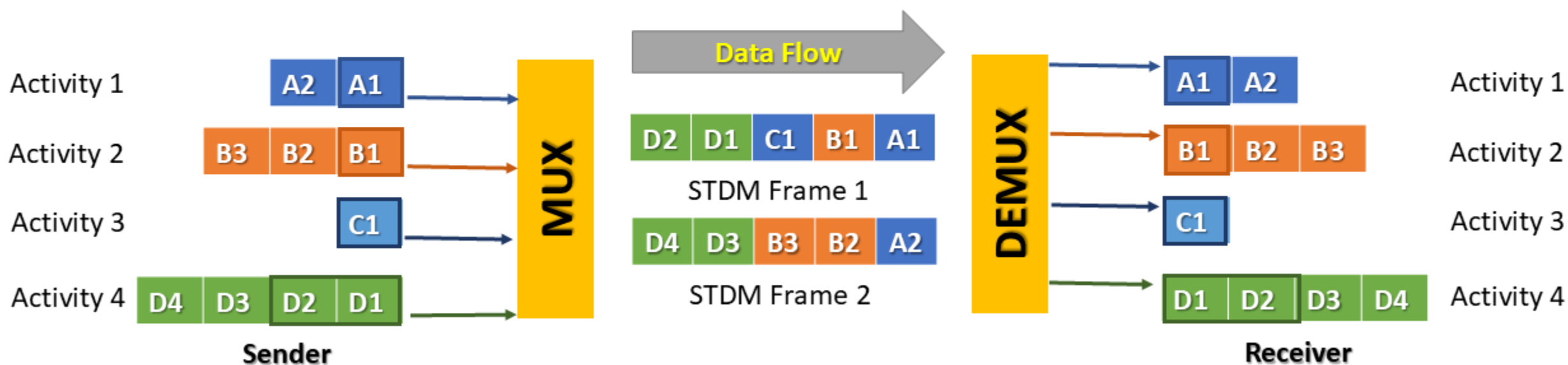
Time division multiplexing (TDM):

It breaks up the time you have available into a stream of fixed-sized slots and distributes those slots among the various activities that need to be accomplished.



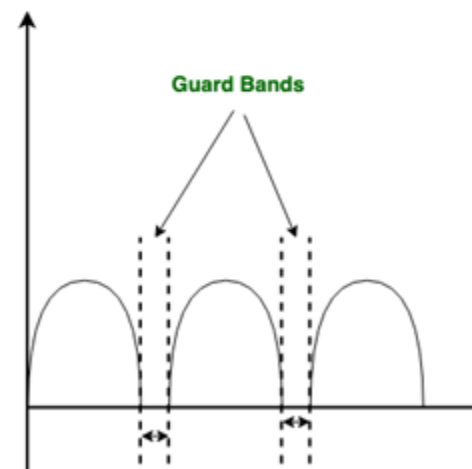
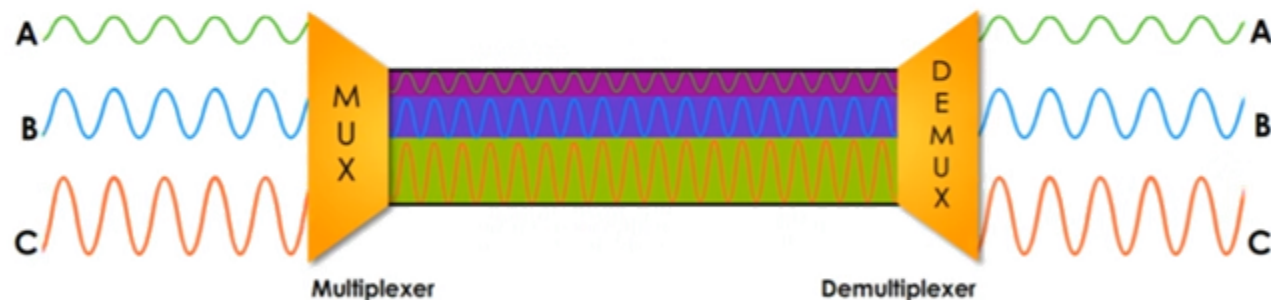
Statistical Time division multiplexing (STDM):

In case of some activities having more data than the others or even different priority, STDM analyze the statistics of each workload (needs or priority) and determine how much time each activity should get (ie. STDM can provide a link utilization improvement, called the *statistical multiplexing gain*).



