



GLA UNIVERSITY

COMPUTER NETWORK

By:
Dr. Ankush Agarwal

Outline

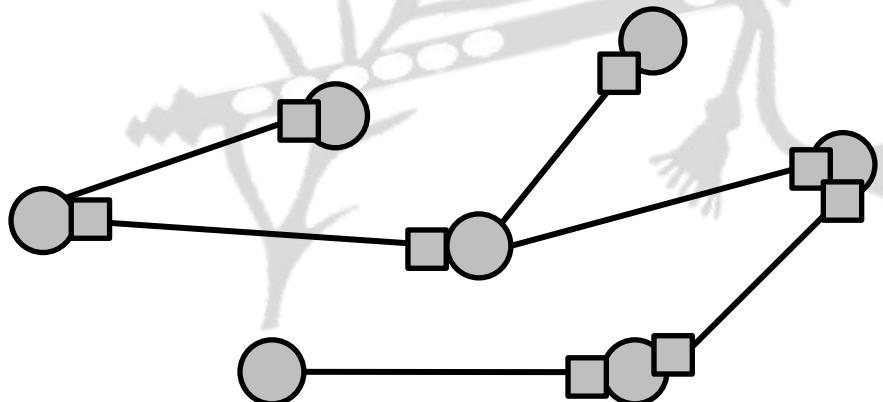
- **Introduction Concepts:**
 - Goals and Applications of networks
 - Network structure and architecture
 - The OSI reference model and services
 - Network topology design
 - Physical Layer Transmission Media
 - Line coding scheme
 - Switching methods (circuit switching, Packet switching)
 - TDM

INTRODUCTION CONCEPTS

Introduction

Network

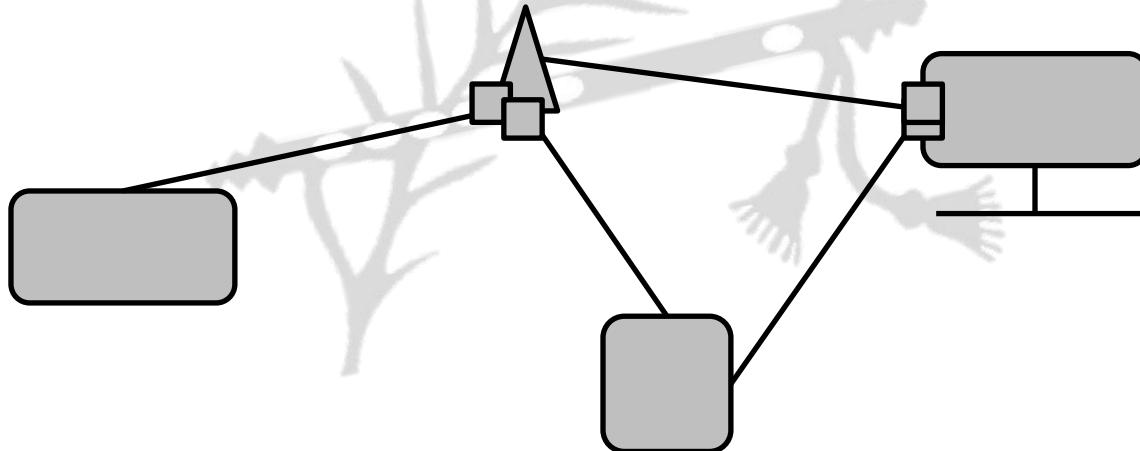
- It is defined as a medium which is responsible for carrying the data from one node to another
- Eg: intranet, internet, PAN, etc



Introduction

Computer Network

- A computer network is comprised of nodes and links
- A node is the end point whereas links are the medium
- It is defined as a network through which one system can communicate with the other system



Goals of network

The main goals of network are:

- Resource sharing
 - Eg: printer on network, shared drives, etc
- High reliability
 - Eg: alternative sources, multiple copies, etc
- Increase system utilization
 - Eg: load sharing, pooling, etc
- Powerful communication medium
 - Eg: update is reflected immediately

Application of network

The main applications of network are:

- Accessing web
- File transfer
- File sharing
- Remote procedure call
- Remote method invocation, etc

Network architecture

- Network architecture is the design of a computer network
- It is a framework for the specification of a network's physical components and their functional organization
- It also defines the set of rules which are followed during communication (also known as protocols)
- Network architecture refers to the way network devices and services are structured to serve the connectivity needs of client devices
- A architecture defines how the computers should get connected to get the maximum advantages of a computer network such as better response time, security, scalability, etc

Network architecture

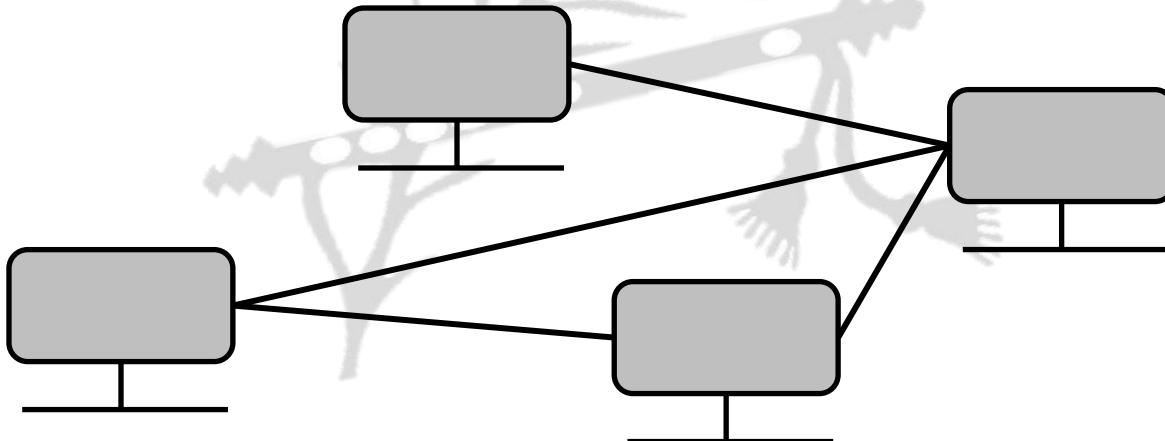
The two most common network architecture are

- Peer-to-Peer
 - Known as P2P
- Client-Server
 - Known as tiered



P2P architecture

- All the nodes in a network are inter-connected with every other nodes
- There is no one who acts as a master (also known as server) for all, rather all acts as a master independently
- It is useful for small environment



P2P architecture

Advantages

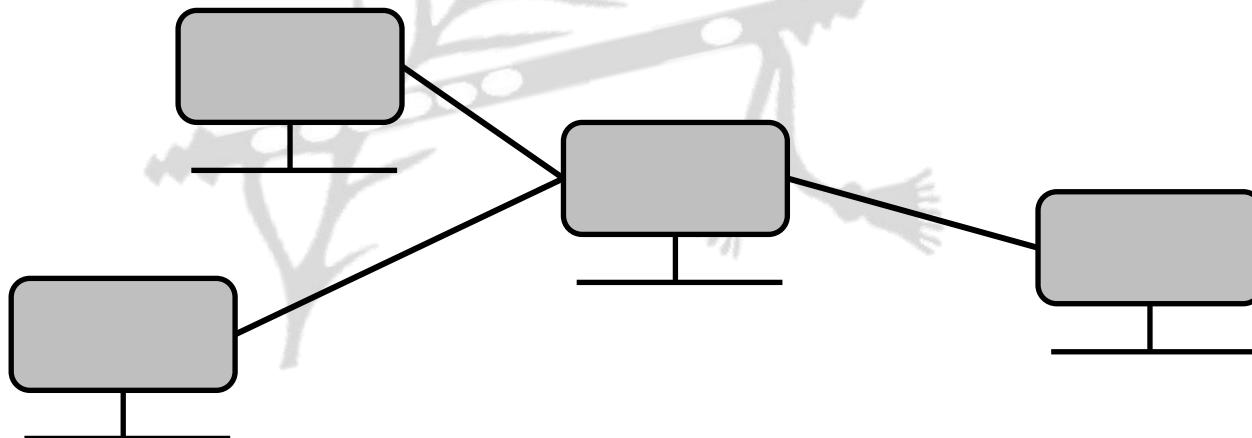
- Less costly as there is no central server
- In case of a node failure, other nodes in the network are not affected
- Installation is quite easy

Disadvantages

- Each computer has to take the backup of its own
- Security measures are to be taken by all the nodes independently
- Scalability is a issue

Client-Server architecture

- All the nodes in a network are connected with the central node (known as master/server)
- The master node receive request from all the other nodes (clients) and respond their request



Client-Server architecture

Advantages

- Data backup is easy
- Performance is better as the response time is greatly improves
- Security is better as unauthorized access are denied by server
- Scalability is not an issue in this architecture as large number of computers can be connected with server.

Disadvantages

- In case of server failure, the entire network is down.
- Server maintenance cost is high
- Cost is high

Network topology

- The topology defines how the nodes in the network are connected
- It also defines the flow of data from one node to another
- There are five types of topologies defines
 - Mesh topology
 - Star topology
 - Bus topology
 - Ring topology
 - Hybrid topology

Network topology

Mesh topology

- In this topology, each node is connected to every other node in the network
- Implementing the mesh topology is expensive and difficult
- In this type of topology, each node may send message to destination through multiple paths
- While the data is travelling, it is automatically configured to reach the destination by taking the shortest route which means the least number of hops

Network topology

Star topology

- Each node is connected to a central device called a hub
- The hub takes a request from any node and pass it to the other node
- Data on a star topology passes through the hub, switch, or concentrator before continuing to its destination
- The hub, switch, or concentrator manages and controls all functions of the network
- The star topology reduces the chance of network failure by connecting all of the systems to a central node

Network topology

Bus topology

- All the nodes topology are connected by one single cable
- A bus topology consists of a main run of cable with a terminator at each end. All nodes (file server, workstations, and peripherals) are connected to the linear cable
- Popular on LANs because they are inexpensive and easy to install

Network topology

Ring topology

- In a ring topology, every device has exactly two neighbors for communication purposes.
- All messages travel through a ring in the same direction.
- A failure in any cable or node breaks the loop and can take down the entire network
- To implement a ring network we use the Token Ring technology
- A token, or small data packet, is continuously passed around the network. When a device needs to transmit, it reserves the token for the next trip around, then attaches its data packet to it

Network topology

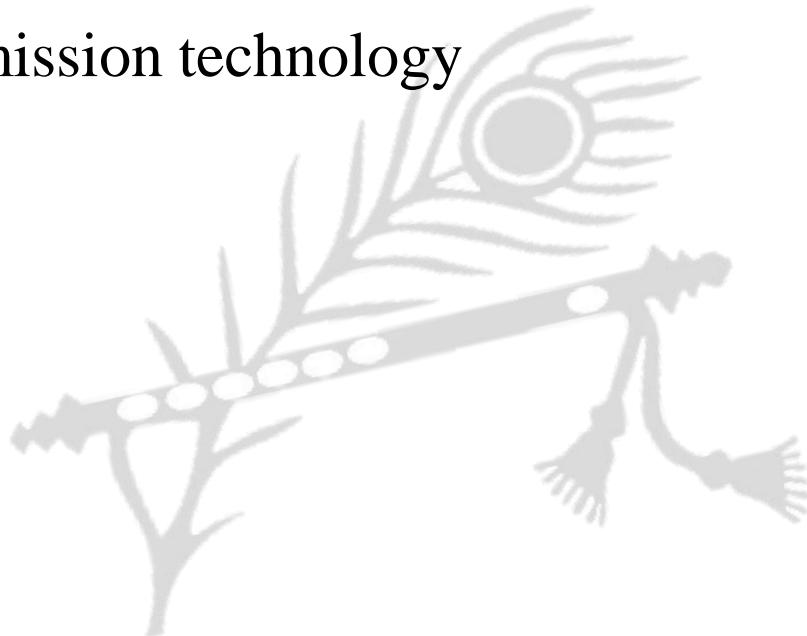
Hybrid topology

- A combination of any two or more network topologies
- A hybrid topology always accrues when two different basic network topologies are connected
- It is a mixture of above mentioned topologies. Usually, a central computer is attached with sub-controllers which in turn participate in a variety of topologies

Network Technologies

It can be classified under two category

- Based on transmission technology
- Based on scale



Network Technologies

Based on transmission technology

- Broadcast
 - Broadcast network have a single communication channel that is shared by all the nodes on the network
- Point to point
 - There may exist multiple paths between a source-destination pair and the nodes in between provide a route to move the data from one to other until it reach to the destination

Network Technologies

Based on scale

- Local Area Network (LAN)
- Metropolitan Area Network (MAN)
- Wide Area Network (WAN)

Network Technologies

Based on scale

- LAN
 - usually privately owned
 - used to links the devices in a single office, building or campus of up to few distance
 - restricted in size
 - run at speeds of 10 to 100 Mbps (but now much higher speeds can be achieved)
 - most common topologies are bus, ring and star

Network Technologies

Based on scale

- **MAN**
 - designed to extend over the entire city
 - may be a single network or a connection of number of LANs

Network Technologies

Based on scale

- WAN
 - provides long-distance transmission of data over large geographical areas that may comprise a country, continent or even the globe
 - not restricted in size

What is a network?

Every network includes:

- At least two nodes
- A cable or wireless pathway, called Transmission Media
- Rules, called Protocols, so that computers can use the unified principle of data communication
- Networking Interface Cards (NIC)

Why Layered Architecture?

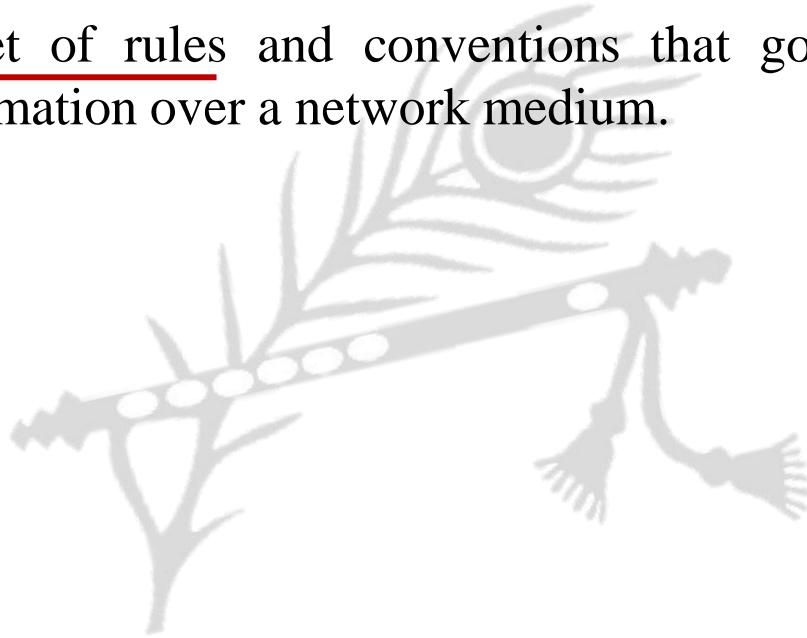
- To make the design process easy by breaking unmanageable tasks into several smaller and manageable tasks (by divide-and-conquer approach)
- Modularity and clear interfaces, so as to provide comparability between the different providers' components
- Ensure independence of layers, so that implementation of each layer can be changed or modified without affecting other layers
- Each layer can be analyzed and tested independently of all other layers

OSI reference model

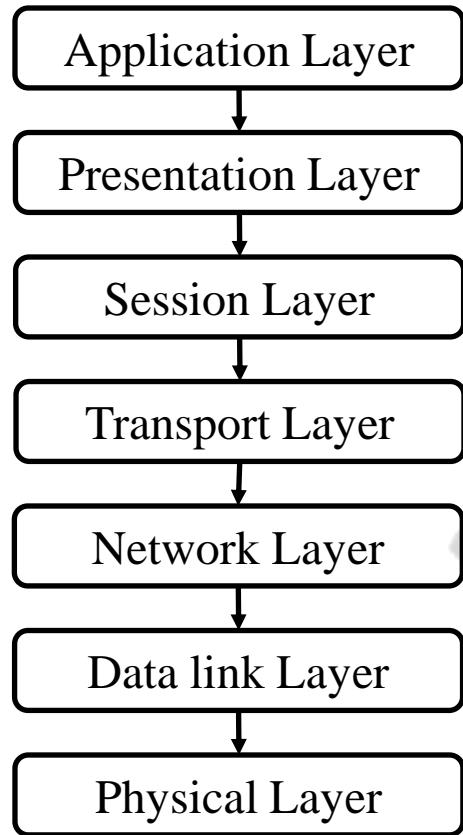
- OSI stands for Open Systems Interconnection
- It has been developed by ISO – “International Organization of Standardization”
- It is a 7 layer architecture
- Each layer is responsible for specific functionality
- All these 7 layers work collaboratively to transmit the data from one end (top to bottom) and receive the data at other end (bottom to top)

OSI reference model (terminology)

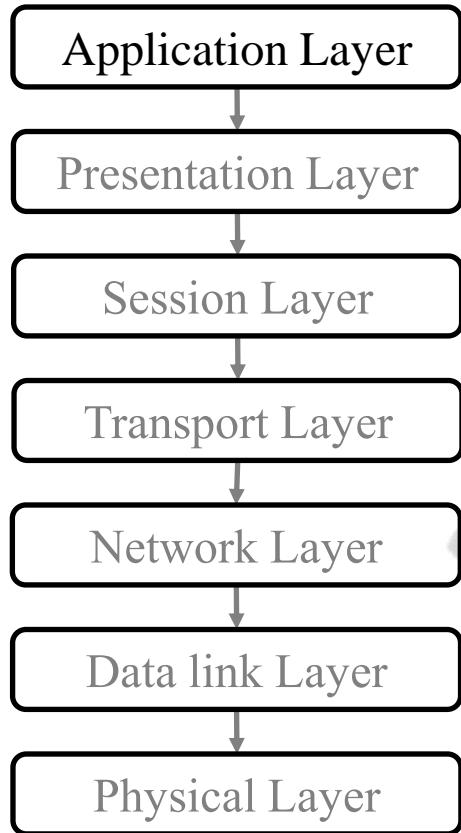
- Protocol
 - is a formal set of rules and conventions that governs how computers exchange information over a network medium.



OSI reference model

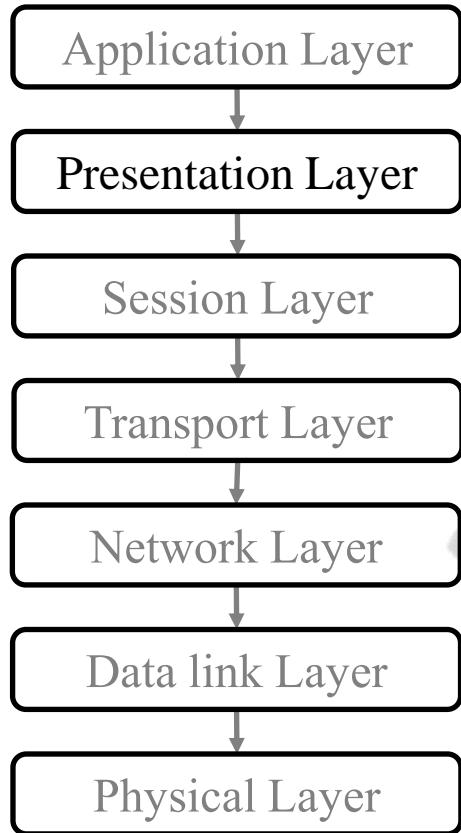


OSI reference model and its services



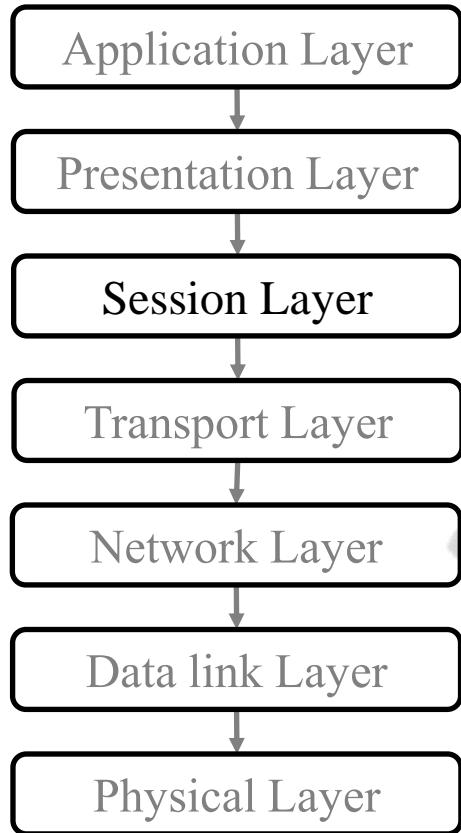
- This layer is responsible to generate the data, which has to be transferred over the network
- Eg: browser

OSI reference model and its services



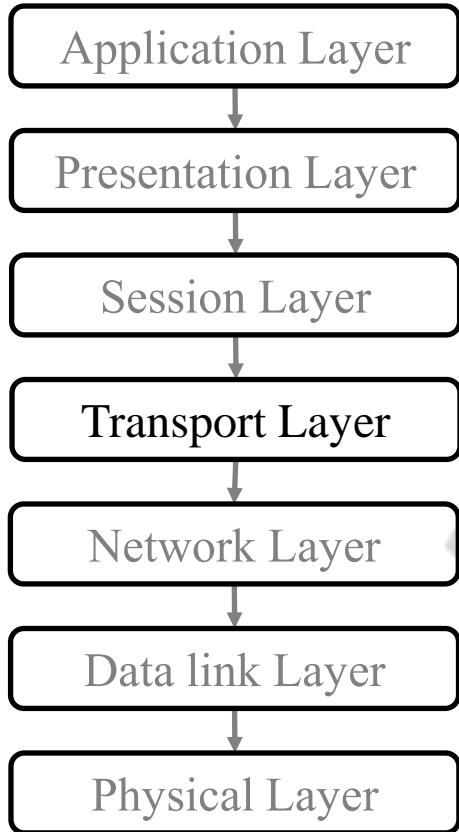
- The data from the application layer is extracted here and converted as per the required format to transmit over the network
- The functions of the presentation layer are :
 - Translation
 - Encryption/ Decryption
 - Compression

OSI reference model and its services



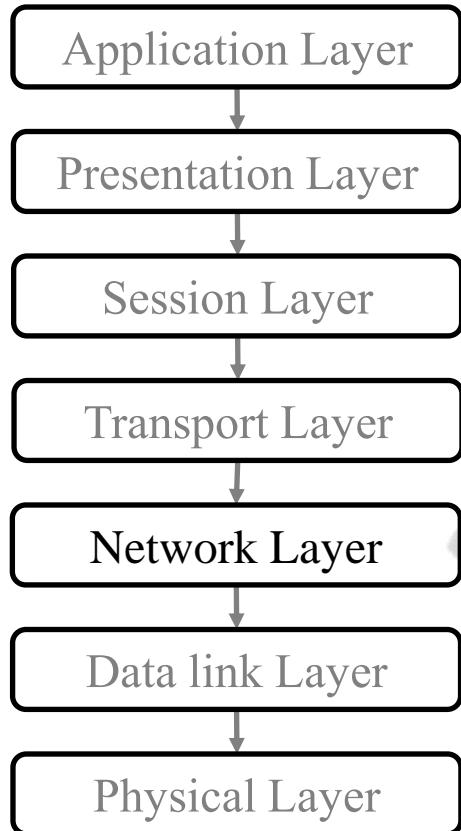
- This layer is responsible for establishment of connection, maintenance of sessions, authentication and security

OSI reference model and its services



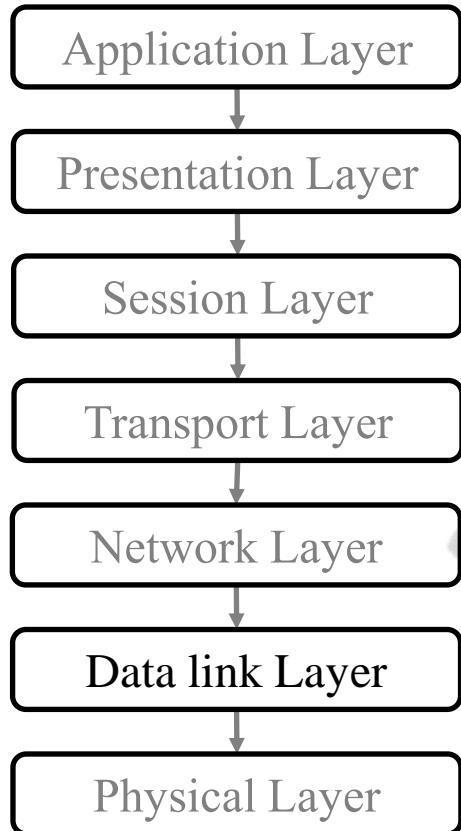
- The data in the transport layer is referred to as segments
- It is responsible for the End to End delivery of the complete message
- The transport layer also provides the acknowledgement of the successful data transmission and re-transmits the data if an error is found
- Two type of services are provided:
 - Connection oriented
 - Connection less

OSI reference model and its services



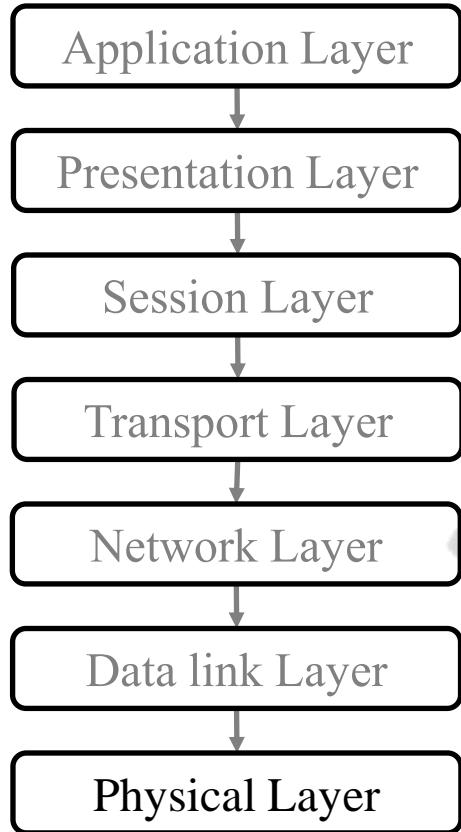
- Network layer works for the transmission of data
- It also takes care of packet routing i.e. selection of the shortest path
- The sender & receiver's IP address are placed in the header by the network layer.