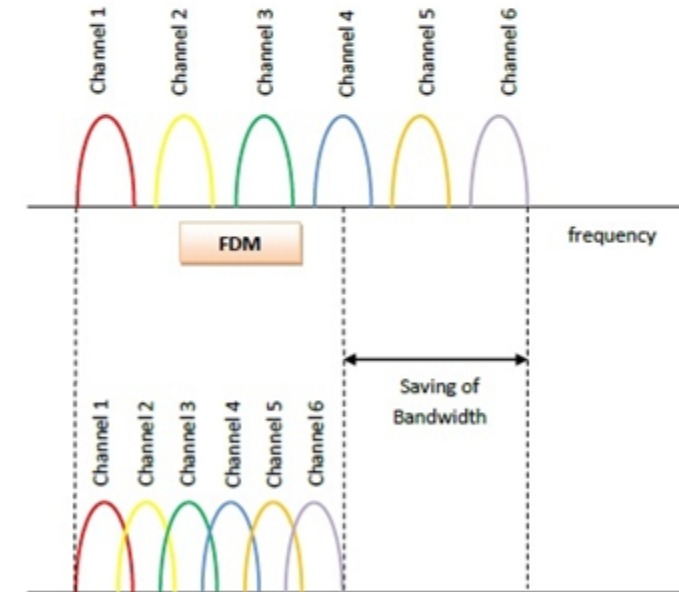
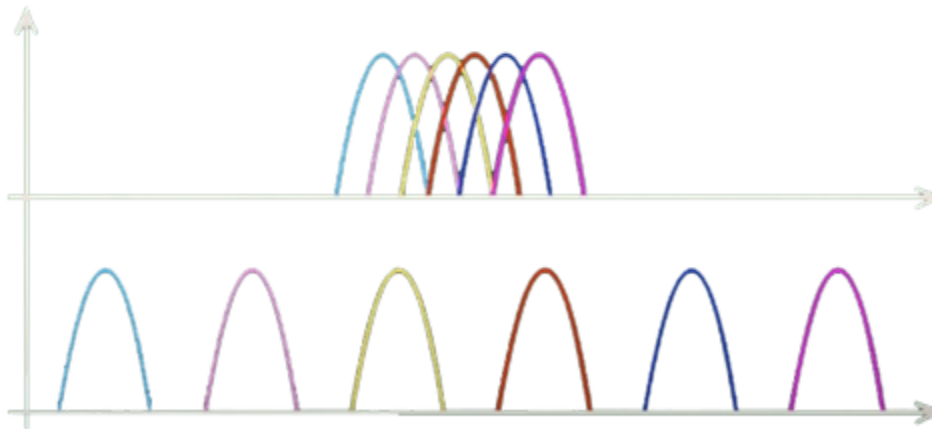
Frequency division multiplexing (FDM):

Frequency division multiplexing (FDM) is the technique of combining different frequency signals over a common medium and transmitting them simultaneously. FDM facilitates the sharing of single media like a copper cable, a wireless channel, or fiber-optic cable between many users. The carrier frequencies are separated by a band of frequencies known as **guard bands** to prevent them from interfering.



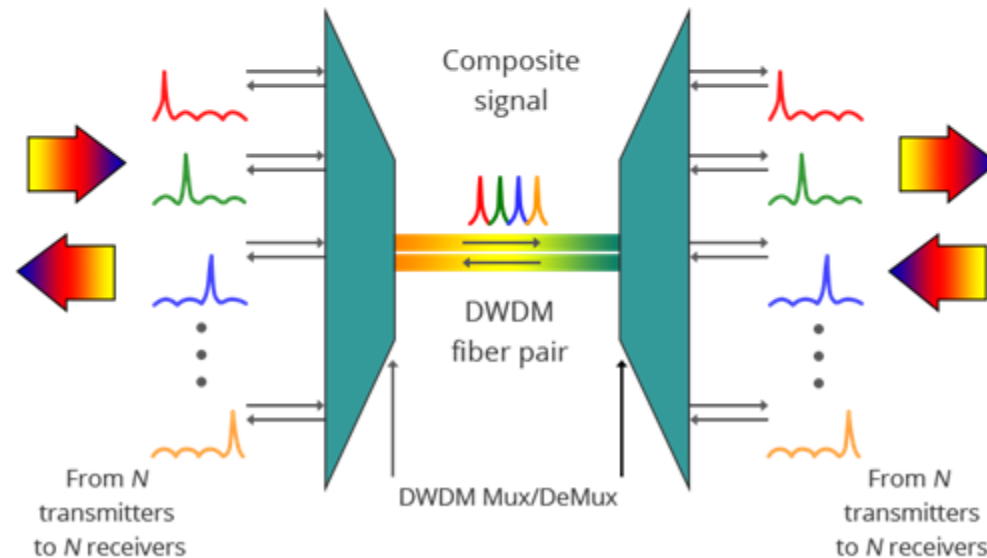
Orthogonal Frequency division multiplexing (OFDM):

OFDM is multiplexing method used with many wireless communication standards such as Wi-Fi 802.11ac, 4G, 5G, WiMAX and satellite. In OFDM, Guard band is not required because signals are orthogonal to each other thus the effect of interference in OFDM is trivial.



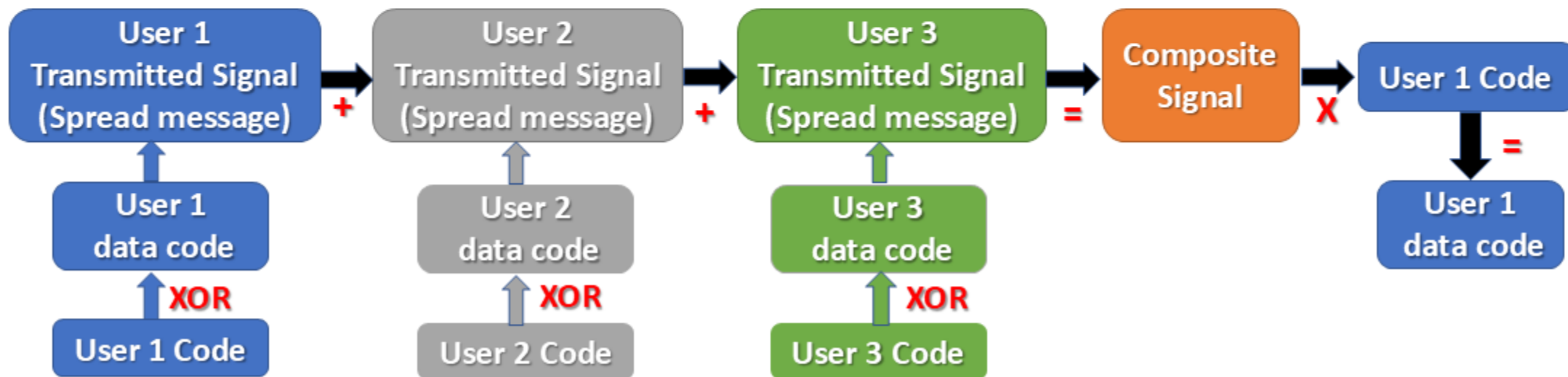
Wave division multiplexing (WDM):

WDM works on the same principle as **FDM**. The only differences are that the media is an **optical fiber cable** and the frequencies to be transmitted are very high. **WDM** combines many light beams into a single light beam and uses an optical fiber cable to transmit. **WDM** is becoming more popular because of the **very high bandwidth** available in fiber optics.



Code division multiplexing (CDM):

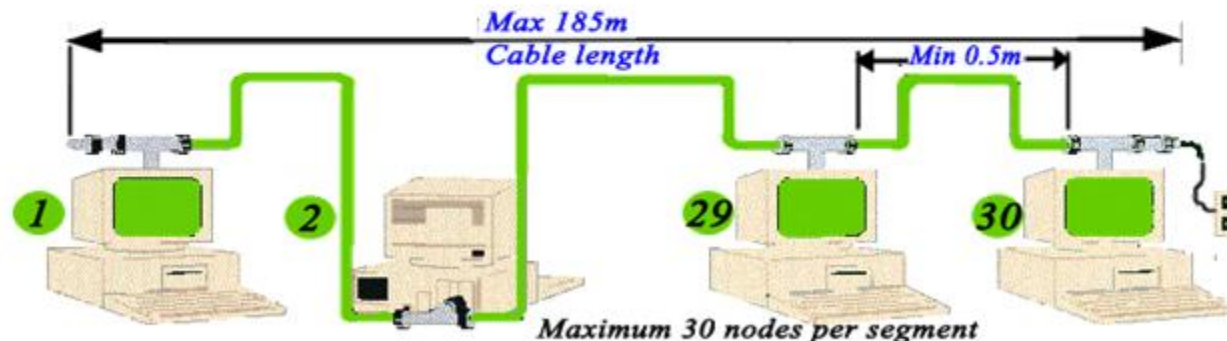
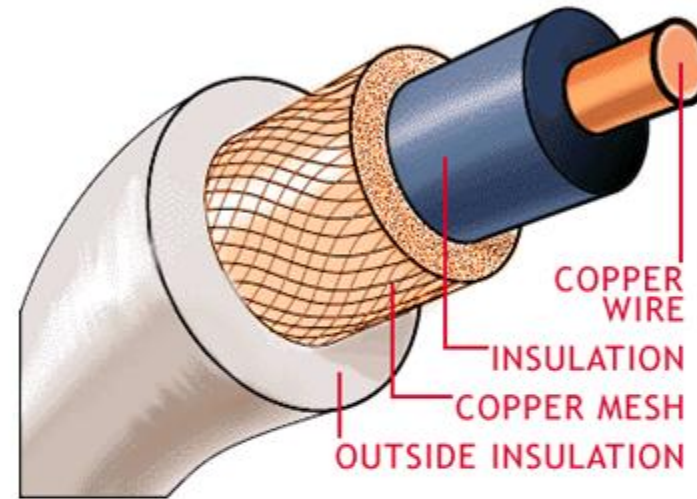
CDM is a multiplexing technique used in the domain of wireless communications. CDM is used to allow multiple signals from multiple users to share a common communication channel. Each group of users is given a **shared code** and individual **conversations are encoded in a digital sequence**. Data is available on the **shared channel**, but only those **users associated with a particular code can access the data**.