OSI reference model and its services



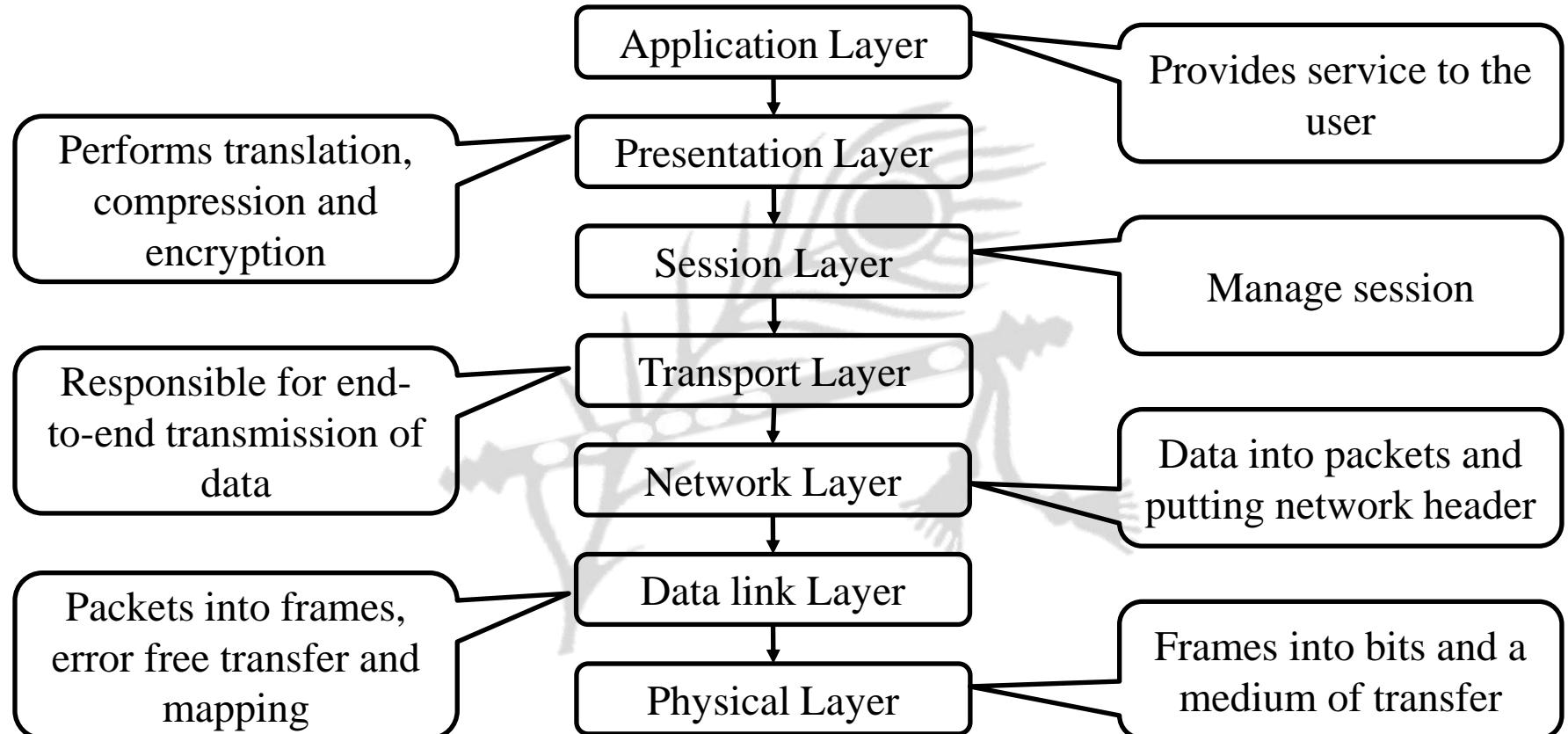
- The main function of this layer is to make sure data transfer is error-free from one node to another, over the physical layer
- When a packet arrives, it is the responsibility of DLL to transmit it to the Host using its MAC address.
- Data Link Layer is divided into two sub layers :
 - Logical Link Control (LLC)
 - Media Access Control (MAC)

OSI reference model and its services

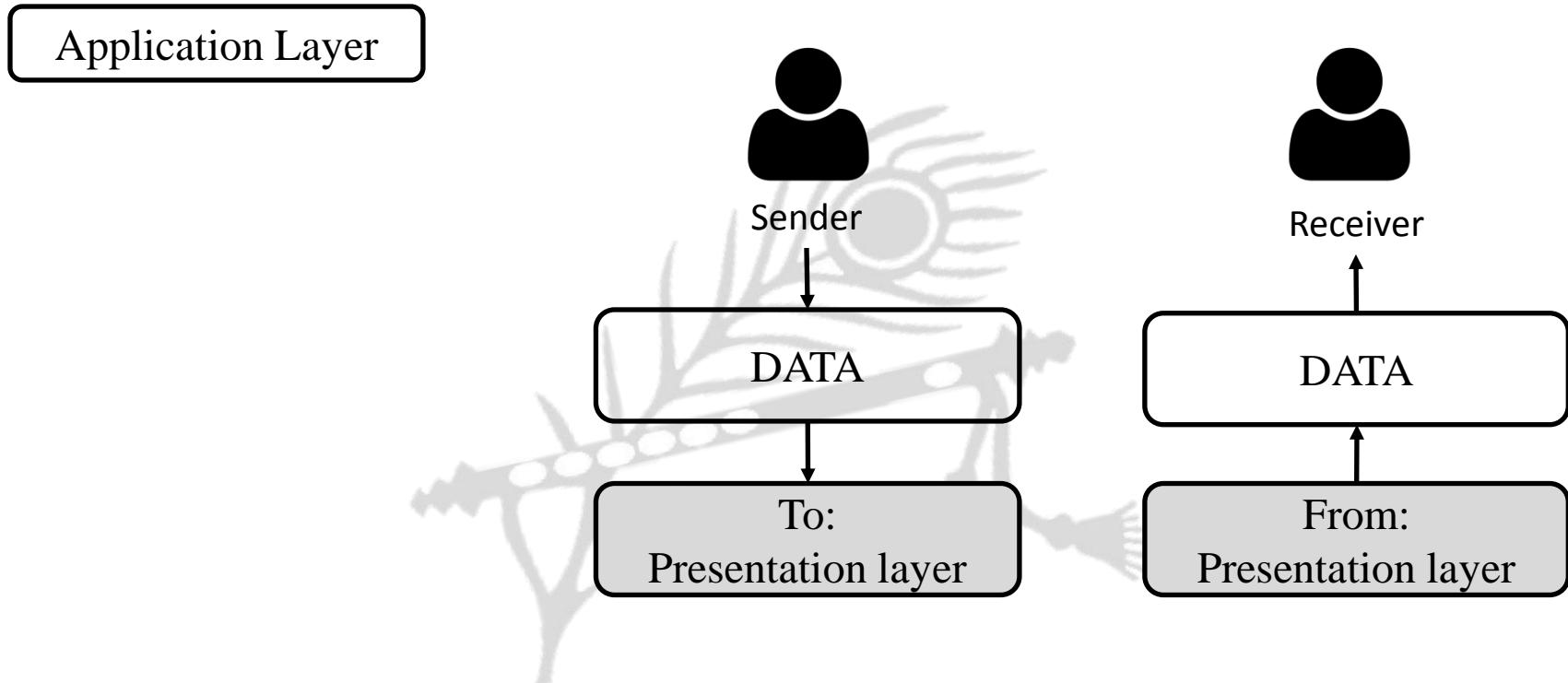


- It is responsible for the actual physical connection between the devices
- The physical layer contains information in the form of bits
- It is responsible for transmitting individual bits
- When receiving data, this layer will get the signal and convert it into 0s and 1s and send them to the Data Link layer, which will put the frame back together.

OSI reference model and its services (in brief)



OSI reference model and its services (review)

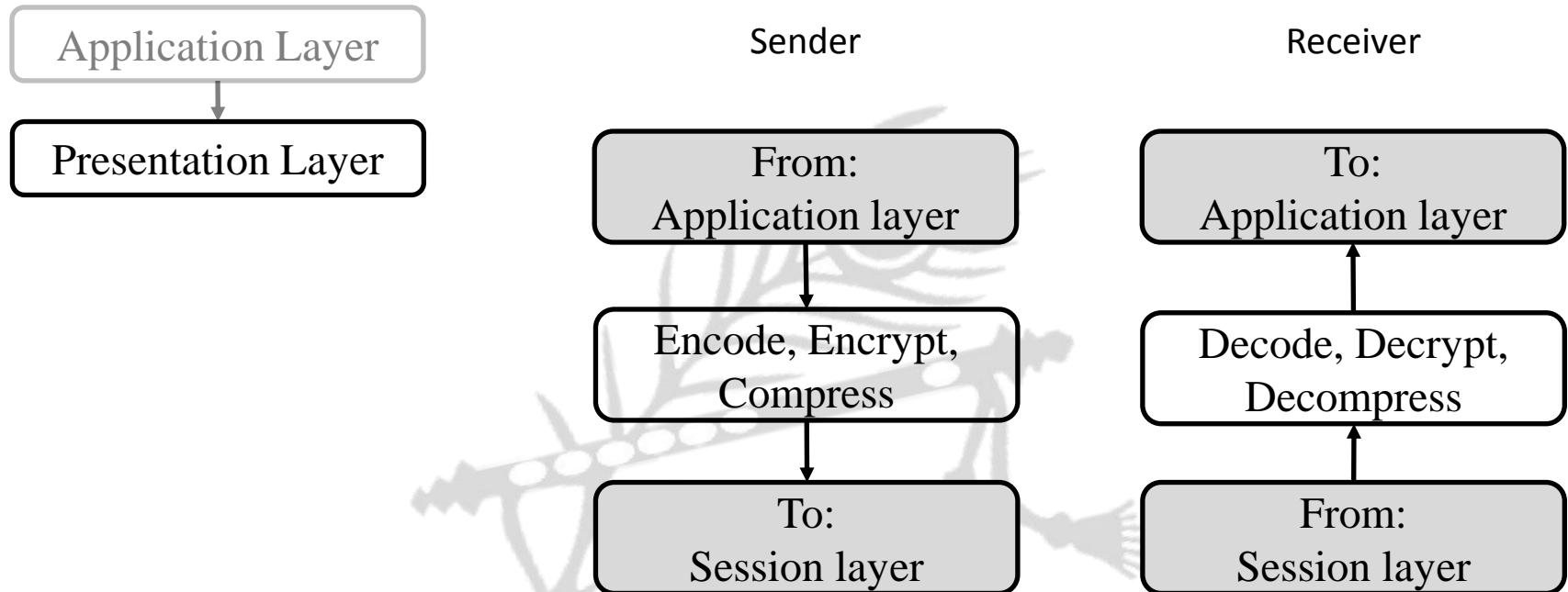


OSI reference model and its services (review)

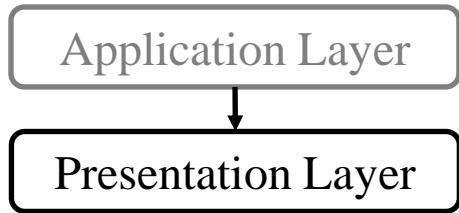
Application Layer

- responsible for generating the data
- contains a variety of protocols that are commonly needed by users
 - HTTP
 - FTP
 - SMTP

OSI reference model and its services (review)

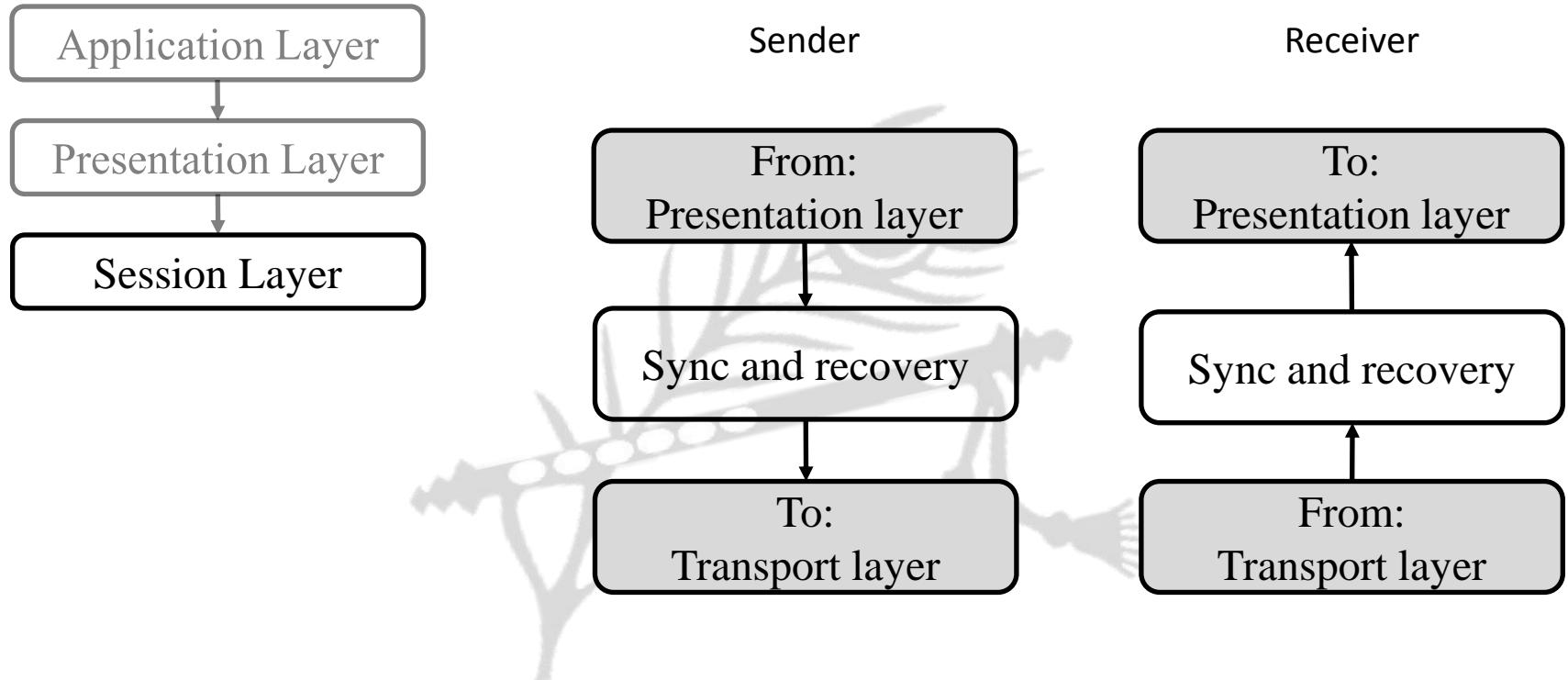


OSI reference model and its services (review)

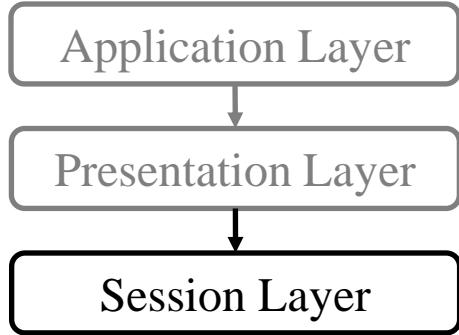


- Purpose
 - Make it possible for computers with different data representations to communicate
- Concerns
 - Syntax and semantics of information transmitted
 - Understands the nature of the data being transmitted
 - Converts ASCII, EBCDIC, etc

OSI reference model and its services (review)

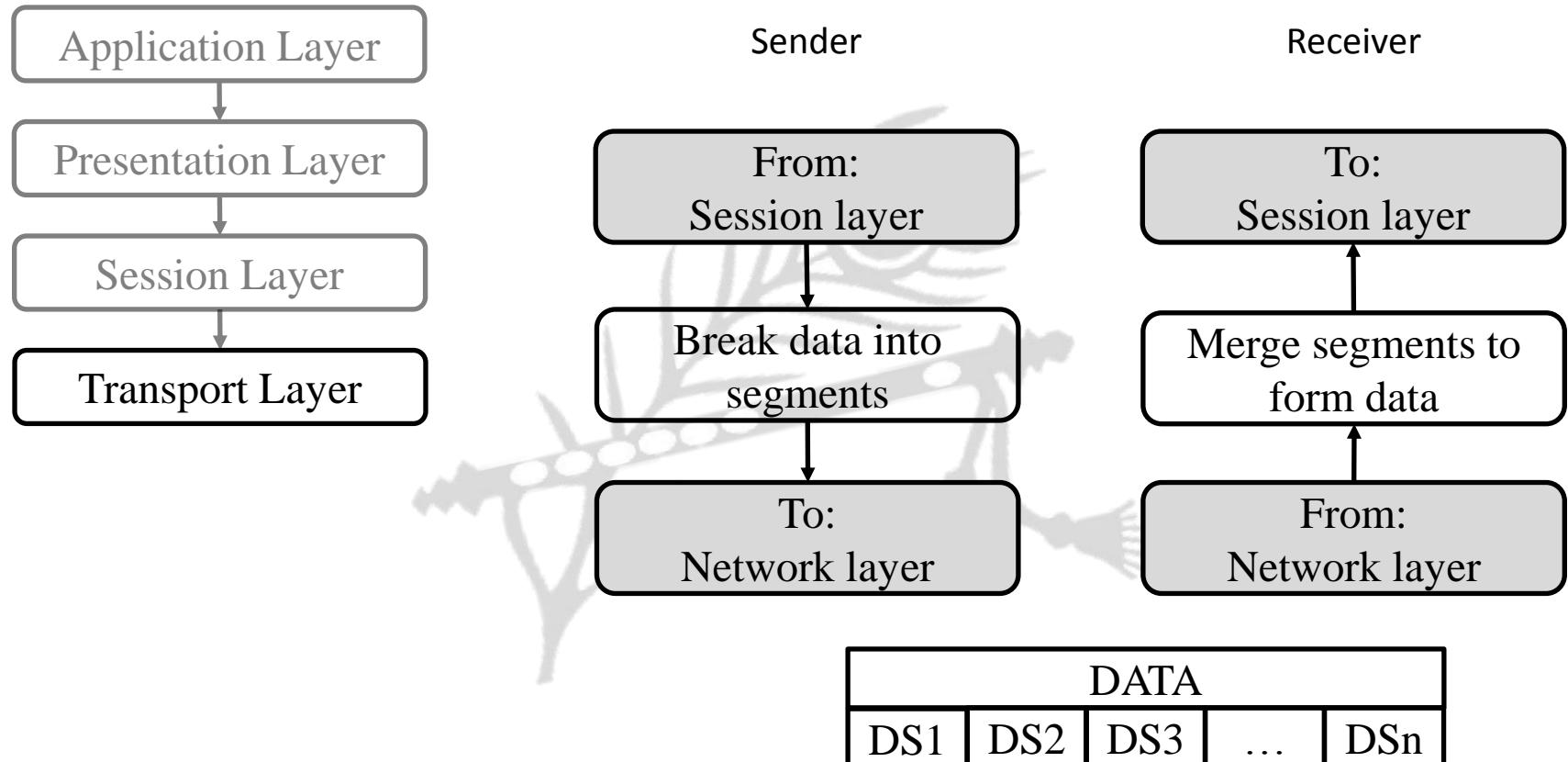


OSI reference model and its services (review)