Physical Media (Network Cabling and Connectors)

Coaxial Cable:

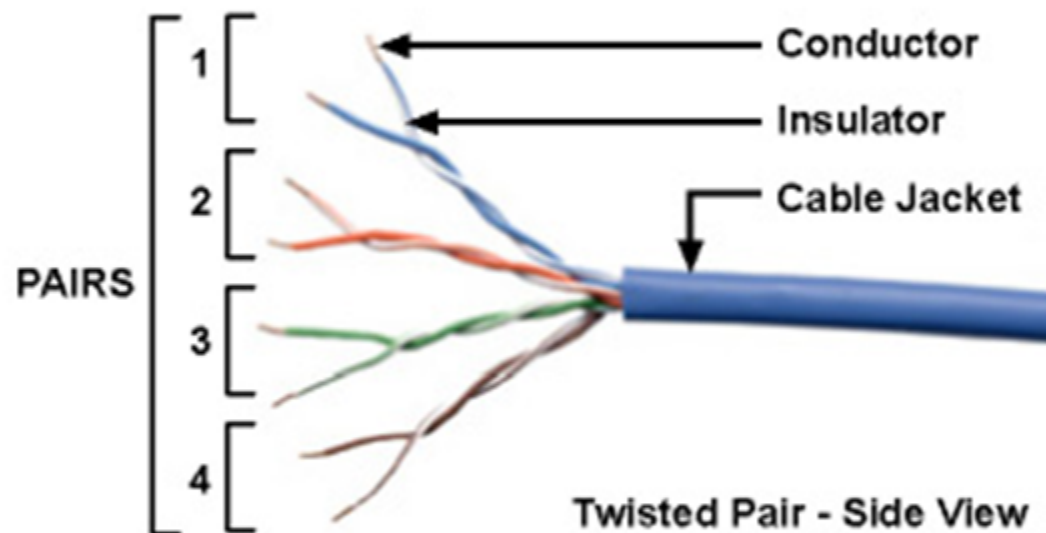
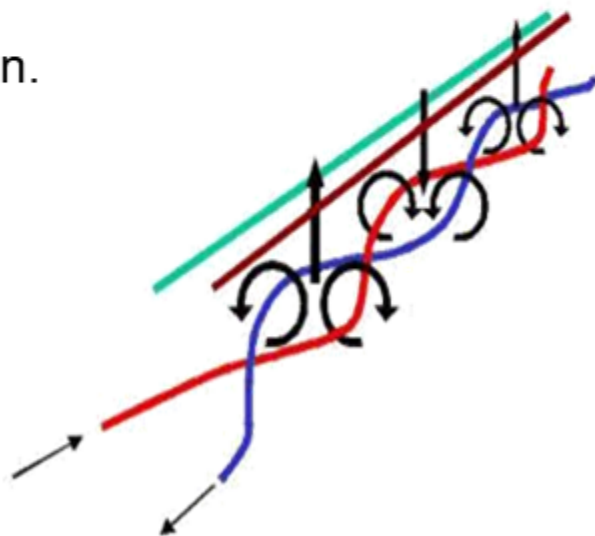
A type of wire that consists of Inner copper core, inner insulator (dielectric), shielded wire mesh (braid), and outer insulator (PVC Jacket). It can travel up to 185 m and data speed up to 10 Mbps. It uses BNC connector.



Physical Media (Network Cabling and Connectors)

Twisted Pair:

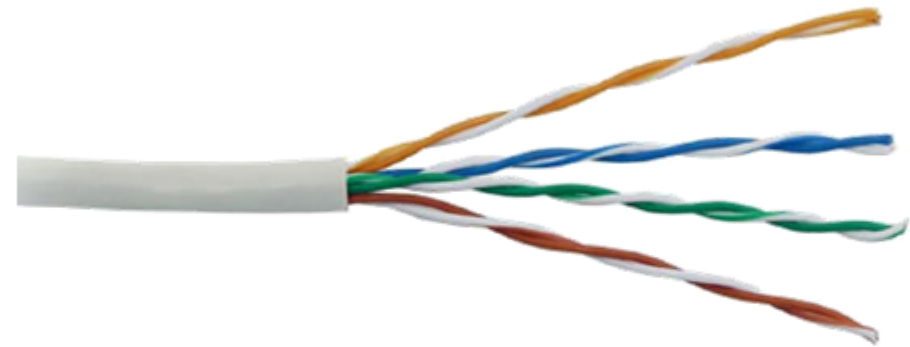
A type of cable that consists of two independently insulated wires twisted around one another. The use of two wires twisted together helps to reduce crosstalk and electromagnetic induction.



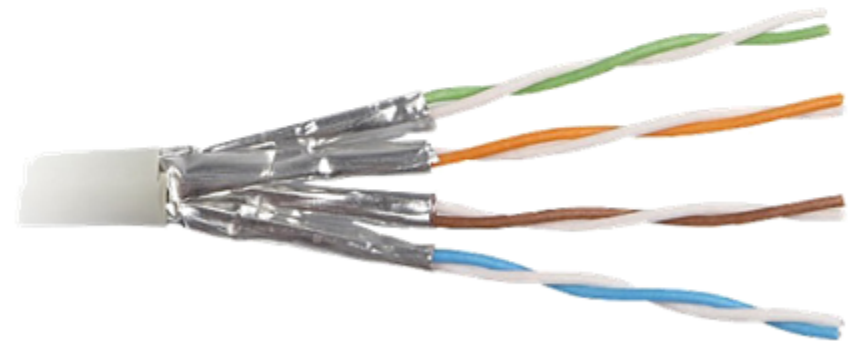
Physical Media (Network Cabling and Connectors)

Types of Twisted Pair:

There are two types of twisted pair cables, **Shielded Twisted Pair (STP)** in which each of the two copper wires that are twisted together are coated with an insulating coating that protects the transmission line from electromagnetic interference leaking into or out of the cable. **Unshielded Twisted Pair (UTP)** a popular type of cable that consists of two unshielded wires twisted around each other.



UTP



STP

Physical Media

(Network Cabling and Connectors)

Categories (CAT) of Twisted Pair:

There are several categories of twisted pair depend on how much data speed that they can handle, the most common categories used in network today are CAT 3= 10 Mbps, CAT 5= 100 Mbps, CAT 5e= 1000 Mbps, and CAT 6= 10 Gbps. All categories can travel up to 100 m before suffering from attenuation and use RJ45 connector.

UTP Categories - Copper Cable

UTP Category	Data Rate	Max. Length	Cable Type	Application
CAT1	Up to 1Mbps	-	Twisted Pair	Old Telephone Cable
CAT2	Up to 4Mbps	-	Twisted Pair	Token Ring Networks
CAT3	Up to 10Mbps	100m	Twisted Pair	Token Ring & 10BASE-T Ethernet
CAT4	Up to 16Mbps	100m	Twisted Pair	Token Ring Networks
CAT5	Up to 100Mbps	100m	Twisted Pair	Ethernet, FastEthernet, Token Ring
CAT5e	Up to 1 Gbps	100m	Twisted Pair	Ethernet, FastEthernet, Gigabit Ethernet
CAT6	Up to 10Gbps	100m	Twisted Pair	GigabitEthernet, 10G Ethernet (55 meters)
CAT6a	Up to 10Gbps	100m	Twisted Pair	GigabitEthernet, 10G Ethernet (55 meters)
CAT7	Up to 10Gbps	100m	Twisted Pair	GigabitEthernet, 10G Ethernet (100 meters)

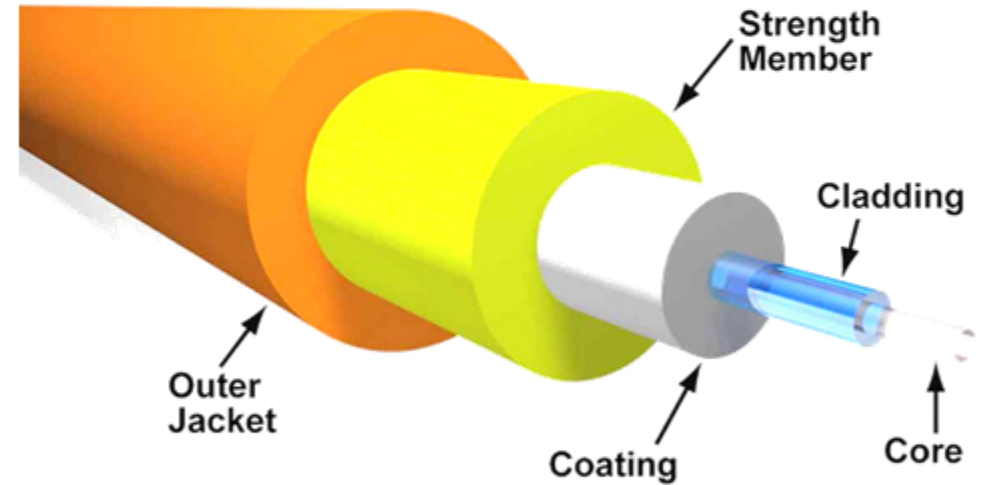
RJ 45 Connector



Physical Media (Network Cabling and Connectors)

Fiber Optic Cable:

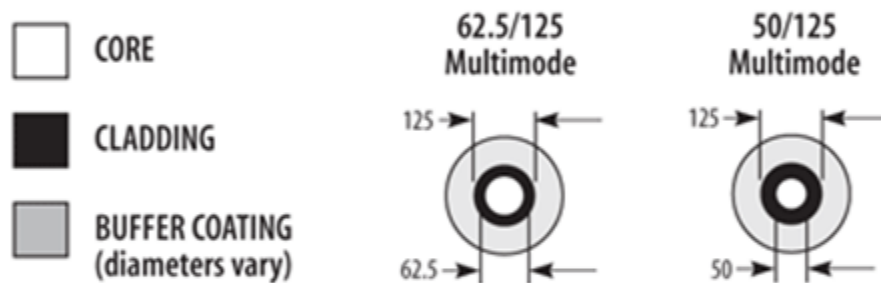
A fiber optic cable consists of a bundle of glass threads, each of which is using light pulses instead of electricity to transmit data. It has a greater bandwidth than metal cables, less susceptible to interference, very fast data speed for long distance. It may be [single-mode](#) or [multi-mode cable](#).