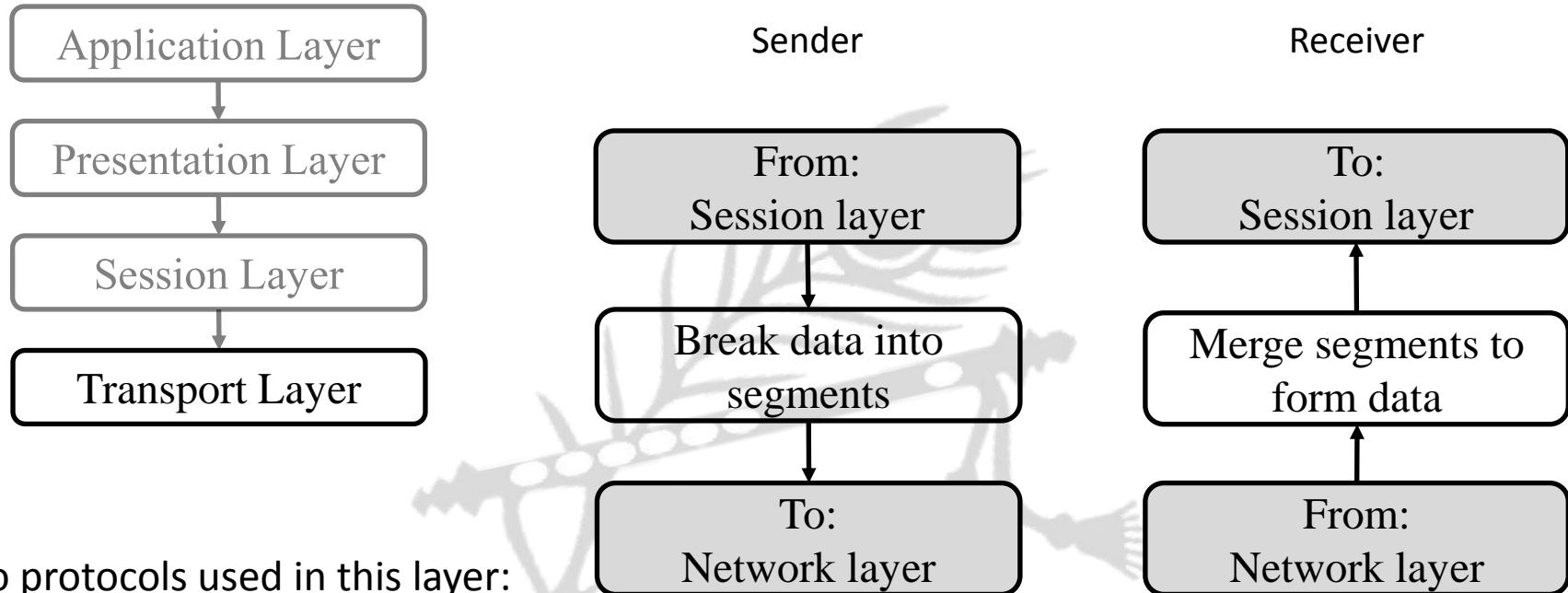


- Purpose
 - Allow users on different machines to establish sessions between them
- Concerns
 - Authentication and authorization
 - Check Pointing
 - Dialog control
 - Logical grouping of operation
 - Synchronization

OSI reference model and its services (review)



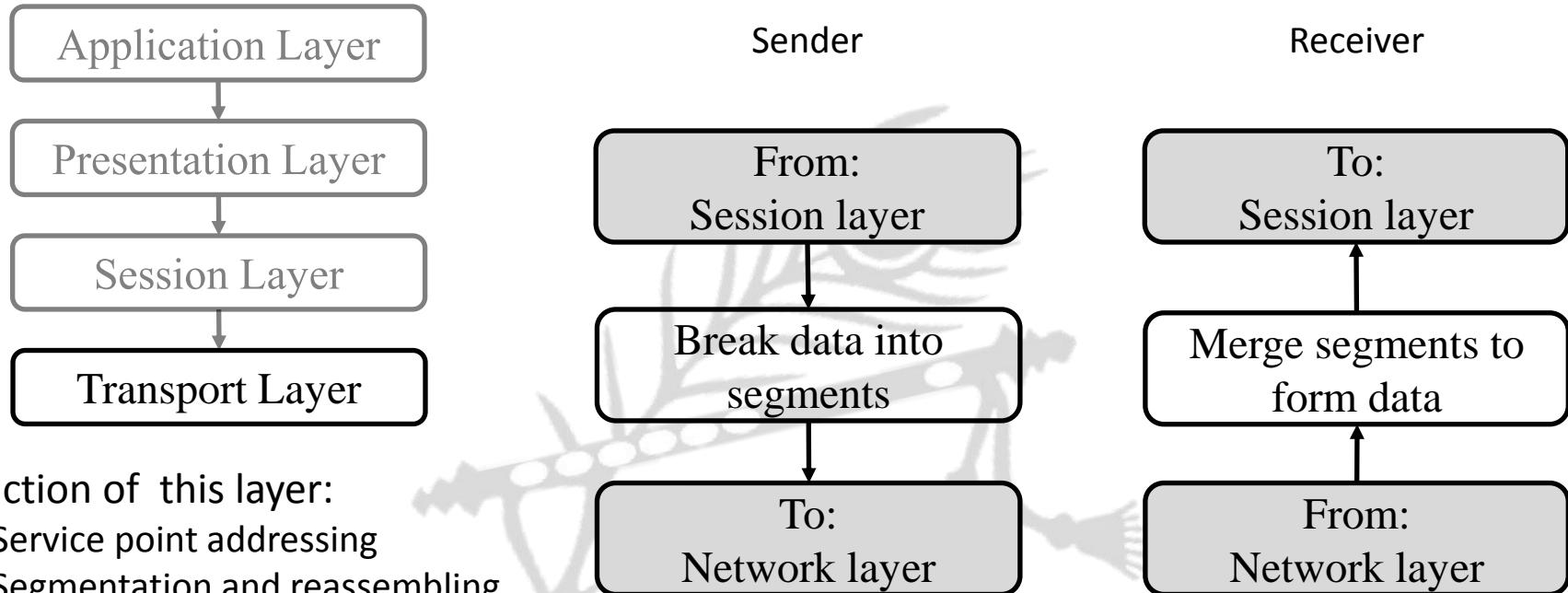
OSI reference model and its services (review)



Two protocols used in this layer:

- TCP – follow same route
- UDP – may follow same route

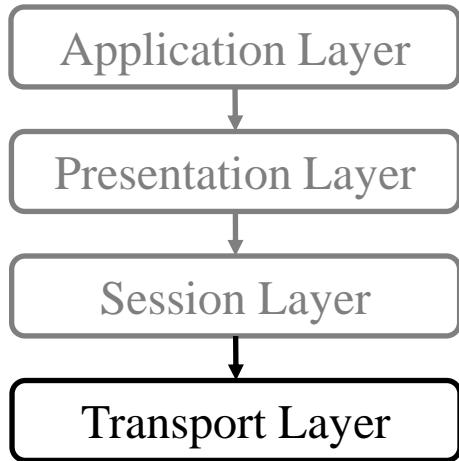
OSI reference model and its services (review)



Function of this layer:

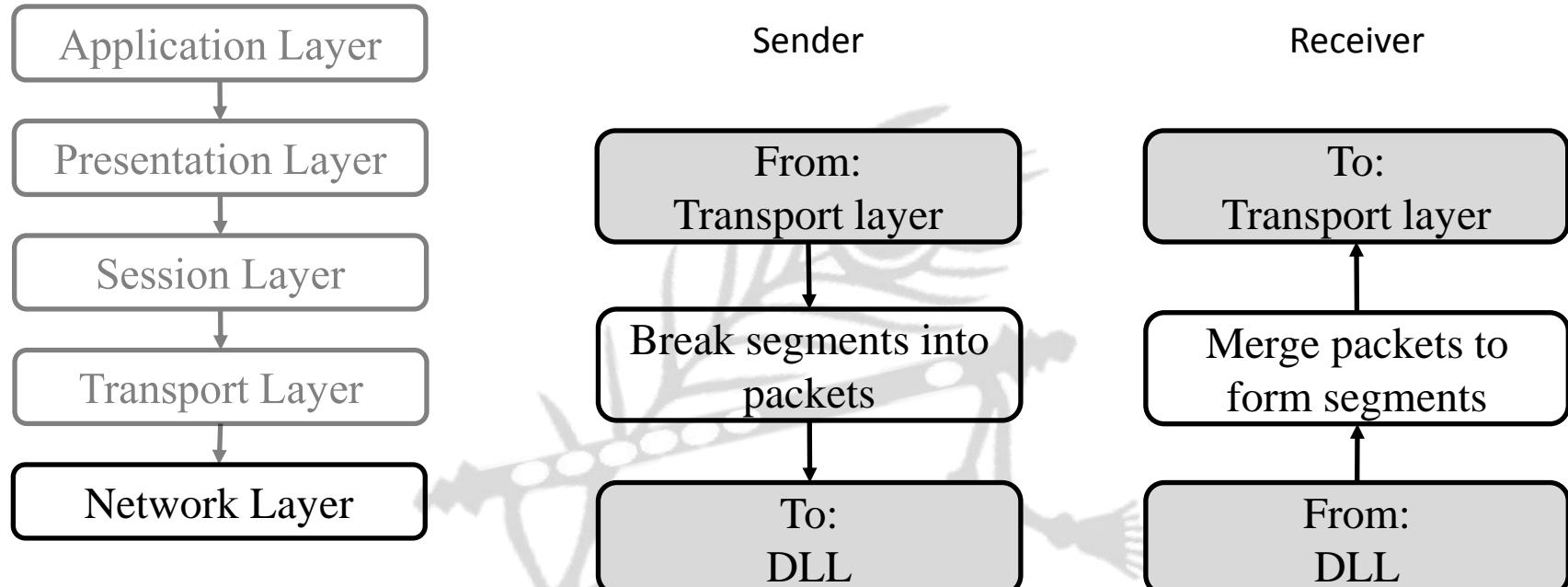
- Service point addressing
- Segmentation and reassembling
- Connection control
- Flow control
- Error control

OSI reference model and its services (review)



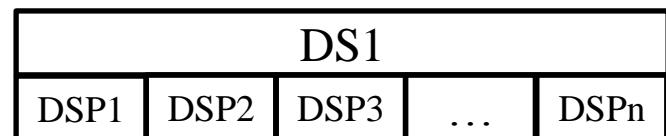
- Purpose
 - Accept data from above it, split it up into smaller units, pass them to network layer, and ensure that the pieces all arrive correctly at the other end
- Concerns
 - Service Decisions: What type of service to provide; error-free point to point, datagram, etc
 - End-to-end: it carries data all the way from the source to the destination
 - Reliability: Ensures that packets arrive at their destination
 - Hides network: Allows details of the network to be hidden from higher level layers
 - Mapping: Determines which messages belong to which connection
 - Flow control: keeps a fast transmitter from flooding a slow receiver

OSI reference model and its services (review)

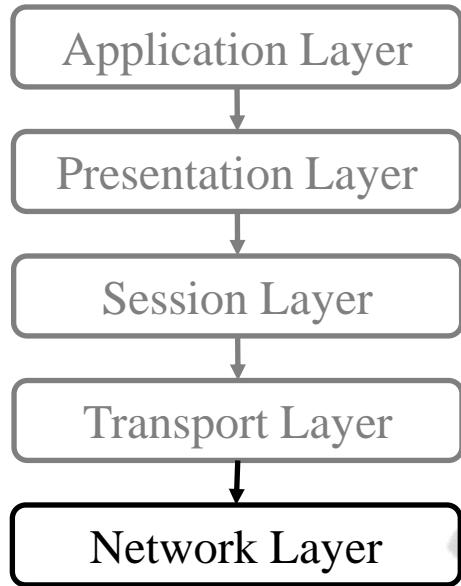


Protocol used:

- IP

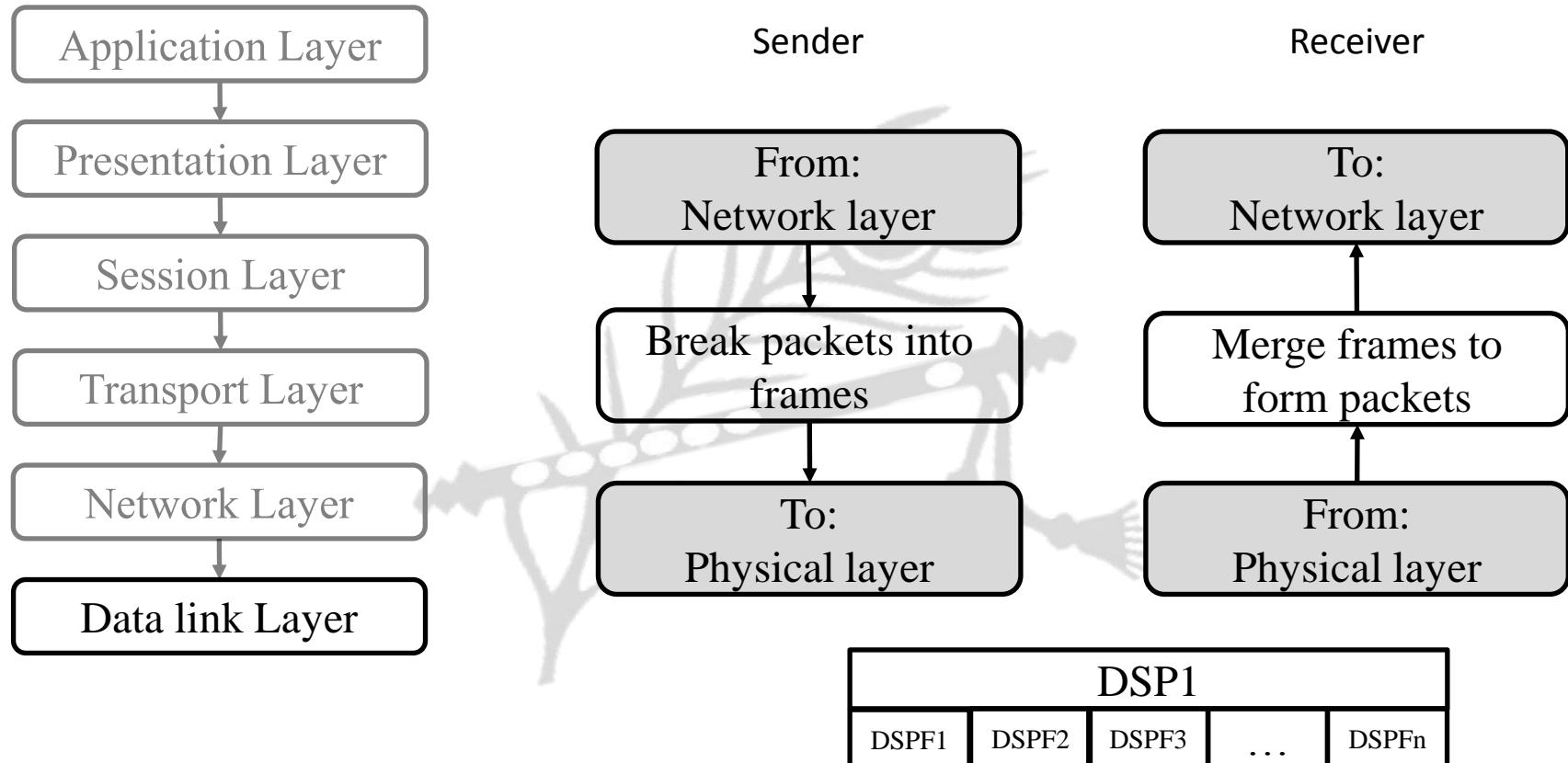


OSI reference model and its services (review)

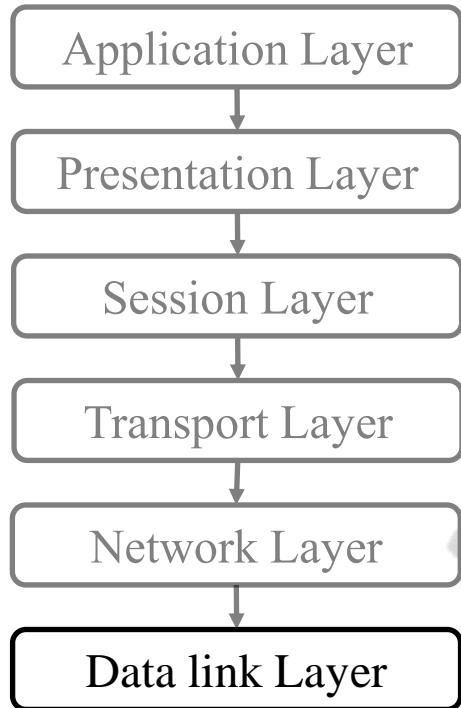


- Purpose
 - Route packets from source to destination
- Concerns
 - Routing: What path is followed by packets from source to destination. Can be based on a static table, can be determined when the connection is created, or can be highly dynamic, being determined anew for each packet, to reflect the current network load
 - Congestion: Controls the number of packets in the subnet
 - QoS: Quality of Service provided
 - Fragmentation
 - Heterogeneity: Interfacing so that one type of network can talk to another
 - Addressing, packet size, protocols

OSI reference model and its services (review)



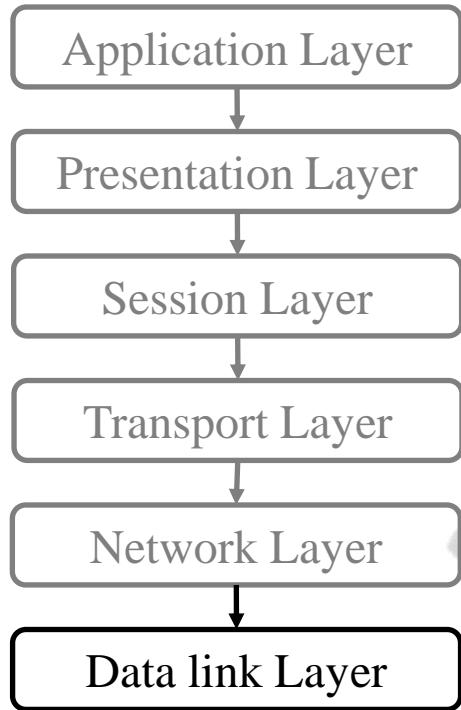
OSI reference model and its services (review)



It contains two sub-layers:

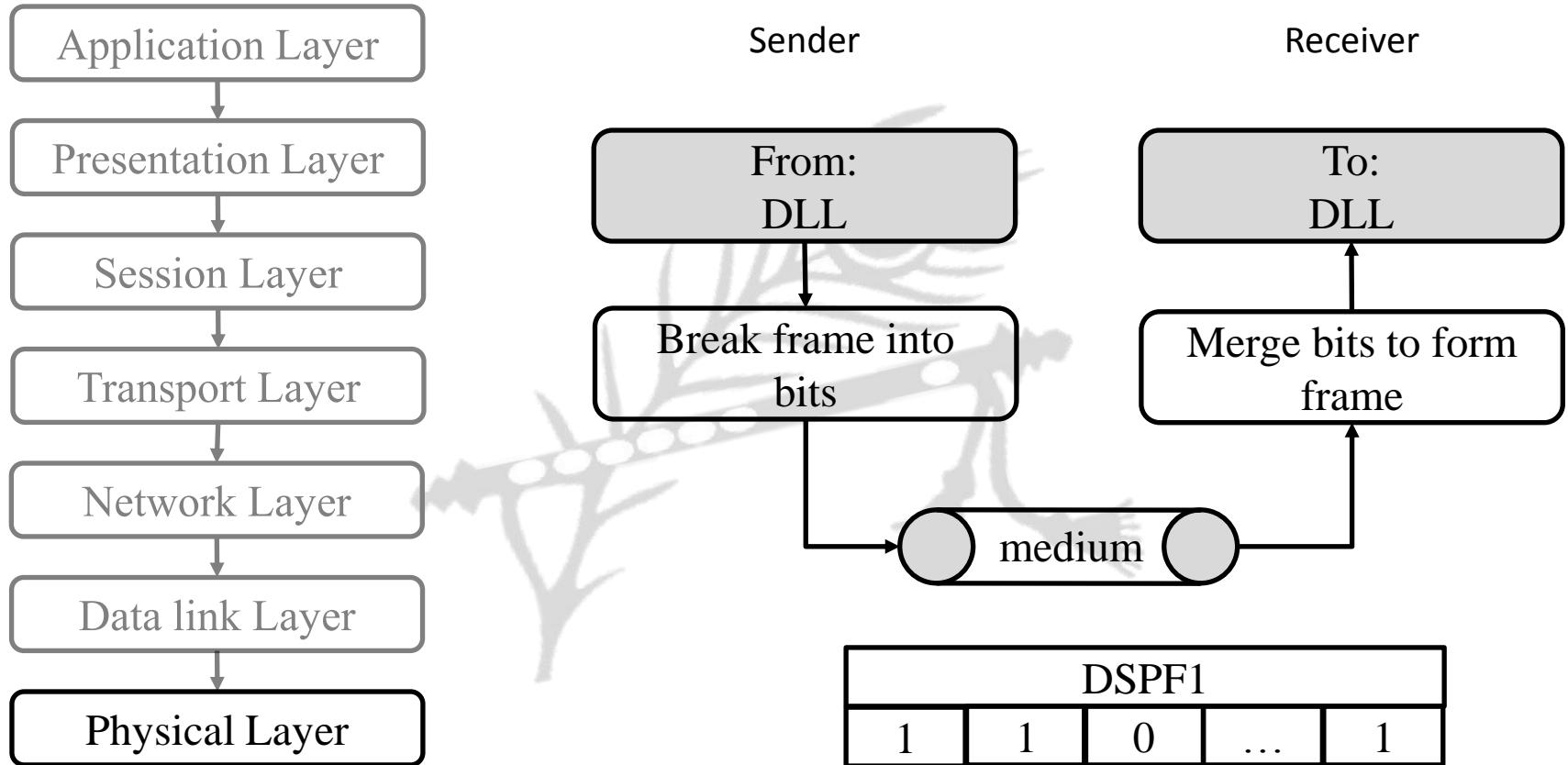
- **Logical Link Control Layer**
 - It identifies the address of the network layer protocol from the header
 - It also provides flow control
- **Media Access Control Layer**
 - A Media access control layer is a link between the Logical Link Control layer and the network's physical layer

OSI reference model and its services (review)

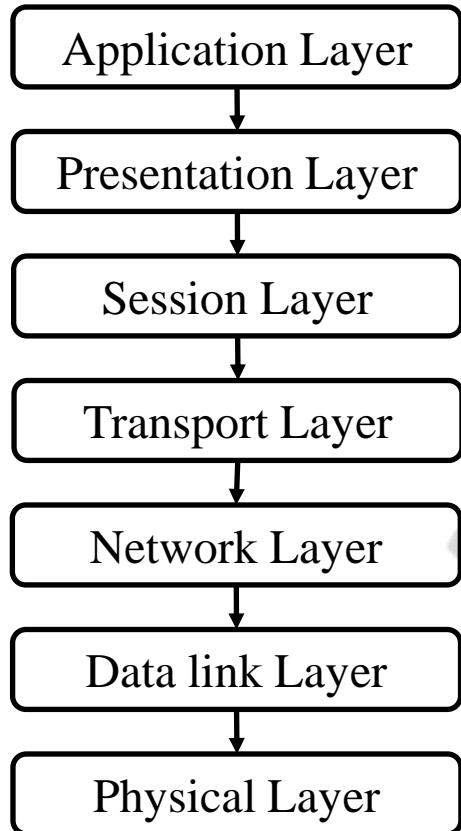


- Purpose
 - Transform a raw transmission line into a line that appears free of undetected transmission errors to the networks layer
- Concerns
 - Framing: Breaks apart input data into frames and transmit the frames sequentially
 - Error handling: if the service is reliable, the receiver confirms correct receipt of each frame by sending back an acknowledgement frame
 - Flow control: keeps a fast transmitter from drowning a slow receiver in data
 - Physical Addressing
 - Access Control (CSMA/CD, Token passing)

OSI reference model and its services (review)