Physical Media (Network Cabling and Connectors)

Multi-Mode fiber:

A type of fiber optic-cable where the core diameter is much larger than the wavelength of light transmitted (all multi-mode cables transmit 850 nm wavelengths). Two common multi-mode fiber types are 50/125 and 62.5/125. Multi-Mode fiber uses LED (light emitting diodes) to send light signals and used in short distances within buildings.



Multimode


Source

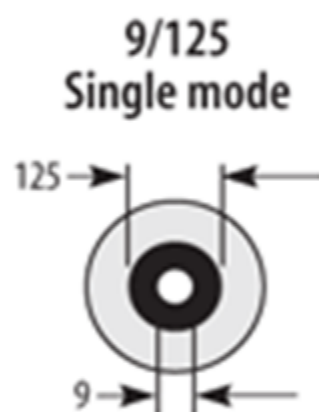
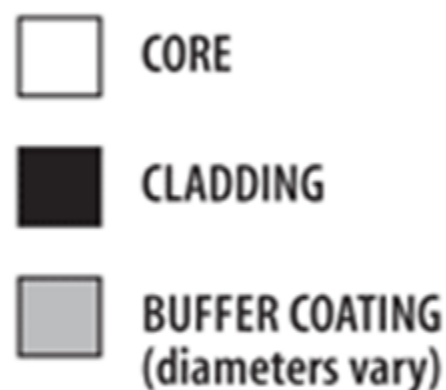
Fiber-Optic Cable


Cladding
Core

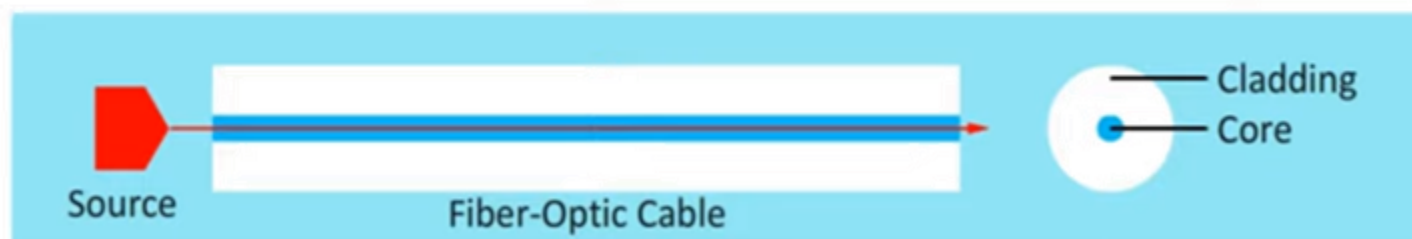
Physical Media (Network Cabling and Connectors)

Single-Mode fiber:

A type of fiber with a small core diameter less than (about ten times) the wavelength of the light transmitted (single-mode transmits either 1310 nm or 1550 nm wavelengths, depending on the laser). One common single-mode fiber type is 9/125. Single-Mode fiber uses laser to send light signals and used in long distance outside and between buildings.



Single-Mode



Physical Media (Network Cabling and Connectors)

Fiber-Optic connectors:

Fiber optic cables come in a broad choice of connector types. There are over one hundred different connectors, but the most four used in network today are **Straight Tip (ST)**, **Subscriber Connector (SC)**, **Lucent Connector (LC)**, and **Ferrule Core (FC)**.

Type	Applications
FC	Used with single mode fibers and used in telephone and high-speed communication links. The style is like that of an ST connector, but it uses a threaded connection, which makes it better suited for high vibration environments.
LC	Used in private and public networks, designed for duplex fiber-optic. They've become the standard for SFP modules and most modern network electronics.
SC	Used for high-density applications, and premises installations.
ST	Used for both single mode and multimode fiber optic. Inter-/Intra buildings.

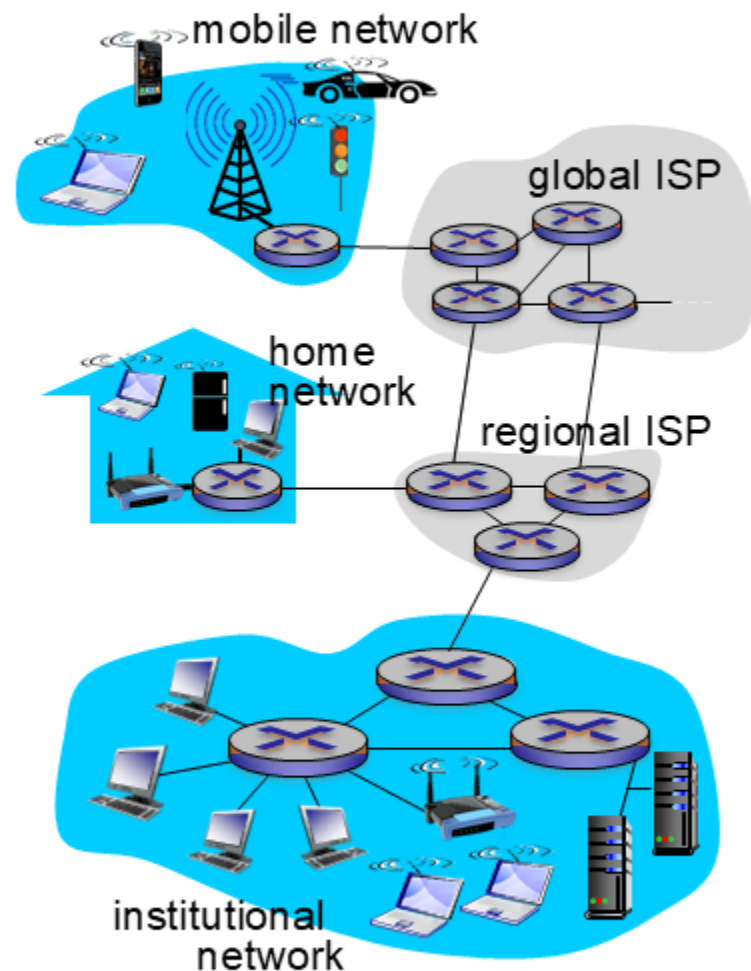
*SC Connector**LC Connector**ST Connector**FC Connector*

How to connect end systems to edge router?

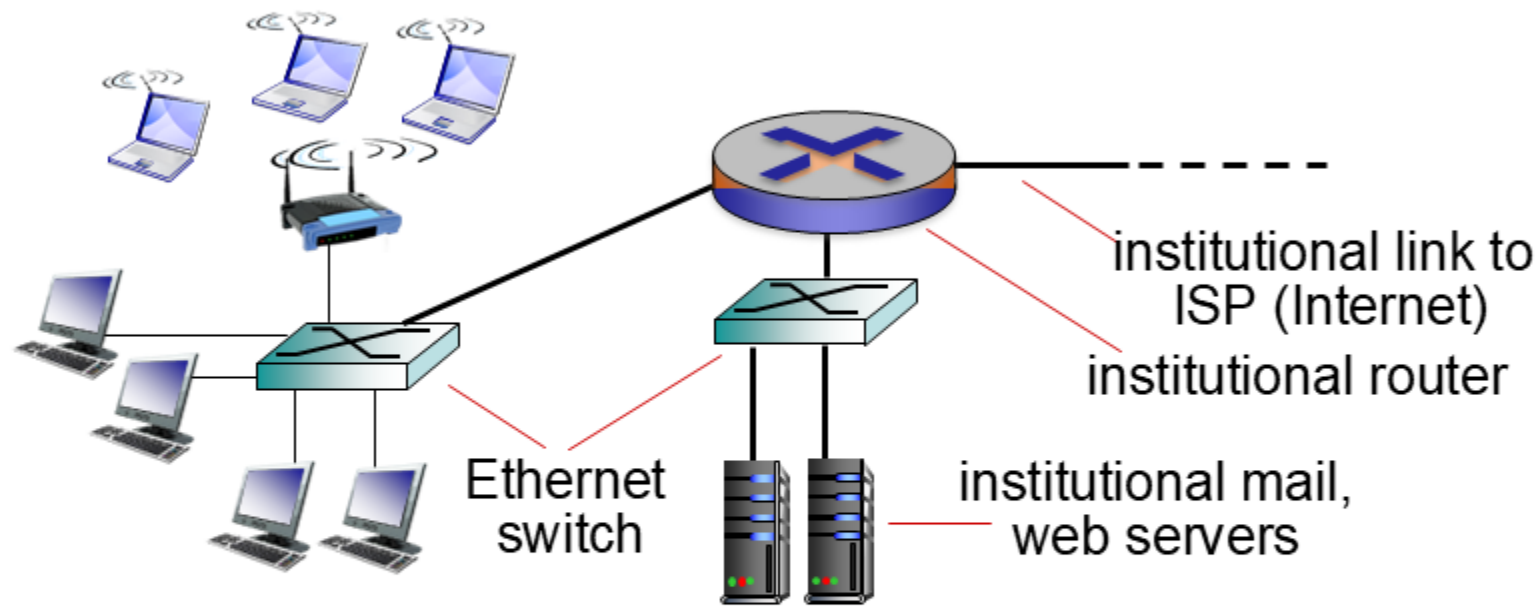
- Residential access nets (Home)
- Institutional access networks (school, company)
- Mobile access networks

keep in mind:

- Bandwidth (bits per second) of access network?
- Shared or dedicated?