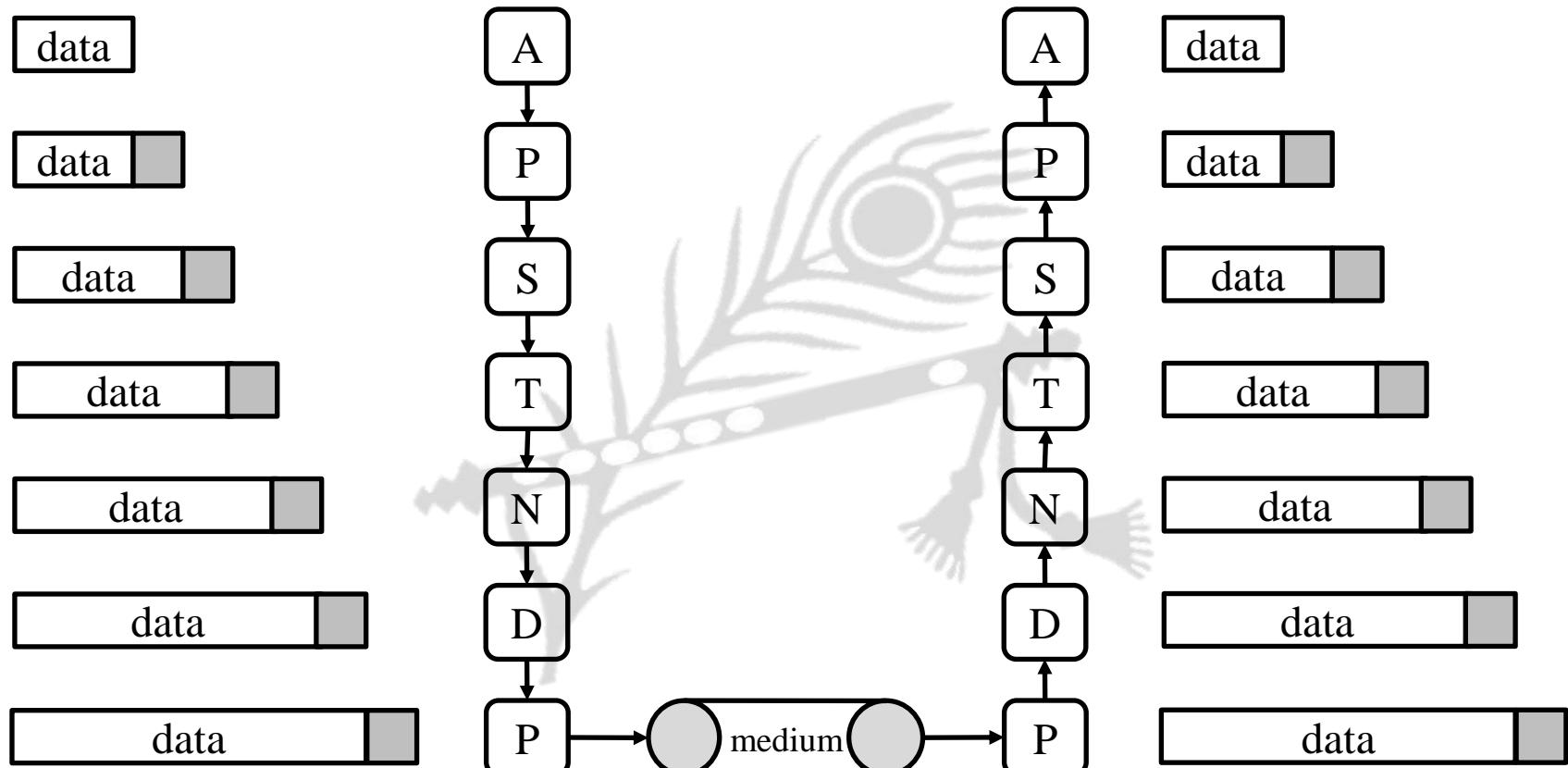


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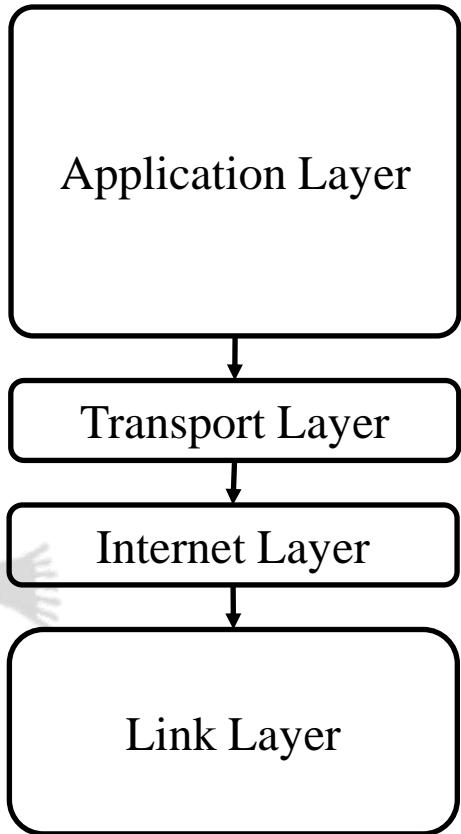
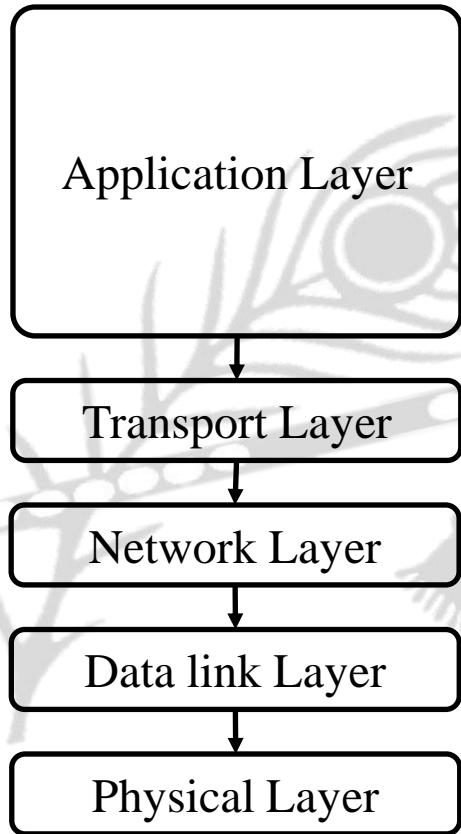
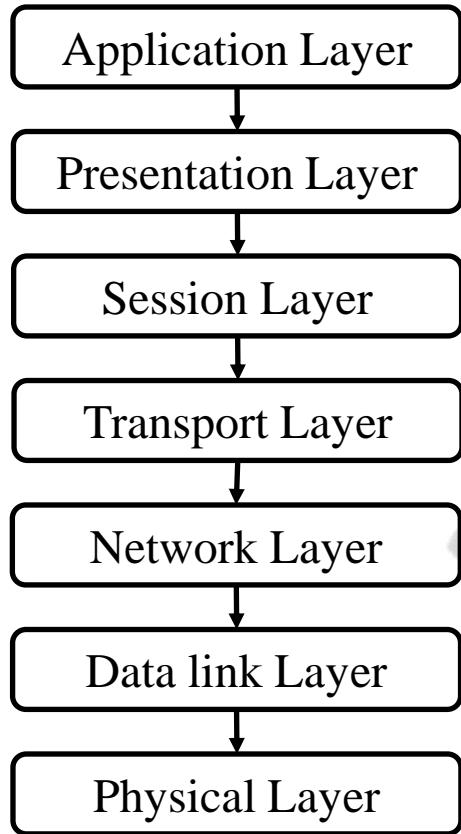


- Purpose
 - Transmits raw bits across a medium
- Functional
 - Flow of data (simplex, half duplex, full duplex)
 - Topology
 - Encoding

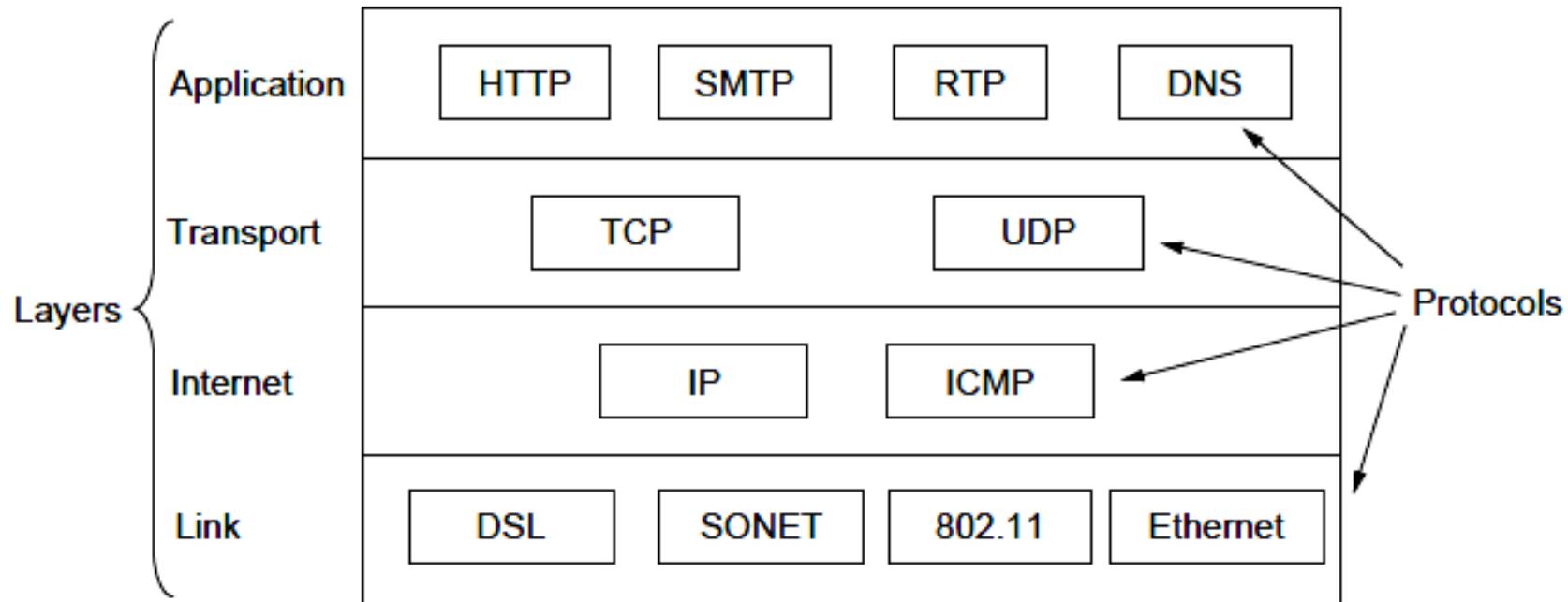
An exchange using OSI reference model



TCP/IP reference model



TCP/IP reference model



TCP/IP reference model

- Concepts central to the OSI model
 - Services
 - Interfaces
 - Protocols
- OSI has good definition of service, interface, and protocol. Fits well with object oriented programming concepts.
- Protocols are better hidden
- TCP/IP model did not distinguish between service, interface, and protocol
- With TCP/IP, the protocols came first; model was just a description of the protocols

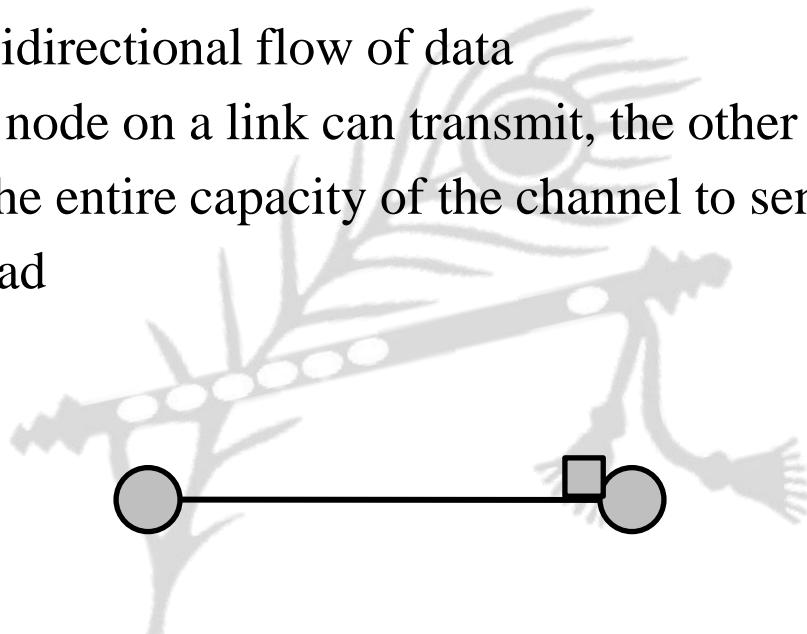
Transmission Mode

- Three types of data flow mode can be used
 - Simplex
 - Half duplex
 - Full duplex



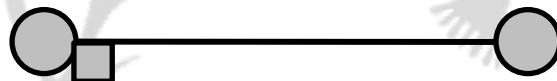
Transmission Mode

- Simplex
 - there is only unidirectional flow of data
 - only one of the node on a link can transmit, the other can only receive
 - this mode use the entire capacity of the channel to send data in one direction
 - Eg: one way road



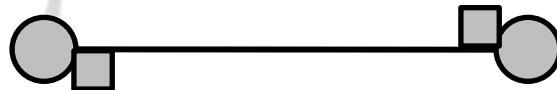
Transmission Mode

- Half duplex
 - there is bidirectional flow of data but at a time only one node can send
 - each node can both transmit and receive, but not at the same time
 - when one node is sending, the other can only receive, and vice versa
 - the entire capacity of the channel can be utilized for each direction
 - Eg: walkie-talkies



Transmission Mode

- Full duplex
 - there is bidirectional flow of data
 - each node can both transmit as well as receive simultaneously which can be achieved by two ways
 - either the link must contain two physically separate transmission paths, one for sending and other for receiving OR
 - the capacity is divided between signals travelling in both directions
 - the entire capacity of the channel can be utilized for both direction
 - Eg: mobile communication



Networking Hardware

- Networking hardware includes all computers, peripherals, interface cards and other equipment needed to perform data-processing and communications within the network like
 - Network Interface Card
 - Switch
 - Router
 - Bridge etc

Networking Hardware

- Network Interface Card
 - Network interface cards, commonly referred to as NICs, are used to connect a PC to a network
 - The NIC provides a physical connection between the networking cable and the computer's internal bus
 - NICs come in three basic varieties: 8-bit, 16-bit, and 32-bit. The larger the number of bits that can be transferred to the NIC, the faster the NIC can transfer data to the network cable

Networking Hardware

- Network Interface Card



Networking Hardware

- Hub

- A hub joins multiple computers (or other network devices) together to form a single network
- On this network, all computers can communicate directly with each other
- The networking hub is a junction box with several ports in the back for receiving the Ethernet cables that are plugged into each computer on the LAN

Networking Hardware

• Hub (Types)

- Passive: This type of hub does not amplify or boost the signal. It does not manipulate or view the traffic that crosses it. The passive hub does not require electrical power to work.
- Active: It amplifies the incoming signal before passing it to the other ports. It requires AC power to do the task.
- Intelligent: They are also called as smart hubs. It function as an active hub and also include diagnostic capabilities. They also provide flexible data rates to network devices. It also enables an administrator to monitor the traffic passing through the hub and to configure each port in the hub.

Networking Hardware

- Repeater
 - Since a signal loses strength as it passes along a cable, it is often necessary to boost the signal with a device called a repeater
 - A repeater is an electronic device that receives a signal, cleans the unnecessary noise, regenerates it, and retransmits it at a higher power level so that the signal can cover longer distances without degradation

Networking Hardware

- Switch
 - A network switch is a small hardware device that joins multiple computers together within one network
 - Network switches appear nearly identical to network hubs, but a switch generally contains more intelligence than a hub
 - Unlike hubs, network switches are capable of inspecting data packets as they are received, determining the source and destination device of each packet, and forwarding them appropriately
 - Allow several users to send information over a network at the same time without slowing each other down

Networking Hardware

- Router
 - A device to interconnect **SIMILAR** networks, e.g. similar protocols and workstations and servers
 - A router is an electronic device that interconnects two or more computer networks, and selectively interchanges packets of data between them
 - Each data packet contains address information that a router can use to determine if the source and destination are on the same network, or if the data packet must be transferred from one network to another

Networking Hardware

- Bridge
 - A bridge is a device that connects a local network to another local network
 - The function of a bridge is to connect separate networks together
 - Bridges map the Ethernet addresses of the nodes residing on each network segment and allow only necessary traffic to pass through the bridge. When a packet is received by the bridge, the bridge determines the destination and source segments

Networking Hardware

- Bridge (types)
 - Local bridges: Directly connect local area networks (LANs)
 - Remote bridges: Can be used to create a wide area network (WAN) link between LANs
 - Wireless bridges: Can be used to join LANs or connect remote stations to LANs (wirelessly)

Networking Hardware

- **Gateway**
 - Gateways are used to interconnect two different networks having different protocols
 - Networks using different protocols use different addressing formats
 - A gateway is a network point acts as an entrance to another network
 - Gateways are also called protocol converters

Difference

- Bridge:
 - device to interconnect two LANs that use the SAME logical link control protocol but may use different medium access control protocols
- Router:
 - device to interconnect SIMILAR networks, e.g. similar protocols and workstations and servers
- Gateway:
 - device to interconnect DISSIMILAR protocols and servers

Difference

Hub

- Physical layer
- signal or bits
- Non-intelligent device
- LAN
- Half duplex
- MAC address

Switch

- Data link layer
- frames
- Intelligent device
- LAN
- Half/Full duplex
- MAC address

Router

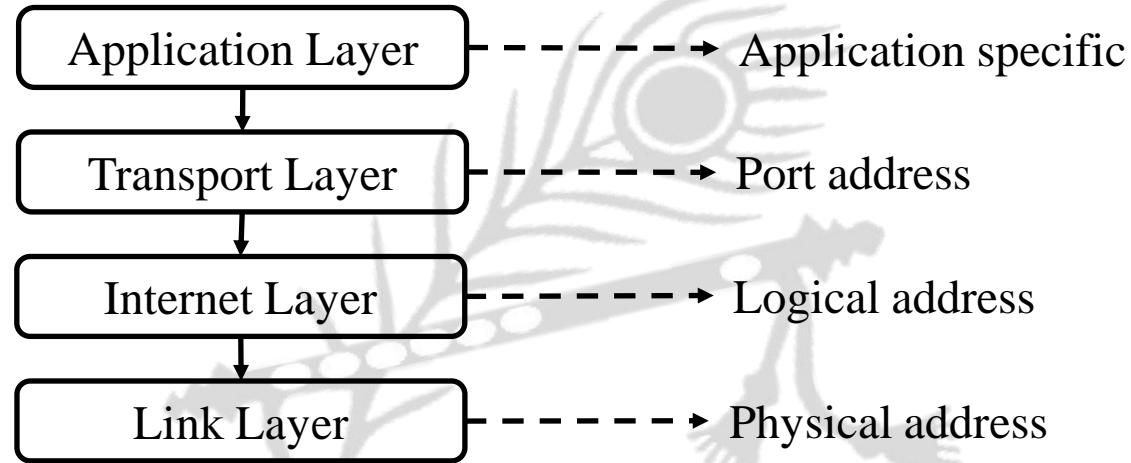
- Network layer
- packets
- Intelligent device
- LAN, MAN, WAN
- Full duplex
- IP address

ADDRESSING

Addressing

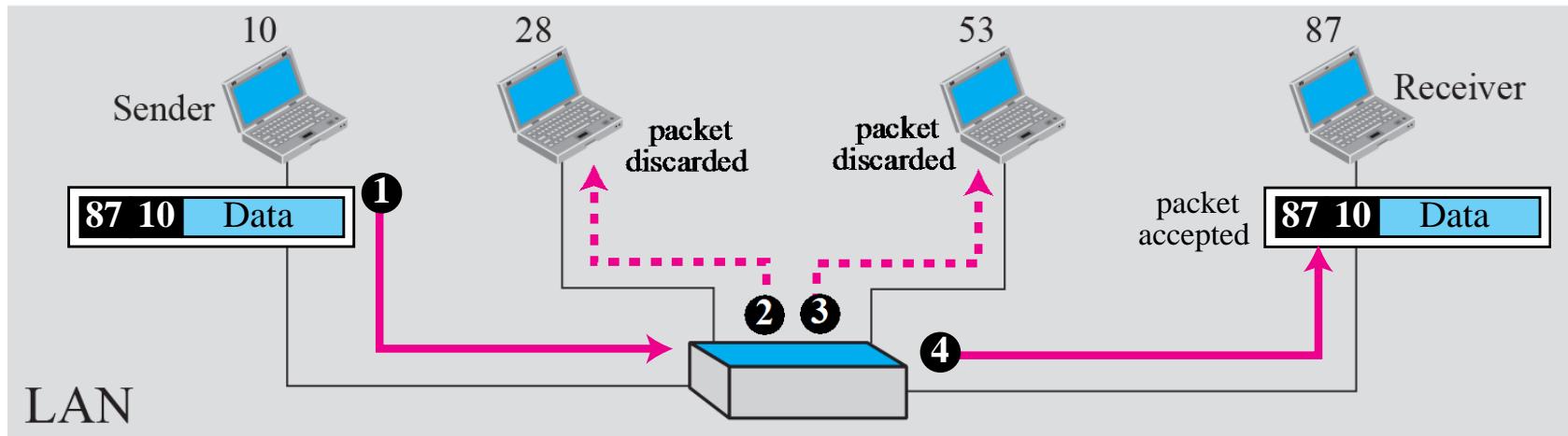
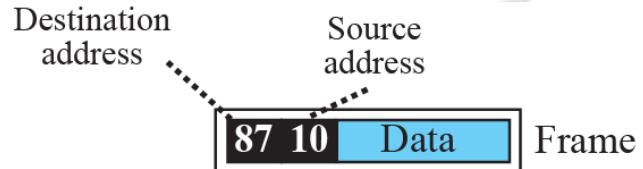
- Four levels of addresses are used in an internet employing the TCP/IP protocols:
 - physical address,
 - logical address,
 - port address, and
 - application-specific address.
- Each address is related to a one layer in the TCP/IP architecture

Addressing



Addressing

- Eg:



Addressing

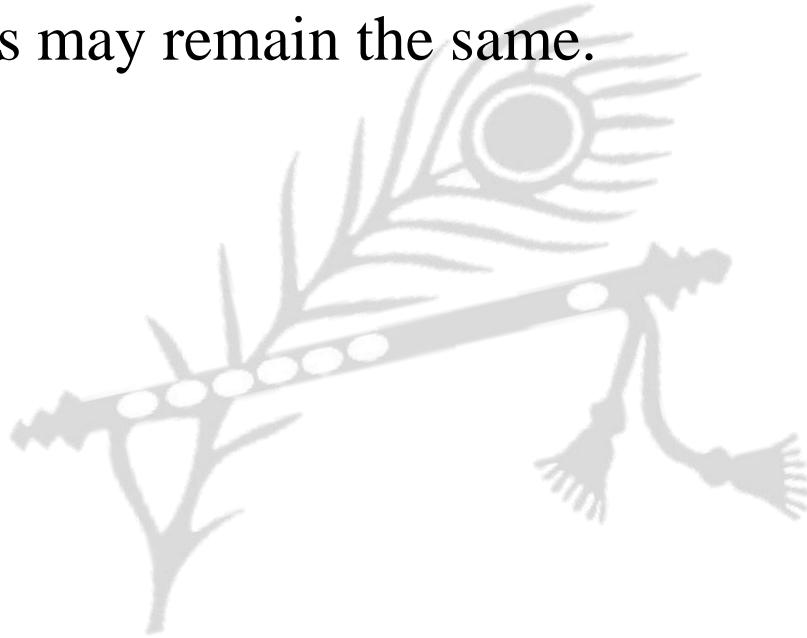
- local area networks use a 48-bit (6-byte) physical address written as 12 hexadecimal digits; every byte (2 hexadecimal digits) is separated by a colon
- Eg:

07:01:02:01:2C:4B

A 6-byte (12 hexadecimal digits) physical address

Addressing

- The physical addresses will change from hop to hop, but the logical addresses may remain the same.



Addressing

- A port address is a 16-bit integer address represented by one decimal number
- This number is assigned automatically by the OS, manually by the user or is set as a default for some popular applications.
- Eg:

753, 443, 8080, etc

A 16-bit port address represented as one single decimal number

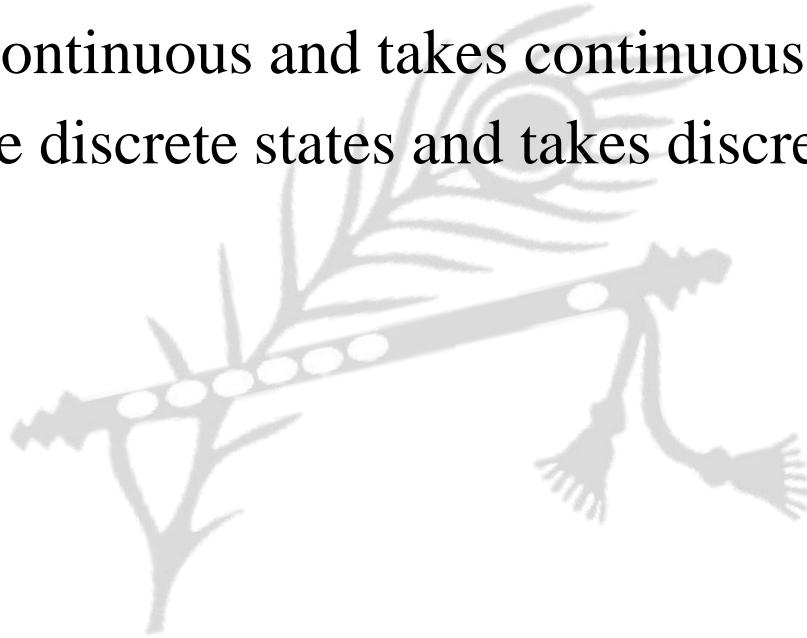
Addressing

Notable well-known port numbers

- 20 File Transfer Protocol (FTP) Data Transfer
- 21 File Transfer Protocol (FTP) Command Control
- 22 Secure Shell (SSH) Secure Login
- 25 Simple Mail Transfer Protocol (SMTP) E-mail routing
- 53 Domain Name System (DNS) service
- 67, 68 Dynamic Host Configuration Protocol (DHCP)
- 80 Hypertext Transfer Protocol (HTTP)
- 110 Post Office Protocol (POP3)
- 161 Simple Network Management Protocol (SNMP)
- 443 HTTP Secure (HTTPS) HTTP over TLS/SSL

Analog and Digital data

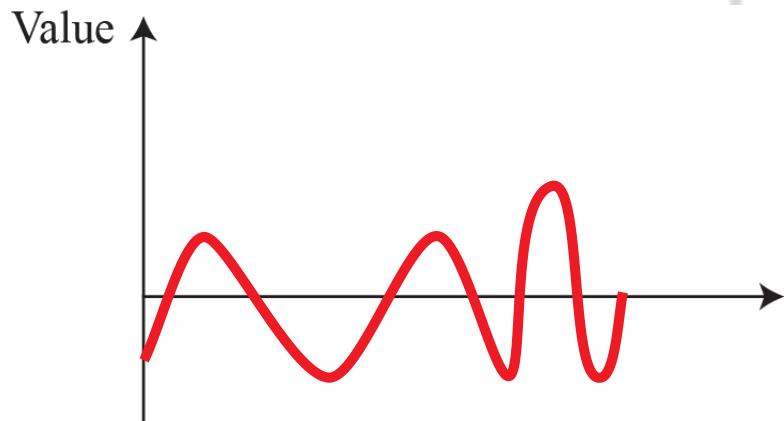
- Data can be analog or digital
- Analog data is continuous and takes continuous values
- Digital data have discrete states and takes discrete values



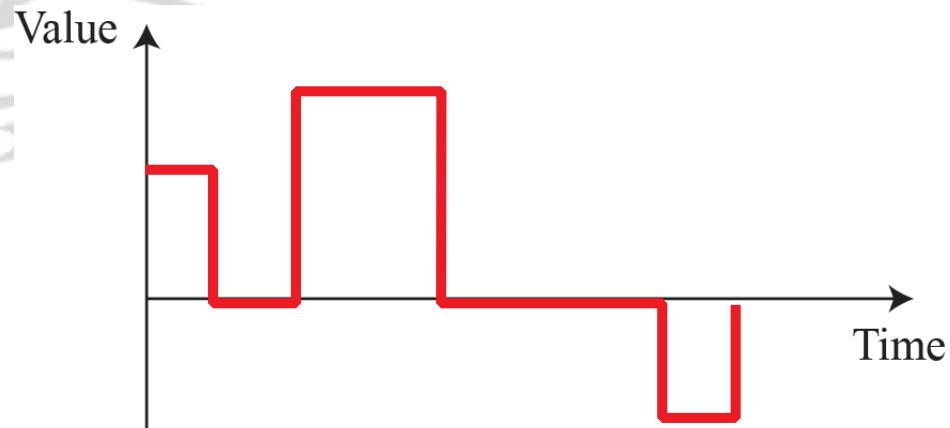
DATA AND SIGNALS

Analog and Digital signal

- Signals can be analog or digital
- Analog signals can have an infinite number of values in a range
- Digital signals can have only a limited number of values



a. Analog signal



b. Digital signal

Difference

Analog

- Analog signals are difficult to get analyzed at first
- Analog signals are more accurate
- Analog signals take time to be stored
- Analog signals produce too much noise
- Eg: Human voice, Thermometer, Analog phones etc

Digital

- Digital signals are easy to analyze
- Digital signals are less accurate
- Digital signals can be easily stored
- Digital signals do not produce noise
- Eg: Computers, Digital Phones, Digital pens, etc

Periodic and Non-periodic

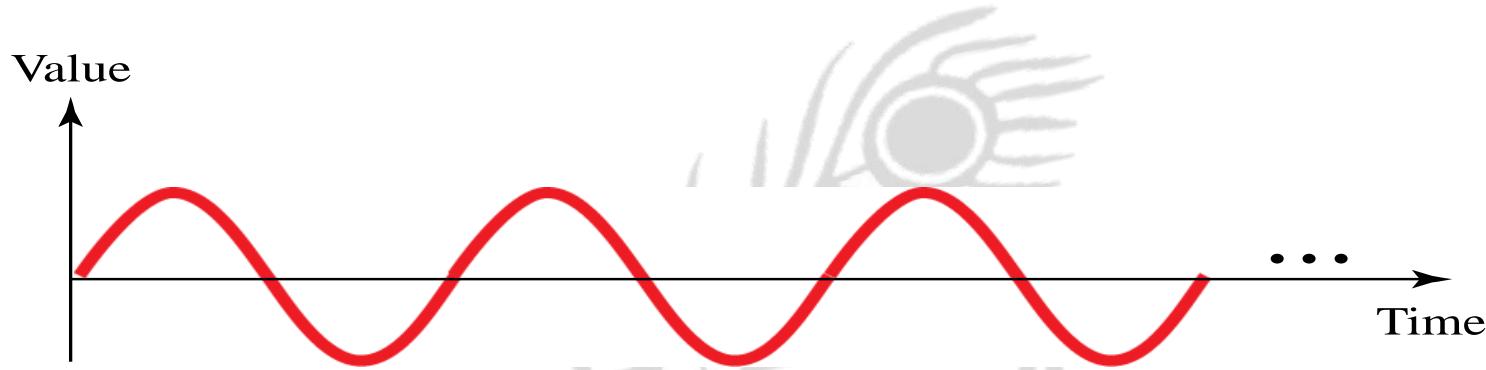
- A periodic signal completes a pattern within a measurable time frame, called a period, and repeats that pattern. The completion of one full pattern is called a cycle.
- A non periodic signal changes without exhibiting a pattern or cycle that repeats over time

Periodic and Non-periodic

- Period refer to amount of time in second a signal need to complete 1 cycle
- Frequency refer to number of period in 1 s
- They are the inverse of each other

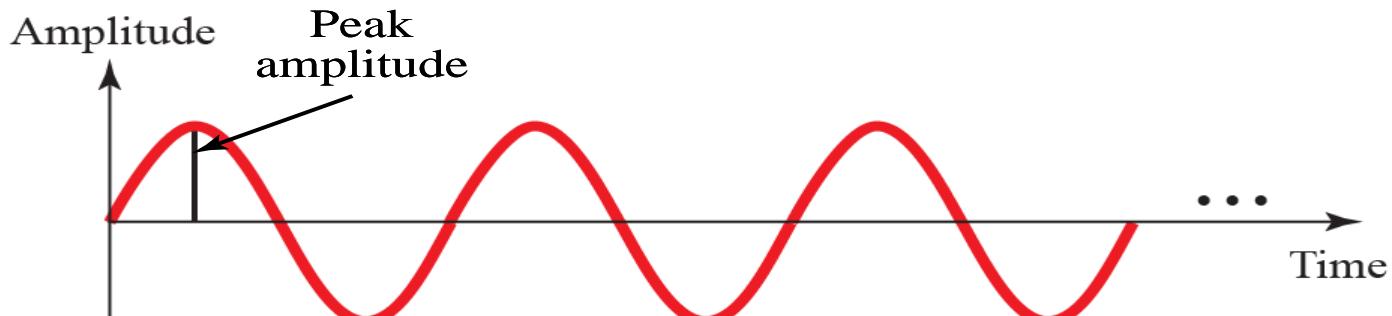
$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$

Periodic and Non-periodic

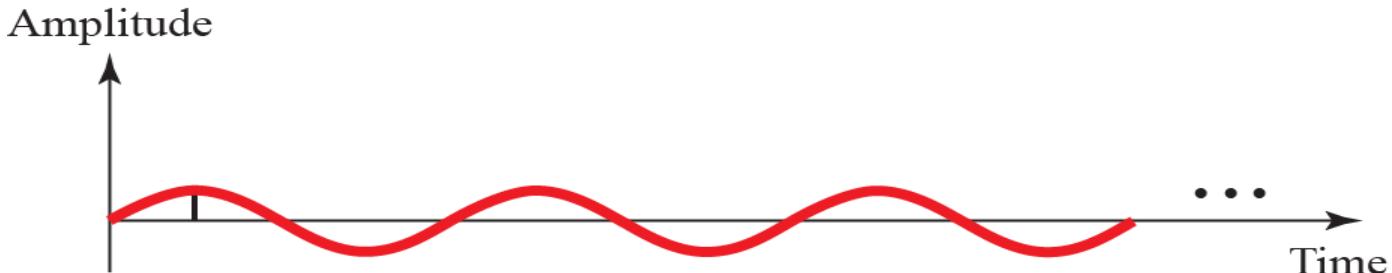


The sine wave is the most fundamental form of a periodic analog signal

Periodic and Non-periodic

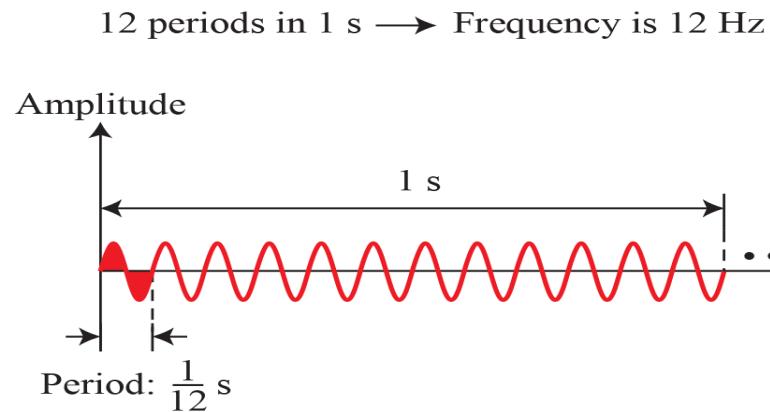


a. A signal with high peak amplitude

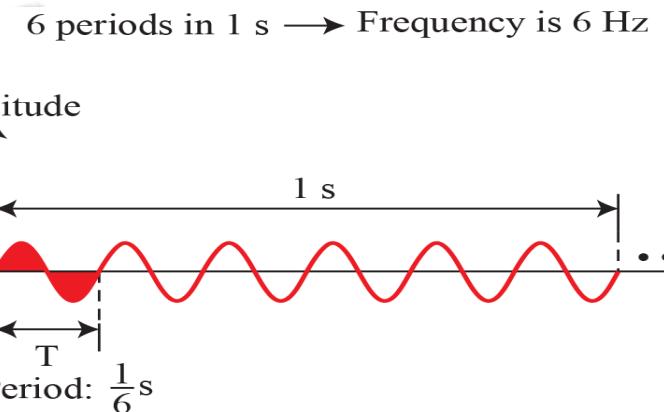


b. A signal with low peak amplitude

Signal



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

Units of period and frequency

Period		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
Picoseconds (ps)	10^{-12} s	Terahertz (THz)	10^{12} Hz

Eg

Express a period of 100 ms in microseconds.

Solution

The equivalents of 1ms (1 ms is 10^{-3} s) and 1s (1s is 10^6 μ s)

By substituting:

$$\begin{aligned} & 100 \text{ ms} \\ & = 100 * 10^{-3} \text{ s} \\ & = 100 * 10^{-3} * 10^6 \mu\text{s} \\ & = 10^5 \mu\text{s} \end{aligned}$$

Eg

The power we use at home has a frequency of 60 Hz. What is the period of that wave?

Solution

$$\begin{aligned} T &= 1/f \\ &= 1/60 \text{ s} \\ &= 0.0166 \text{ s} \\ &= 0.0166 * 10^3 \text{ ms} \\ &= 16.6 \text{ ms} \end{aligned}$$

Eg

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

Solution

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

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

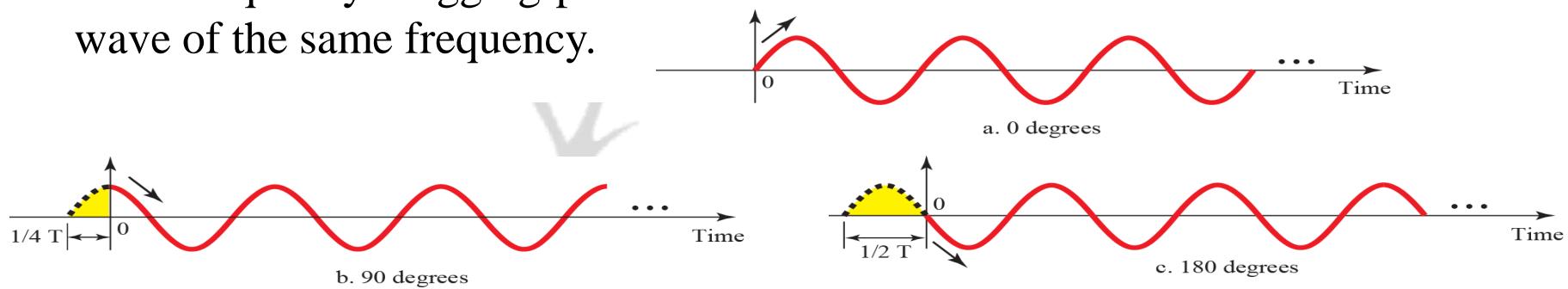
$$f = \frac{1}{T} = \frac{1}{10^{-1}} \text{ Hz} = 10 \text{ Hz} = 10 \times 10^{-3} \text{ kHz} = 10^{-2} \text{ kHz}$$

Frequency

- Frequency is the rate of change with respect to time
- Change in a short span of time means high frequency
- Change over a long span of time means low frequency
 - If a signal does not change at all, its frequency is zero
 - If a signal changes instantaneously, its frequency is infinite

Phase

- The term PHASE, or PHASE SHIFT, describes the position of the waveform relative to time 0
- A complete cycle is defined as 360 degrees of phase
- Phase difference , also called phase angle , in degrees is conventionally defined as a number greater than -180, and less than or equal to +180
- Leading phase refers to a wave that occurs "ahead" of another wave of the same frequency. Lagging phase refers to a wave that occurs "behind" another wave of the same frequency.



Phase

- Eg:
 - A sine wave is offset 1/6 cycle with respect to time 0. What is its phase in degrees and radians?

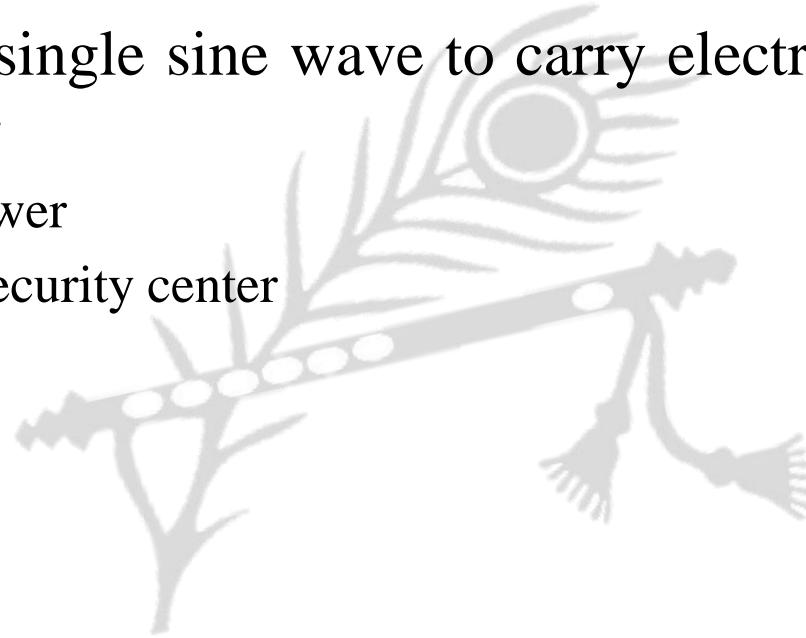
Solution

- We know that 1 complete cycle is 360° . Therefore, 1/6 cycle is

$$\begin{aligned} & \frac{1}{6} * 360 \\ &= 60^\circ \\ &= 60^\circ * \frac{2\pi}{360} \text{ rad} \\ &= \frac{\pi}{3} \text{ rad} \end{aligned}$$

Application of Simple Signals

- Simple sine waves have many applications in daily life
- We can send a single sine wave to carry electric energy from one place to another
 - Eg: electric power
 - an alarm to a security center



Signals and Communication

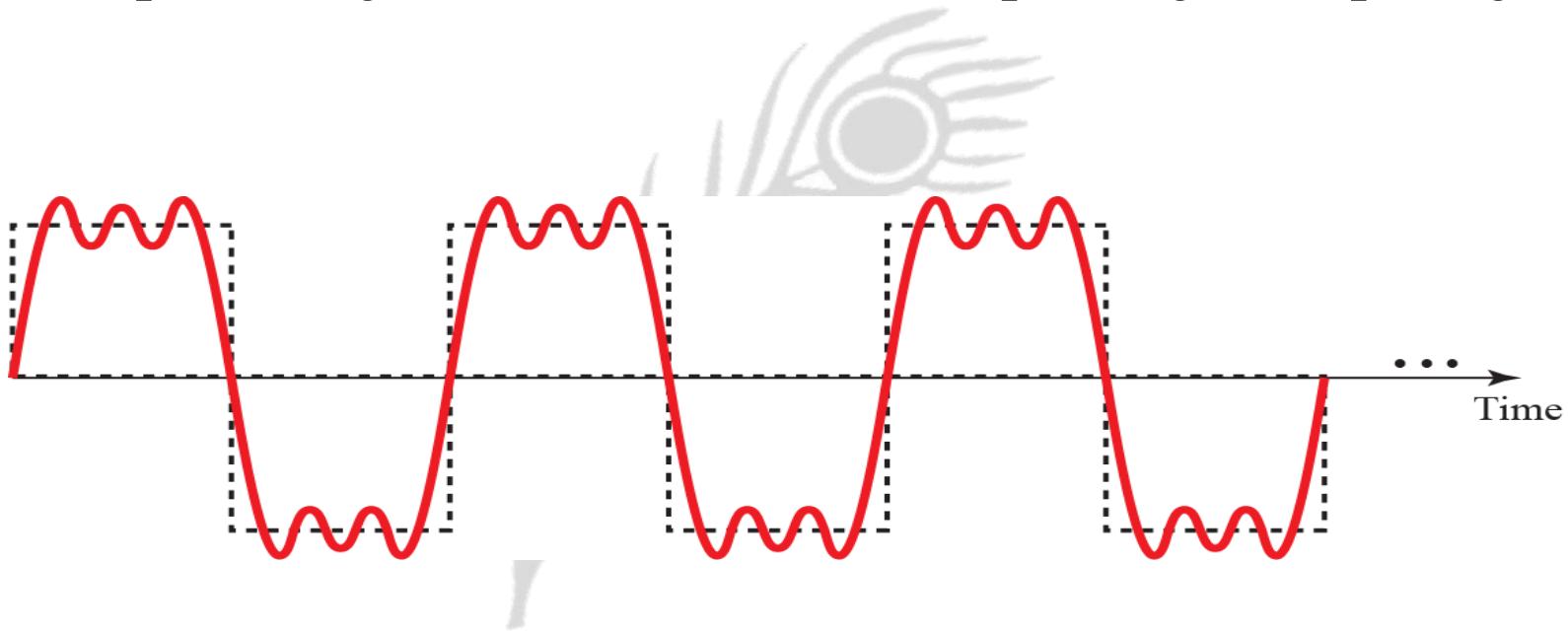
- A single-frequency sine wave is not useful in data communications
- We need to send a composite signal, a signal made of many simple sine waves
- According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases

Composite Signals and Periodicity

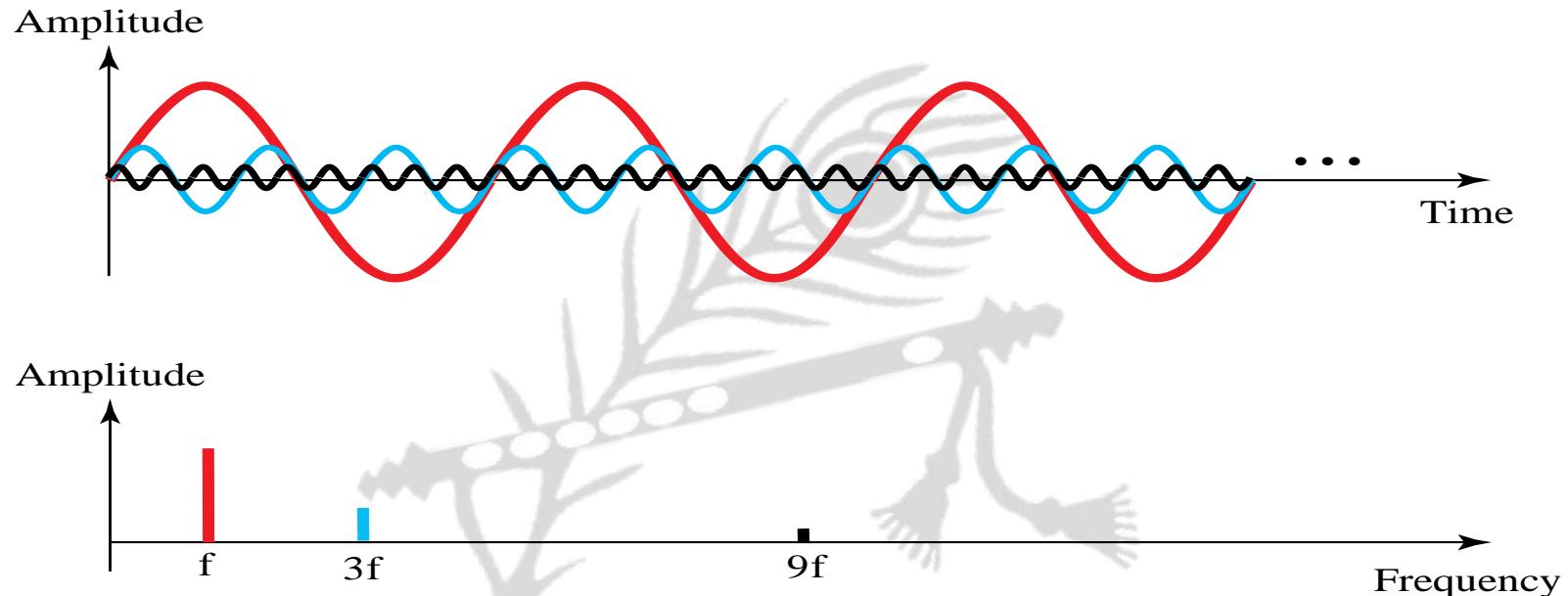
- If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies
- If the composite signal is non-periodic, the decomposition gives a combination of sine waves with continuous frequencies

Composite Period Signal

- A Composite Signal is collection of multiple simple signals

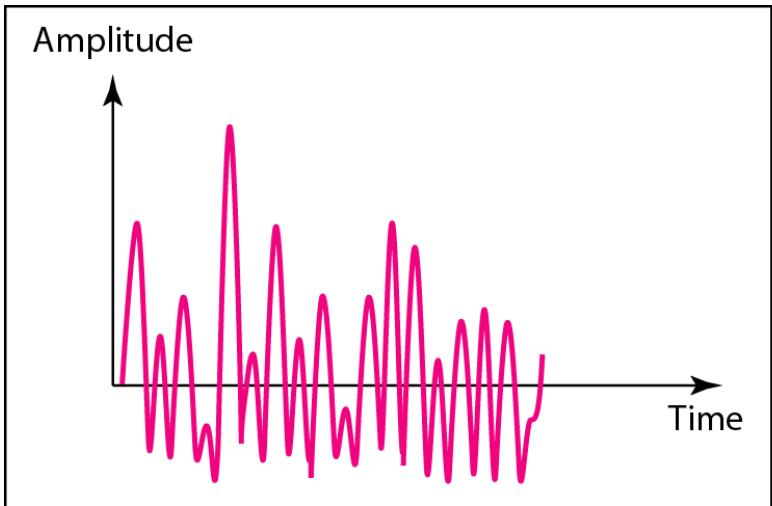


Decomposition of a composite periodic signal

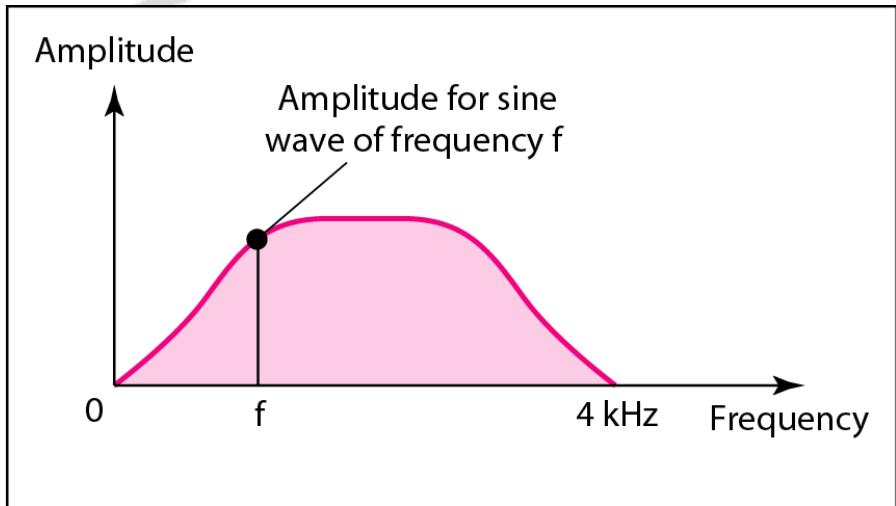


b. Frequency-domain decomposition of the composite signal

Decomposition of a composite non-periodic signal



a. Time domain

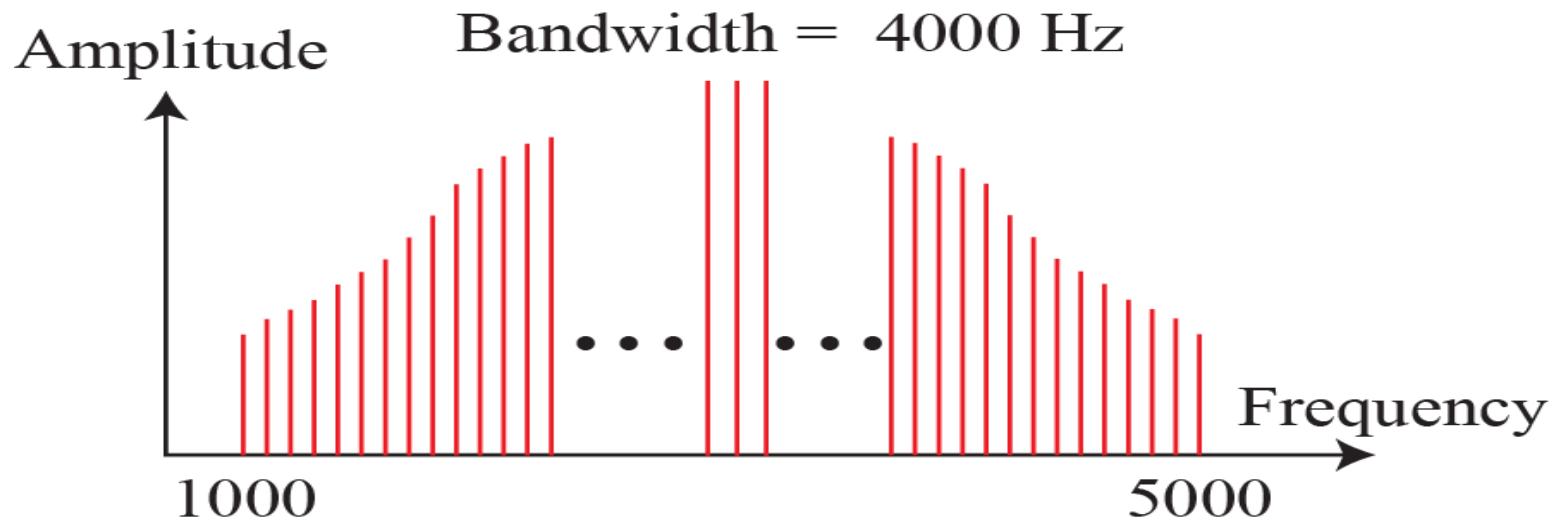


b. Frequency domain

Bandwidth

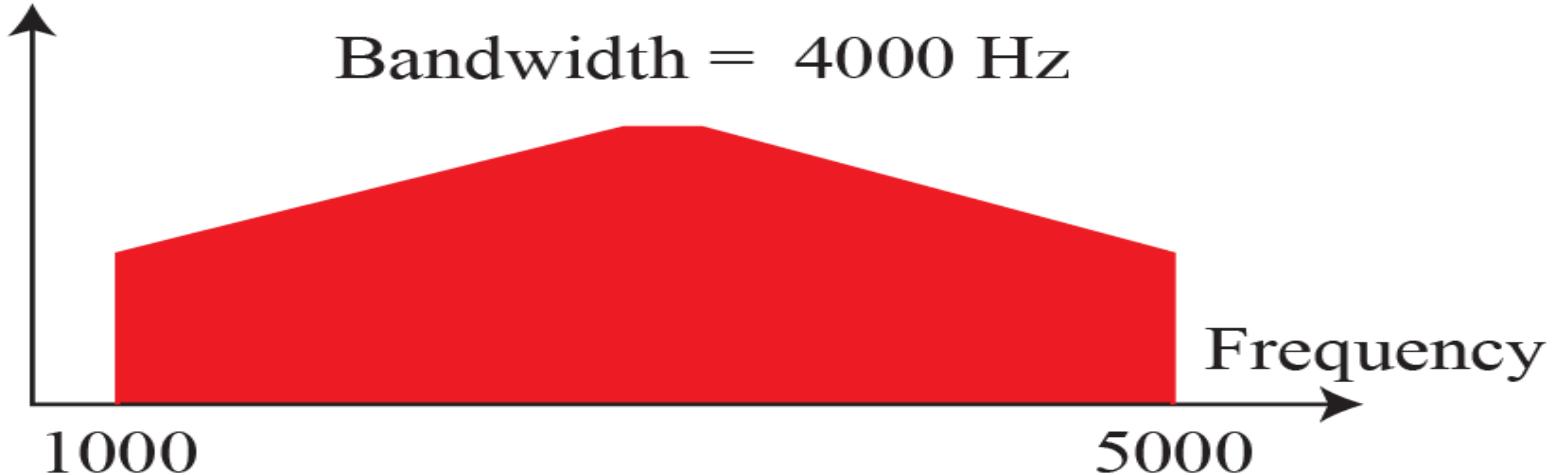
- The range of frequencies contained in a composite signal is its bandwidth
- The bandwidth is normally a difference between two numbers
- Eg:
 - if a composite signal contains frequencies between 1000 and 5000, its bandwidth is $5000 - 1000$, or 4000

Bandwidth



Bandwidth

Amplitude



b. Bandwidth of a nonperiodic signal

Bandwidth

- Eg:
 - If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth?

Solution

- Let f_h be the highest frequency, f_l the lowest frequency, and BW the bandwidth. Then,

$$\begin{aligned} \text{BW} &= f_h - f_l \\ &= 900 - 100 \\ &= 800 \text{ Hz} \end{aligned}$$

Bandwidth

- Eg:
 - A periodic signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency?

Solution

- Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then,

$$B = f_h - f_l$$

$$20 = 60 - f_l$$

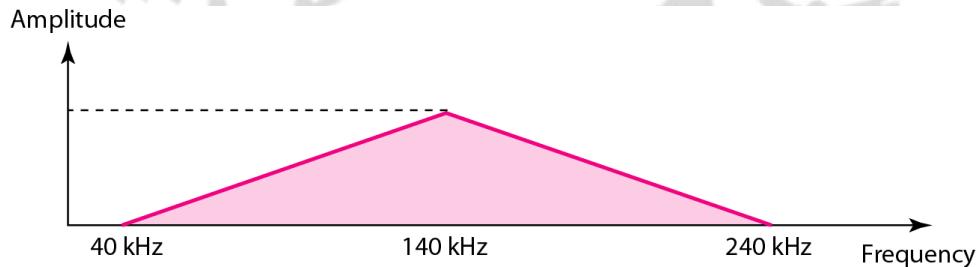
$$f_l = 40 \text{ Hz}$$

Bandwidth

- Eg:
 - A non-periodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal

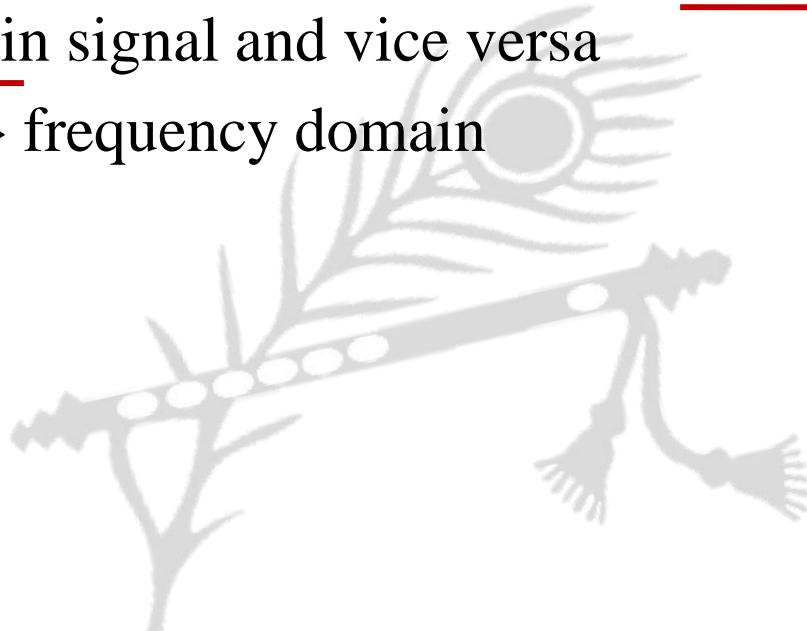
Solution

- The lowest frequency must be at 40 kHz and the highest at 240 kHz



Fourier Analysis

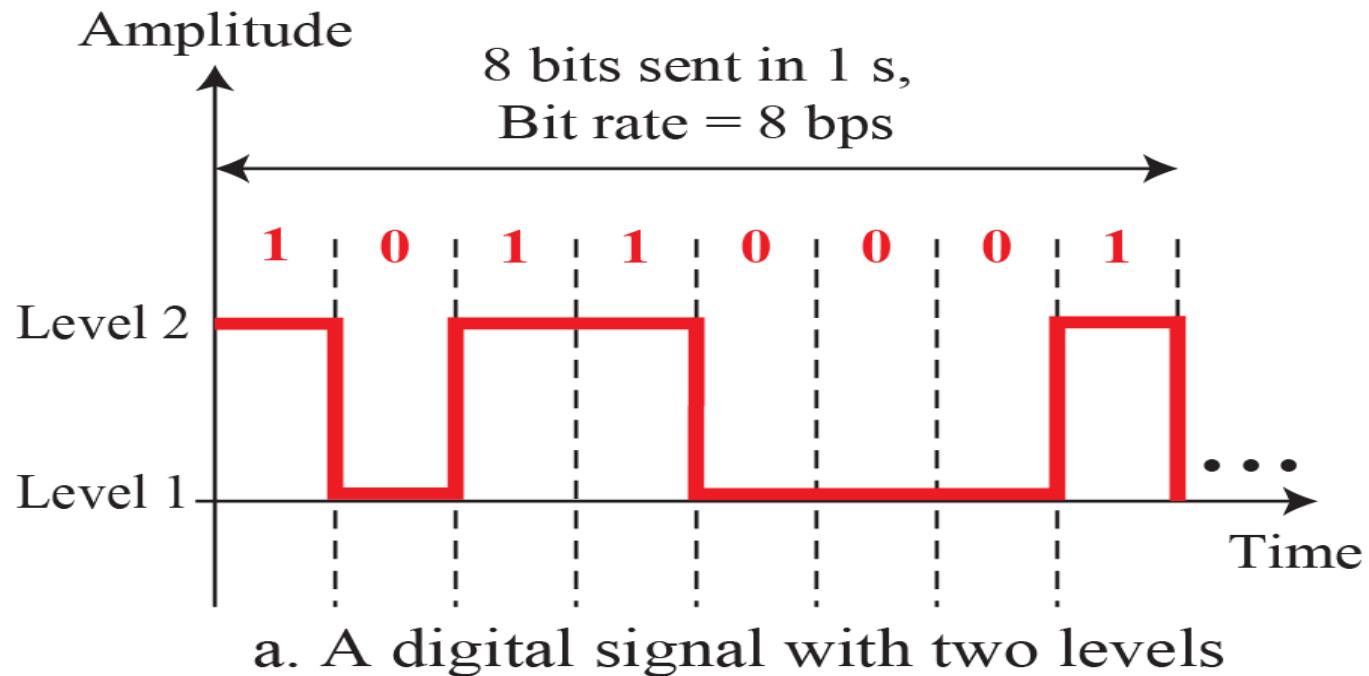
- Fourier analysis is a tool that changes a time domain signal to a frequency domain signal and vice versa
- Time domain \leftrightarrow frequency domain



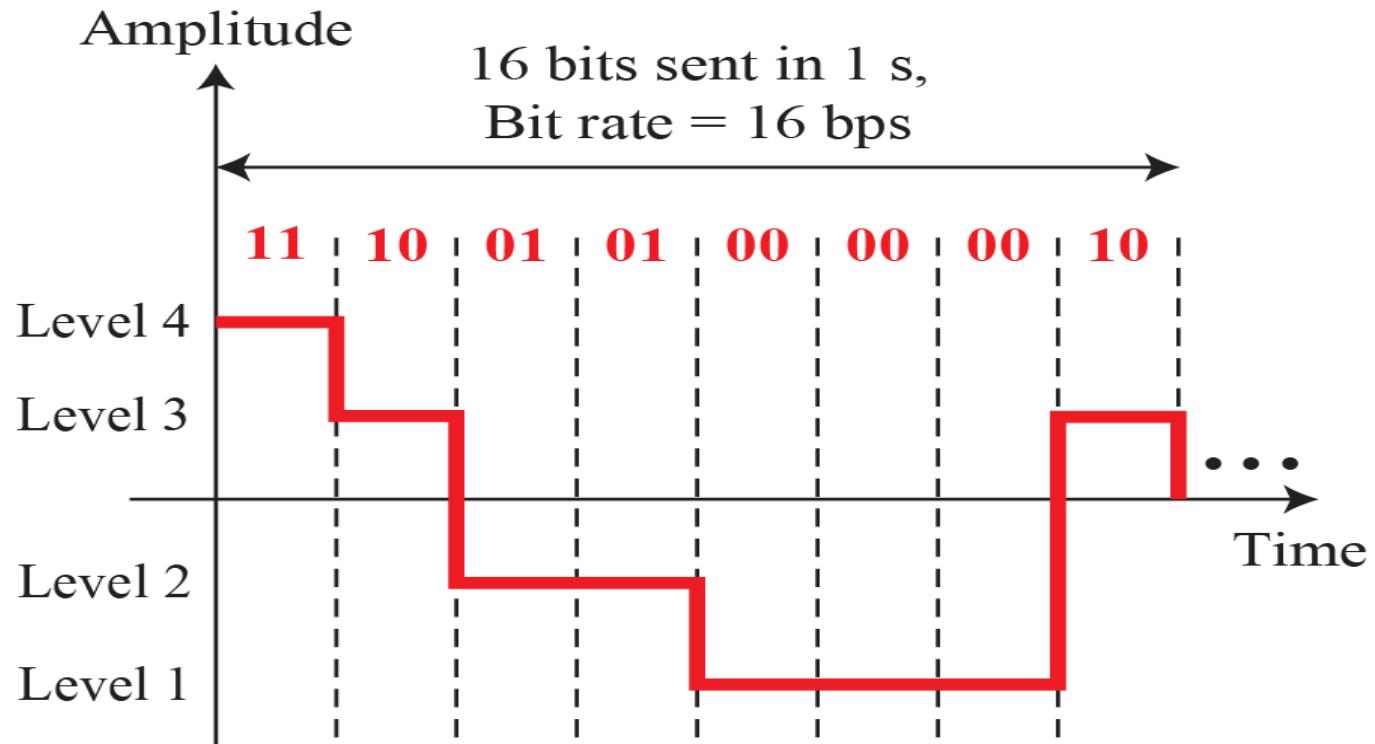
Digital Signals

- In addition to being represented by an analog signal, information can also be represented by a digital signal
- Eg:
 - 1 can be encoded as a positive voltage and a 0 as zero voltage
- A digital signal can have more than two levels

Digital Signal



Digital Signal



b. A digital signal with four levels

Digital Signal

- Eg:
 - A digital signal has eight levels. How many bits are needed per level?

Solution

$$\text{number of levels} = 2^n$$

$$8 = 2^n$$

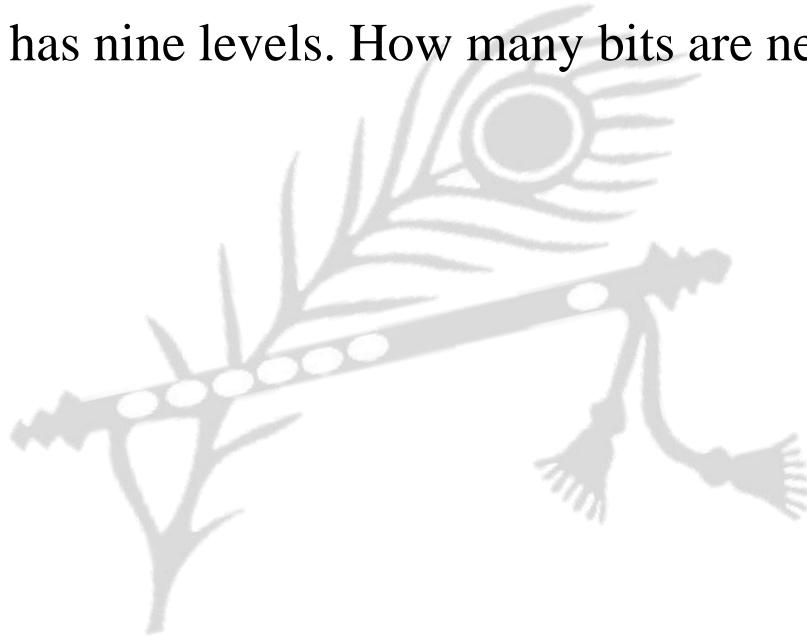
$$\log_2 8 = \log_2 2^n$$

$$\log_2 8 = n \log_2 2$$

$$n = 3$$

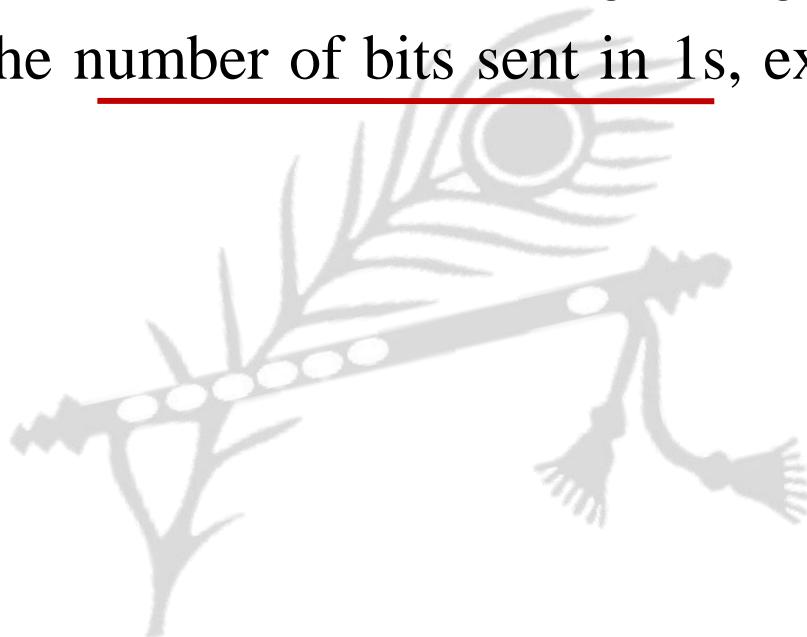
Digital Signal

- Eg:
 - A digital signal has nine levels. How many bits are needed per level?