Access Network; Ethernet



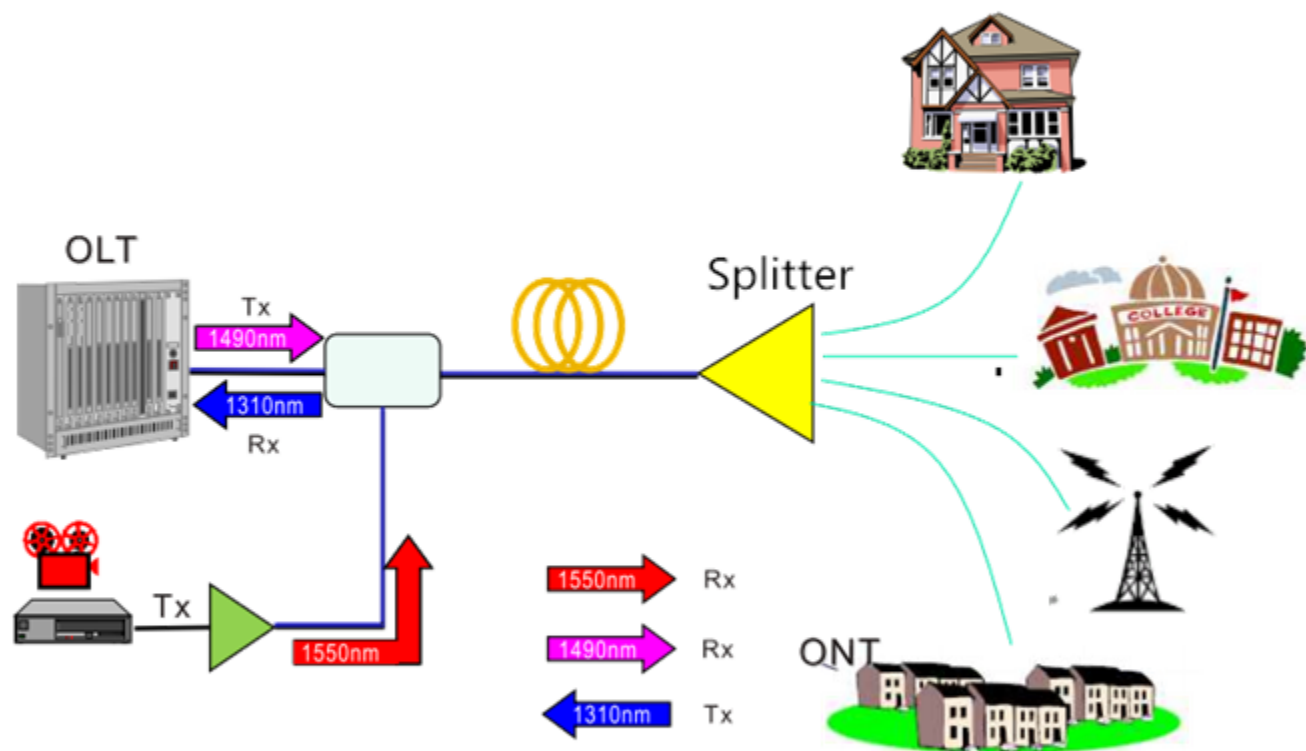
It is the most installed wired LAN technology uses coaxial cable or twisted pair wires. Typically used in Home, companies, universities, etc. the transmission rates today are 10 Mbps, 100Mbps, 1Gbps, 10Gbps. End systems typically connect into Ethernet switch.

The diagram illustrates the architecture of DSL access multiplexing. On the left, inside a house, a computer is connected to a DSL modem. The DSL modem is connected to a splitter, which is also connected to a telephone. A line from the splitter goes outside the house to a central office. In the central office, the line enters a DSLAM (DSL Access Multiplexer), represented by a blue trapezoidal device. The DSLAM is connected to a telephone network (represented by a black dot) and an ISP (Internet Service Provider) network (represented by four blue circular nodes). A red line connects the DSLAM to the ISP network. Labels include: 'DSL modem', 'splitter', 'central office', 'DSLAM', 'telephone network', and 'ISP'. A red line points from the text 'dedicated line to central office' to the line between the house and the central office. Another red line points from the text 'DSL access multiplexer' to the DSLAM.

voice, data transmitted
at different frequencies over
dedicated line to central office

DSL access
multiplexer

Fiber to the home (FTTH) uses optical fiber from a central Office (CO) directly to individual buildings and it provides high-speed Internet access among all access networks. it is the most expensive and most future-proof option amongst all these access networks.



Access Network; Wireless LANs

It links two or more devices using wireless communication within building (30.5m). It uses high-frequency radio waves and often include an access point for connecting to the Internet. The transmission rate are 11, 54, 450 Mbps.

Wide-area wireless access It sends or receives packets through a nearby (within 10's km) base station operated by the cellular network provider, 3G, 4G: LTE.