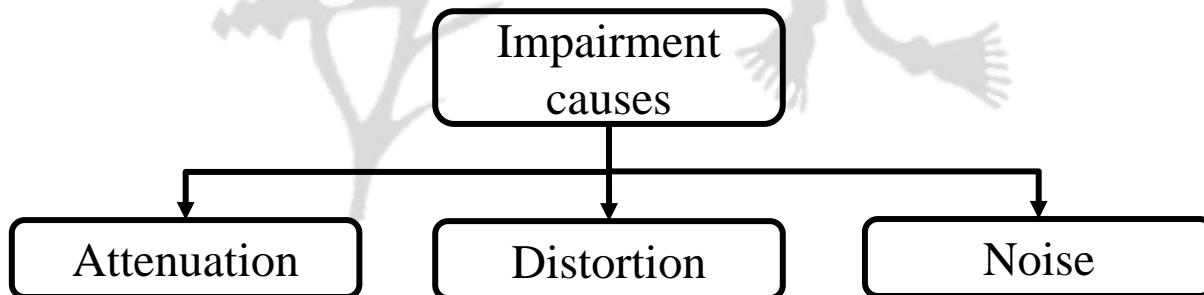
Bit Rate

- The term Bit Rate is used to describe digital signals
- The bit rate is the number of bits sent in 1s, expressed in bits per second (bps).



Transmission Impairment

- Signals travel through transmission media, which are not perfect, the imperfection causes signal impairment (damage/loss/weak)
- 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
- Three causes of impairment are attenuation, distortion, and noise



Impairment

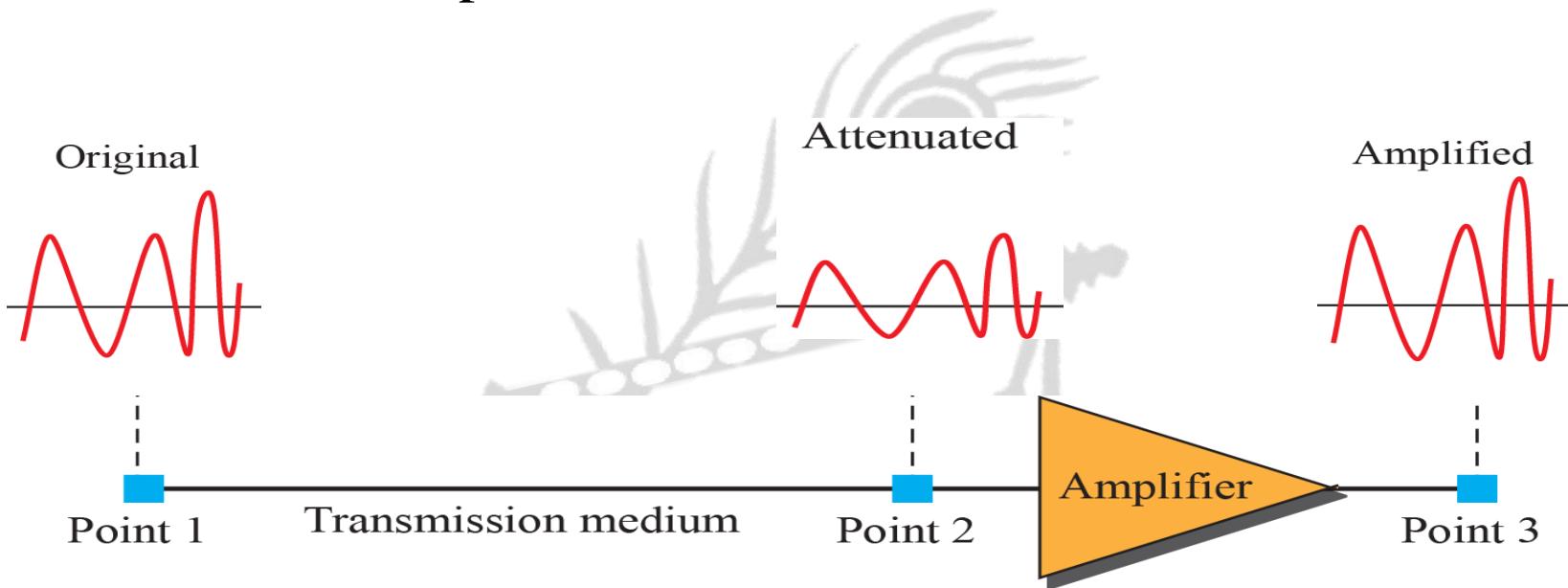
Attenuation

- Attenuation means a loss of energy
- When a signal travels through a medium, it loses some of its energy in overcoming the resistance of the medium
- Some of the electrical energy in the signal is converted to heat. That is why a wire carrying electric signals gets warm
- To compensate for this loss, amplifiers are used to amplify the signal
- Decibel (dB) is used to measure the attenuation

$$dB = 10 \log_{10} P2/P1$$

Impairment

Attenuation and Amplification



Impairment

Attenuation and Amplification

- Eg:
 - Suppose a signal travels through a transmission medium and its power is reduced to one half. This means that $P_2 = 0.5 P_1$. In this case, the attenuation (loss of power) can be calculated as

Solution

$$\begin{aligned} & 10 \log_{10} P_2/P_1 \\ &= 10 \log_{10} (0.5 P_1/P_1) \\ &= 10 \log_{10} (0.5) \\ &= 10 (-0.3) \\ &= -3 \text{ dB} \end{aligned}$$

Impairment

Attenuation and Amplification

- Eg:
 - A signal travels through an amplifier, and its power is increased 10 times. This means that $P_2 = 10P_1$. In this case, the amplification (gain of power) can be calculated as

Solution

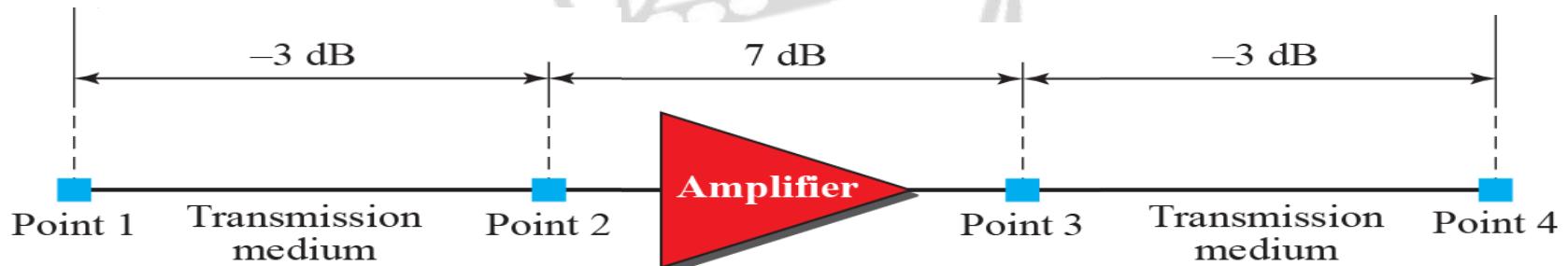
$$\begin{aligned} & 10 \log_{10} P_2/P_1 \\ &= 10 \log_{10} (10 P_1/P_1) \\ &= 10 \log_{10} (10) \\ &= 10 (1) \\ &= 10 \text{ dB} \end{aligned}$$

Impairment

Attenuation and Amplification

- Eg:
 - How much total gain/loss in signal from point 1 to point 4

Solution



Impairment

Attenuation and Amplification

- Eg:
 - Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dB_m and is calculated as $\text{dB}_m = 10 \log_{10} P_m$, where P_m is the power in milliwatts. Calculate the power of a signal if its $\text{dB}_m = -30$

Solution

$$10 \log_{10} P_m = \text{dB}_m$$

$$10 \log_{10} P_m = -30$$

$$\log_{10} P_m = -3$$

$$P_m = 10^{-3} \text{ mW}$$

Impairment

Attenuation and Amplification

- Eg:
 - The loss in a cable is usually defined in decibels per kilometer (dB/km). If the signal at the beginning of a cable with -0.3 dB/km has a power of 2 mW, what is the power of the signal at 5 km?

Solution

Loss in the cable is $(-0.3) * 5 = -1.5$ dB

Now, the power can be calculated as

$$10 \log_{10} P_2/P_1 = -1.5$$

$$\log_{10} P_2/P_1 = -0.15$$

$$P_2/P_1 = 10^{-0.15} = 0.7$$

$$P_2 = 0.7P_1$$

$$P_2 = 0.7*2 = 1.4 \text{ mW}$$

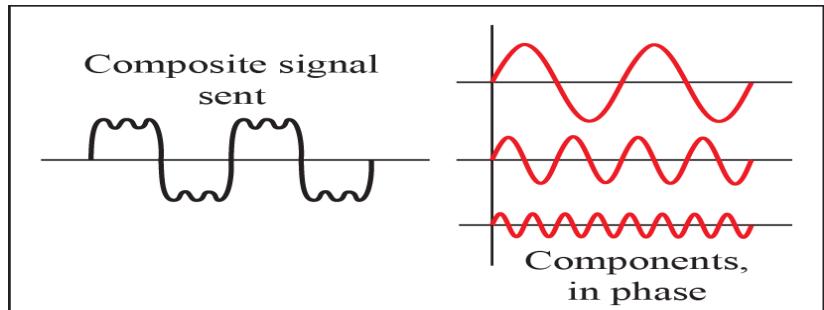
Impairment

Distortion

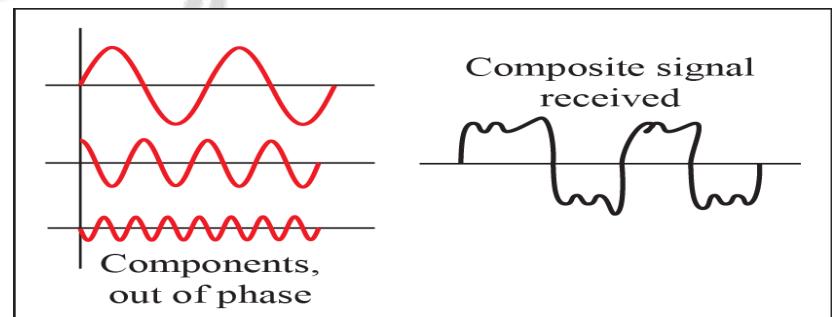
- Distortion means that the signal changes its form or shape
- Distortion can occur in a composite signal made of different frequencies
- Each signal component has its own propagation speed through a medium and, therefore, its own delay in arriving at the final destination
- Differences in delay may create a difference in phase if the delay is not exactly the same as the period duration

Impairment

- Distortion



At the sender



At the receiver

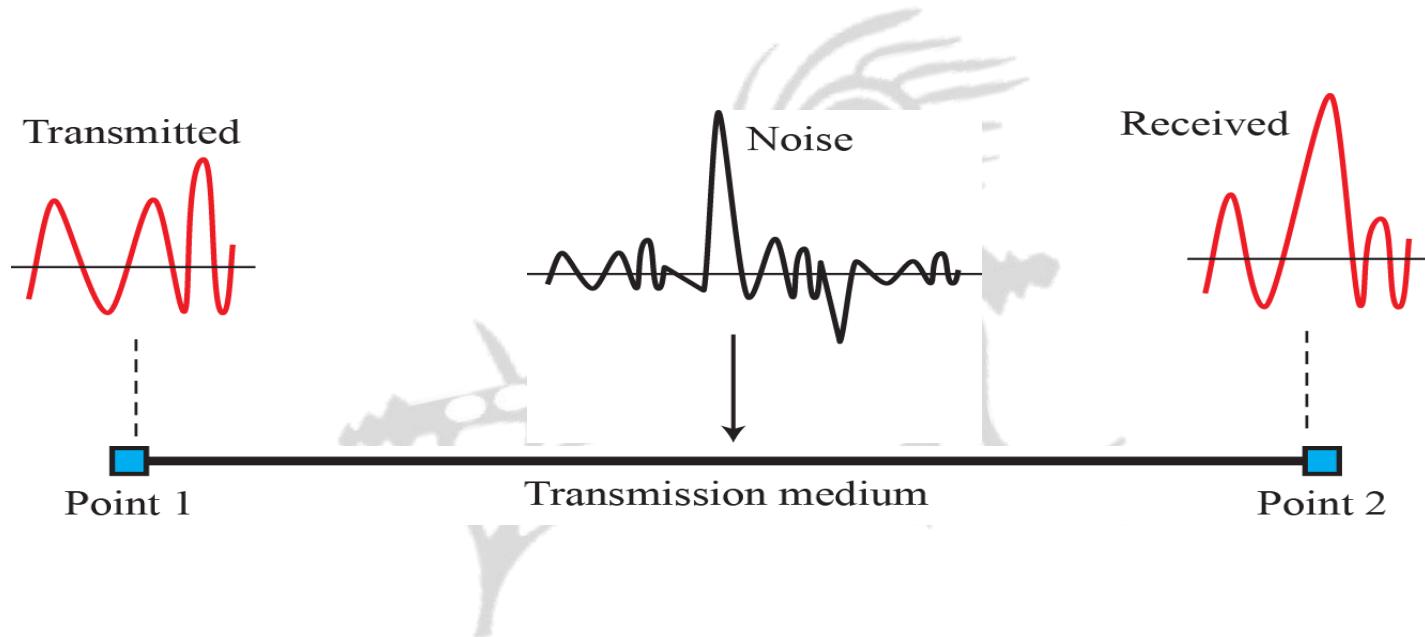
Impairment

Noise

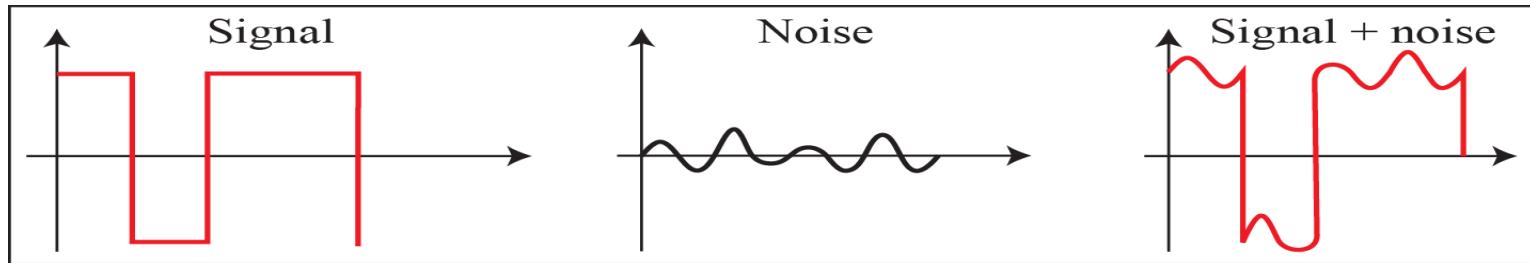
- Noise is another cause of impairment
- Several types of noise, such as thermal noise, induced noise, crosstalk, etc may corrupt the signal
 - Thermal noise is the random motion of electrons in a wire, which creates an extra signal not originally sent by the transmitter
 - Induced noise comes from sources such as motors
 - Crosstalk is the effect of one wire on the other
- Noise is measured in terms of SNR (Signal to Noise Ratio)

Impairment

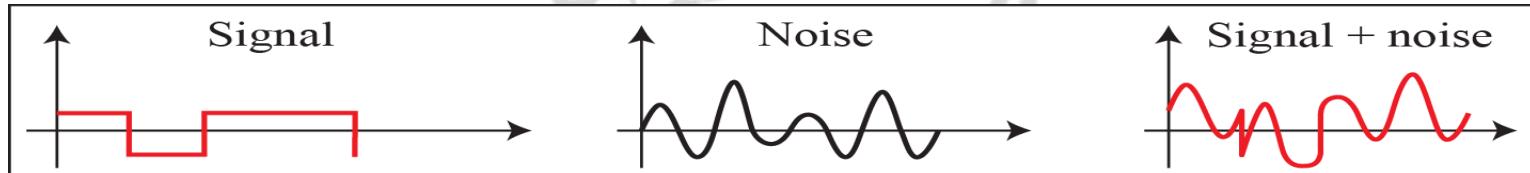
Noise



Two cases of SNR: a high SNR and a low SNR



a. High SNR



b. Low SNR

- Eg:
 - The power of a signal is 10 mW and the power of the noise is 1 μW. What are the values of SNR and SNR_{dB}?

Solution

- The values of SNR and SNR_{dB} can be calculated as follows:

$$\begin{aligned} \text{SNR} &= 10 * 10^{-3} / 10^{-6} \\ &= 10 * 10^3 \\ &= 10000 \text{ dB} \end{aligned}$$

$$\begin{aligned} \text{SNR}_{\text{dB}} &= 10 \log_{10} 10000 \\ &= 10 \log_{10} 10^4 \\ &= 40 \text{ dB} \end{aligned}$$

- The values of SNR and SNR_{dB} for a noiseless channel are

Solution

$$\begin{aligned}\text{SNR} &= (\text{signal power})/0 \\ &= \infty\end{aligned}$$

$$\begin{aligned}\text{SNR}_{\text{dB}} &= 10 \log_{10} \infty \\ &= \infty\end{aligned}$$

We can never achieve this ratio in real life; it is an ideal

Noiseless Channel: Nyquist Rate

- For a noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate

$$\text{Bit rate} = 2 * BW * \log_2 L$$

Nyquist Rate

- Eg:
 - 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

Solution

$$\begin{aligned}\text{Bit rate} &= 2 * 3000 * \log_2 2 \\ &= 6000 \text{ bps}\end{aligned}$$

Nyquist Rate

- Eg:
 - Consider the same noiseless channel transmitting a signal with 2 bits for each level. The maximum bit rate can be calculated as

Solution

$$\begin{aligned}\text{Bit rate} &= 2 * 3000 * \log_2 4 \\ &= 12000 \text{ bps}\end{aligned}$$

Noisy Channel: Shannon Capacity

- In reality, we cannot have a noiseless channel, the channel is always noisy
- In 1944, Shannon introduced a formula, called the Shannon capacity, to determine the theoretical highest data rate for a noisy channel

$$C = BW * \log_2(1 + SNR)$$

Noisy Channel: Shannon Capacity

- Eg:
 - Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. For this channel the capacity C is calculated as

Solution

$$\begin{aligned}C &= \text{BW} * \log_2(1 + \text{SNR}) \\&= \text{BW} * \log_2(1+0) \\&= \text{BW} * 0 \\&= 0\end{aligned}$$

- This means that the capacity of this channel is zero regardless of the bandwidth. In other words, we cannot receive any data through this channel

Noisy Channel: Shannon Capacity

- Eg:
 - Assume that $\text{SNR}_{\text{dB}} = 36$ and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as

Solution

$$\text{SNR}_{\text{dB}} = 10 \log_{10} \text{SNR}$$

$$36 = 10 \log_{10} \text{SNR}$$

$$\text{SNR} = 10^{3.6}$$

$$\text{SNR} = 3981$$

$$\begin{aligned} C &= \text{BW} * \log_2(1+\text{SNR}) \\ &= 2 * 10^6 * \log_2 3982 \\ &= 2 * 10^6 * 11.95 \\ &= 24 \text{ Mbps} \end{aligned}$$

Noisy Channel: Shannon Capacity

- Eg:
 - We have a channel with a 1-MHz bandwidth. The SNR for this channel is 63. What are the appropriate bit rate and signal level?

Solution

- First, we use the Shannon formula to find the upper limit
- Then we use the Nyquist formula to find the number of signal levels

$$\begin{aligned}
 C &= BW * \log_2(1+SNR) \\
 &= 10^6 * \log_2 64 \\
 &= 6 \text{ Mbps}
 \end{aligned}$$

$$\begin{aligned}
 \text{Bit rate} &= 2 * BW * \log_2 L \\
 6 &= 2 * 1 * \log_2 L \\
 L &= 2^3 = 8
 \end{aligned}$$

Latency or Delay

- The latency or delay defines 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
- We can say that latency is the sum made of four components:
 - propagation time
 - transmission time
 - queuing time
 - processing delay

$$\text{Latency} = P_d + T_t + Q_t + P_t$$

Types of delay

- Propagation speed
 - speed at which a bit travels though the medium from source to destination
- Transmission speed
 - the speed at which all the bits in a message arrive at the destination (difference in arrival time of first and last bit)

Types of delay

- Queuing delay
 - is the time spent by the packet in a queue, waiting to be transmitted onto the link
- Processing delay
 - time taken by the routers to process the packet header

Bandwidth

- One characteristic that measures network performance is bandwidth
- However, the term can be used in two different contexts with two different measuring values
 - bandwidth in hertz
 - bandwidth in bits per second

Bandwidth

- The first, bandwidth in hertz, refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass
- The second, bandwidth in bits per second, refers to the speed of bit transmission in a channel or link, often referred to as Capacity

Throughput

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

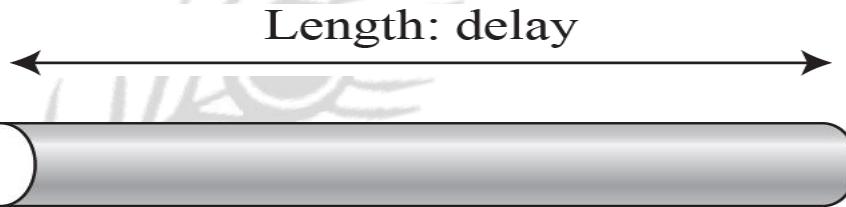
OR

- How much data can be transferred from source to destination in a given time frame
- A link may have a bandwidth of BW bps, but we can only send T bps through this link with T always less than B ($T < B$)

Bandwidth-Delay

- Bandwidth and delay are two performance metrics of a link

Cross section:
bandwidth



$$\text{Volume} = \text{bandwidth} \times \text{delay}$$

Bandwidth-Delay

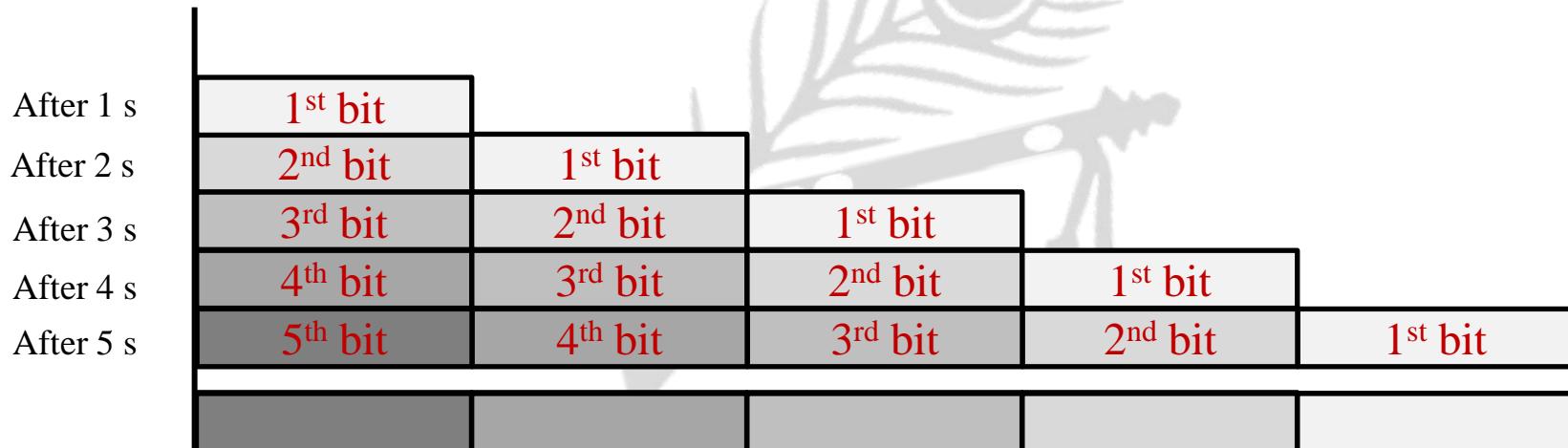


Sender

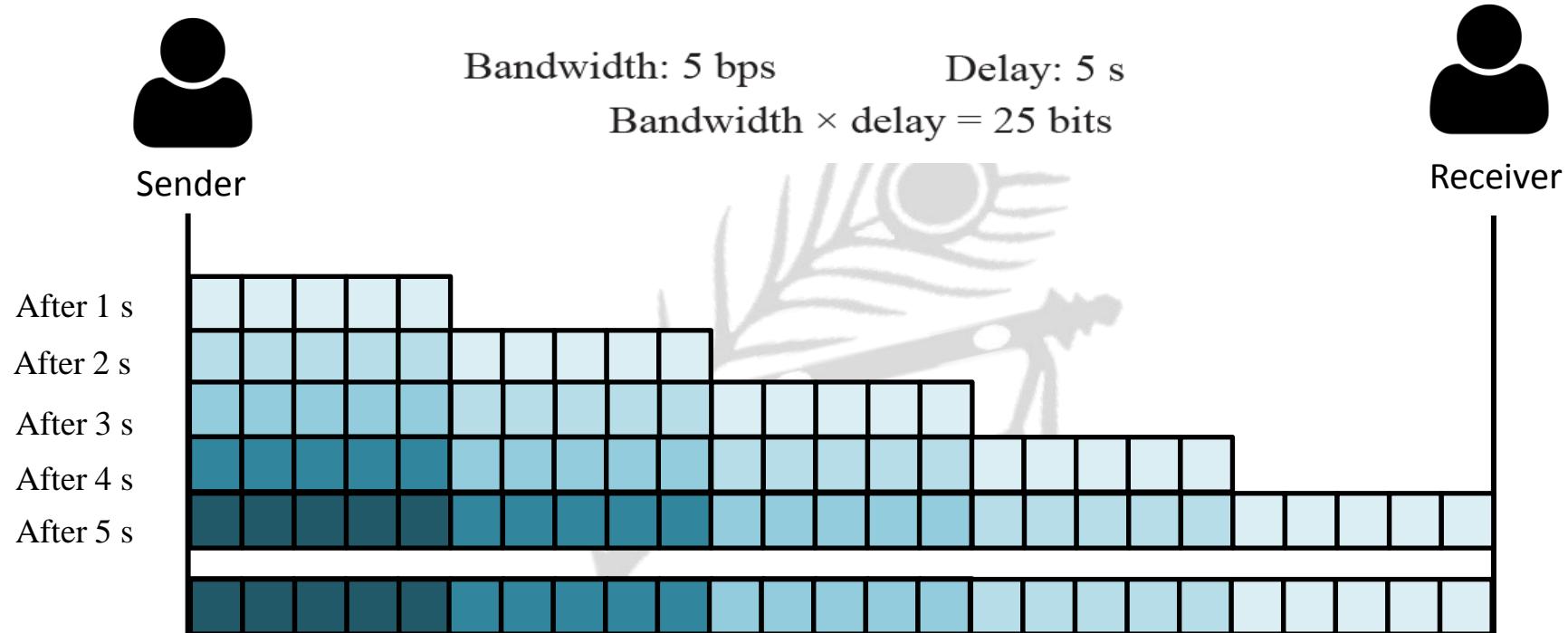
Bandwidth: 1 bps Delay: 5 s
 $\text{Bandwidth} \times \text{delay} = 5 \text{ bits}$



Receiver



Bandwidth-Delay



Delay

- Eg:
 - 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?

Solution

- We can calculate the throughput as

$$\begin{aligned}\text{Throughput} &= (12000 * 10000)/60 \\ &= 2 * 10^6 \\ &= 2 \text{ Mbps}\end{aligned}$$

Delay

- Eg:
 - 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

Solution

- We can calculate the propagation time as

$$\begin{aligned}\text{Propagation Time} &= (12000 * 1000) / (2.4 * 10^8) \\ &= 0.05 \text{ s} \\ &= 50 \text{ ms}\end{aligned}$$

Delay

- Eg:
 - What are the propagation time and the transmission time for a 2.5 KB message 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

Solution

$$\begin{aligned}
 \text{Propagation Time} &= (12000 * 1000) / (2.4 * 10^8) \\
 &= 0.05 \text{ s} \\
 &= 50 \text{ ms}
 \end{aligned}$$

$$\begin{aligned}
 \text{Transmission Time} &= (2.5 * 10^3 * 8) / (10^9) \\
 &= 20000 / 10^9 \\
 &= 0.00002 \text{ s} = 0.02 \text{ ms}
 \end{aligned}$$

Delay

- Eg:
 - What are the propagation time and the transmission time for a 5 MB message if the bandwidth of the network is 1 Mbps? 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

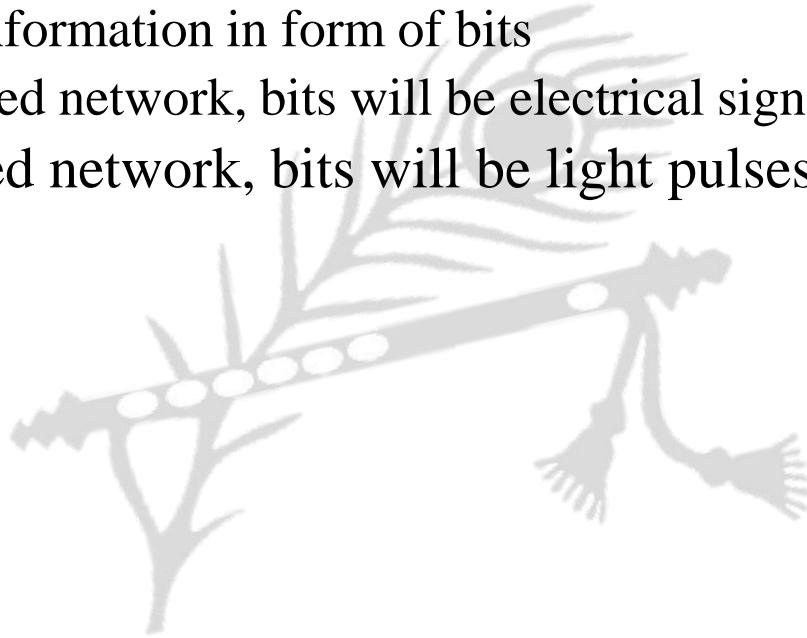
Solution

$$\begin{aligned}\text{Propagation Time} &= (12000 * 1000) / (2.4 * 10^8) \\ &= 50 \text{ ms}\end{aligned}$$

$$\begin{aligned}\text{Transmission Time} &= (5 * 10^6 * 8) / (10^6) \\ &= 40 \text{ s}\end{aligned}$$

Media

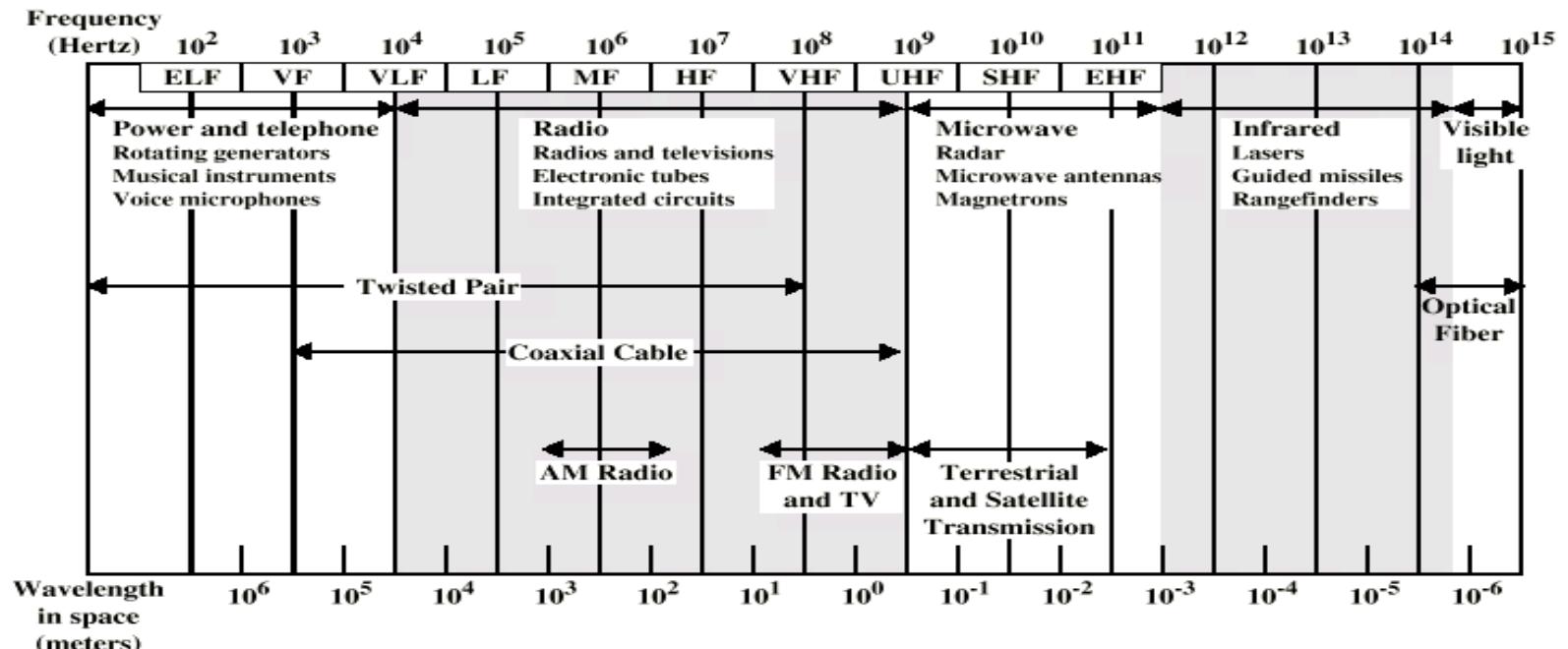
- Basic function of media
 - carry flow of information in form of bits
 - In a copper based network, bits will be electrical signals
 - In a fiber based network, bits will be light pulses



Transmission Media

- Physical path between transmitter and receiver
- Wired and Wireless
- Communication is in the form of electromagnetic waves
- Characteristics and quality of data transmission are determined by characteristics of medium and signal
- In wired media, medium characteristics is more important, whereas in wireless media, signal characteristics is more important

Electromagnetic Spectrum



ELF = Extremely low frequency

VF = Voice frequency

VLF = Very low frequency

LF = Low frequency

MF = Medium frequency

HF = High frequency

VHF = Very high frequency

UHF = Ultrahigh frequency

SHF = Superhigh frequency

EHF = Extremely high frequency

Basic limitations

- Attenuation
- Delay Distortion
- Noise
 - Thermal/White Noise
 - Intermodulation Noise
 - Crosstalk
 - Echo
 - Impulse Noise

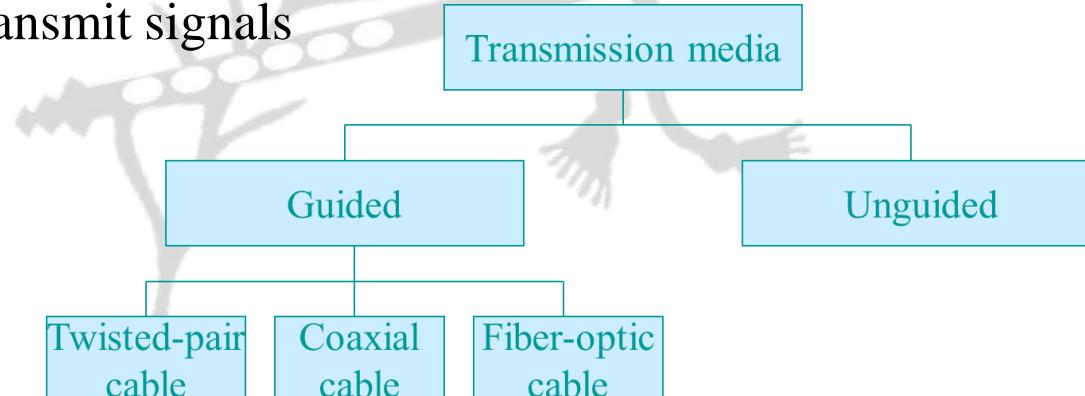


Design Factors for Transmission Media

- Bandwidth: All other factors remaining constant, the greater the band-width of a signal, the higher the data rate that can be achieved.
- Transmission impairments: Limit the distance a signal can travel.
- Interference: Competing signals in overlapping frequency bands can distort or wipe out a signal.
- Number of receivers: Each attachment introduces some attenuation and distortion, limiting distance and/or data rate.

Classes of Transmission Media

- Conducted or guided media
 - use a conductor such as a wire or a fiber optic cable to move the signal from sender to receiver
- Wireless or unguided media
 - use radio waves of different frequencies and do not need a wire or cable conductor to transmit signals



Wire Conductors

- Wire types: *single conductor, twisted pair, & shielded multiconductor bundles*
- Large installed base
- Reasonable cost
- Relatively low bandwidth, however, recent LAN speeds in the 100 Mbps range have been achieved
- Susceptible to external interference
- Shielding can reduce external interference
- Can transmit both analog and digital signals. Amplifier required every 5 to 6 km for analog signals. For digital signals, repeaters required every 2 to 3 km

Wired - Twisted Pair

- The oldest, least expensive, and most commonly used media
- Pair of insulated wires twisted together to reduce susceptibility to interference : ex) capacitive coupling, crosstalk
- Skin effect at high frequency
- Up to 250 kHz analog and few Mbps digital signaling (for long-distance point-to-point signaling)
- Need repeater every 2-3 km (digital), and amplifier every 5-6 km (analog)

Twisted Pair

- Consists of two insulated copper wires arranged in a regular spiral pattern to minimize the electromagnetic interference between adjacent pairs
- Often used at customer facilities and also over distances to carry voice as well as data communications
- Low frequency transmission medium
- Telephone (subscriber loop: between house and local exchange)
- High-speed (10 - 100 Mbps) LAN
 - token ring, fast - Ethernet

— Separately insulated
 — Twisted together
 — Often "bundled" into cables
 — Usually installed in building when built



(a) Twisted pair

Types of Twisted Pair

- STP (shielded twisted pair)
 - the pair is wrapped with metallic foil or braid to insulate the pair from electromagnetic interference
- UTP (unshielded twisted pair)
 - each wire is insulated with plastic wrap, but the pair is encased in an outer covering

Ratings of Twisted Pair

- Category 3
 - UTP cables and associated connecting hardware whose transmission characteristics are specified up to 16 MHZ.
 - data rates of up to 16mbps are achievable
- Category 4
 - UTP cables and associated connecting hardware whose transmission characteristics are specified up to 20 MHz.
- Category 5
 - UTP cables and associated connecting hardware whose transmission characteristics are specified up to 100 MHz.
 - data rates of up to 100mbps are achievable
 - more tightly twisted than Category 3 cables
 - more expensive, but better performance
- Category 5 enhanced, Cat 6, cat 7
 - Fast and giga-ethernet
- STP
 - More expensive, harder to work with

Twisted Pair Advantages

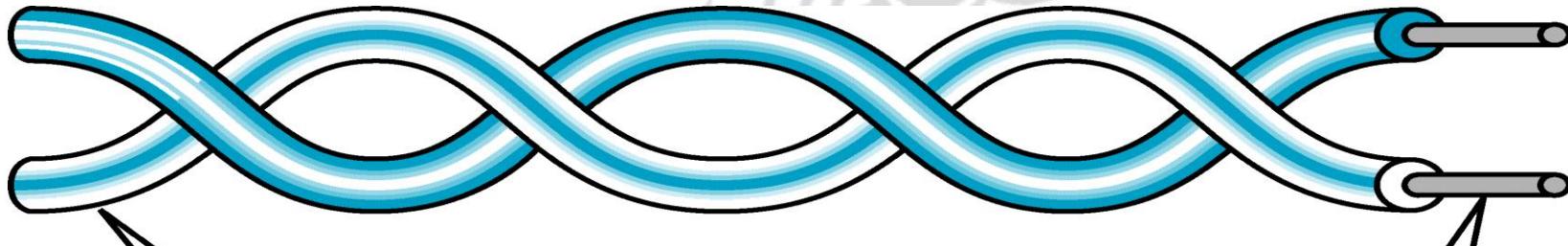
- Advantages
 - Inexpensive and readily available
 - Flexible and light weight
 - Easy to work with and install
- Disvantages
 - Susceptibility to interference and noise
 - Attenuation problem
 - For analog, repeaters needed every 5-6km
 - For digital, repeaters needed every 2-3km
 - Relatively low bandwidth (MHz)

Twisted-Pair Cable

Twisted-pair cable

100 Hz

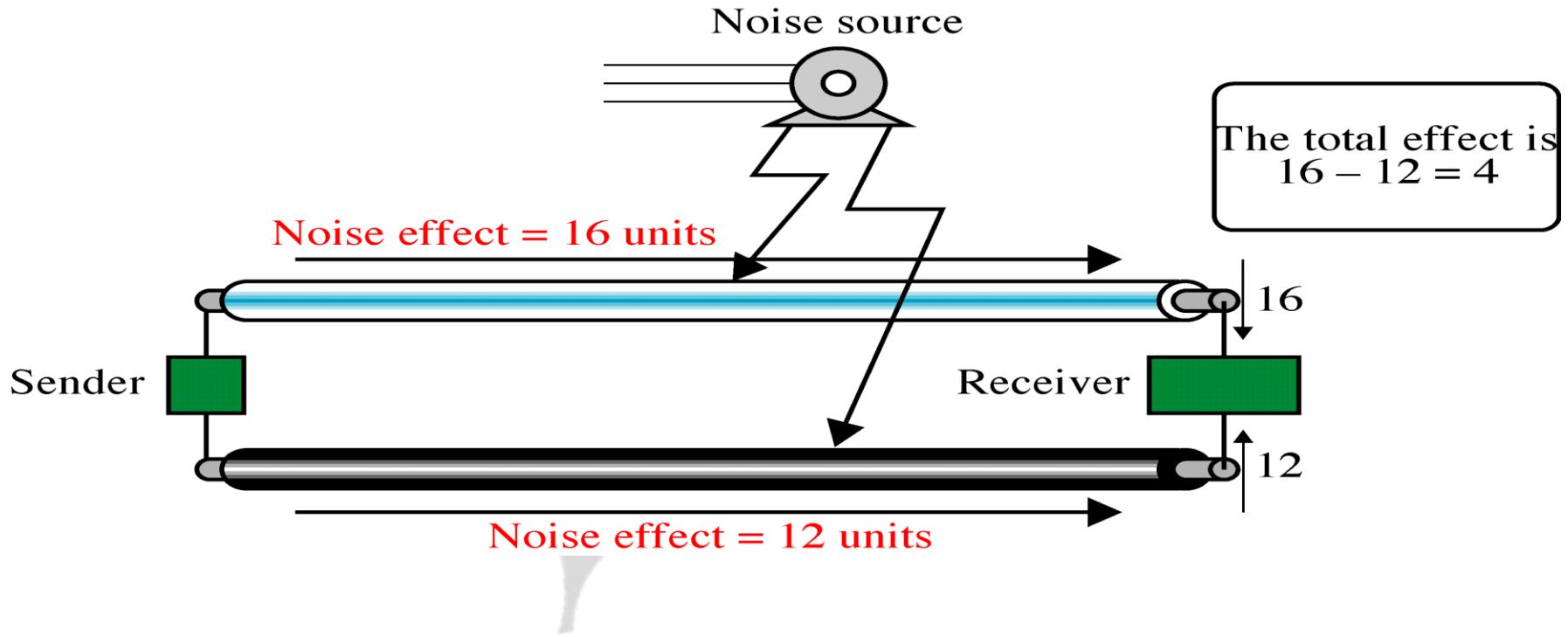
5 MHz



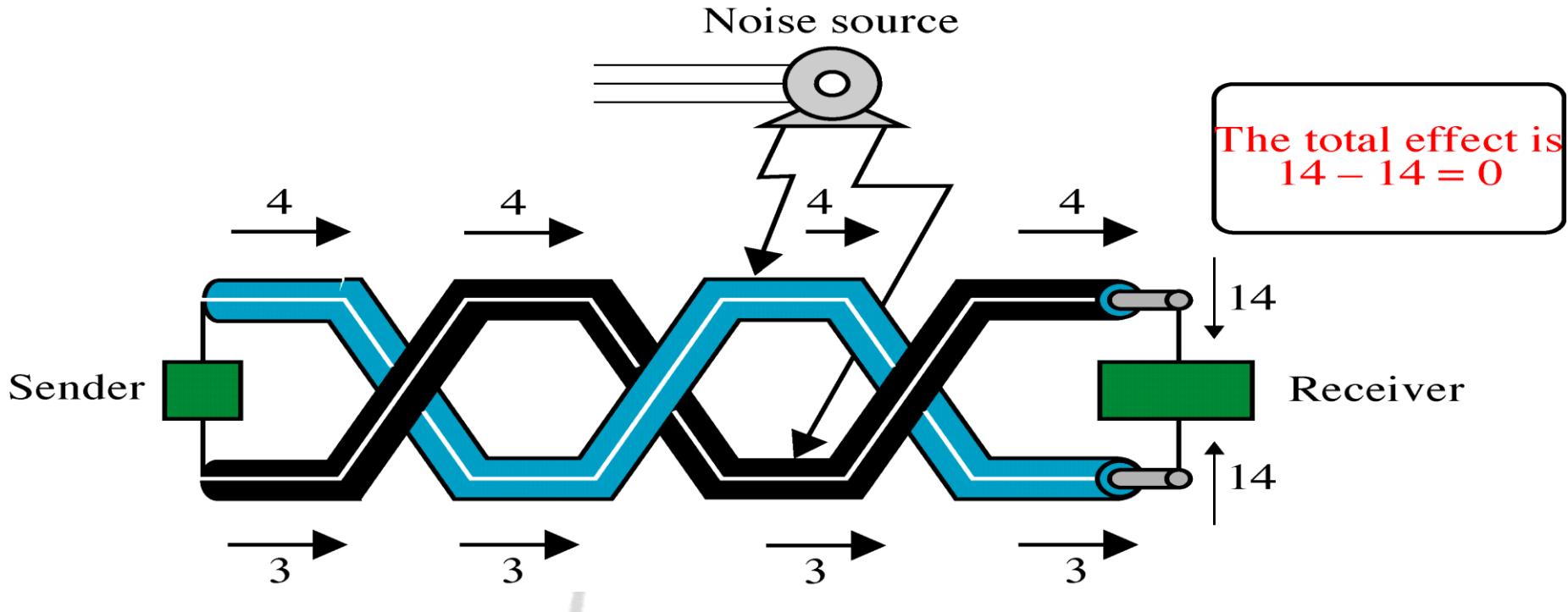
Outer insulator
or PVC

Solid copper
conductors

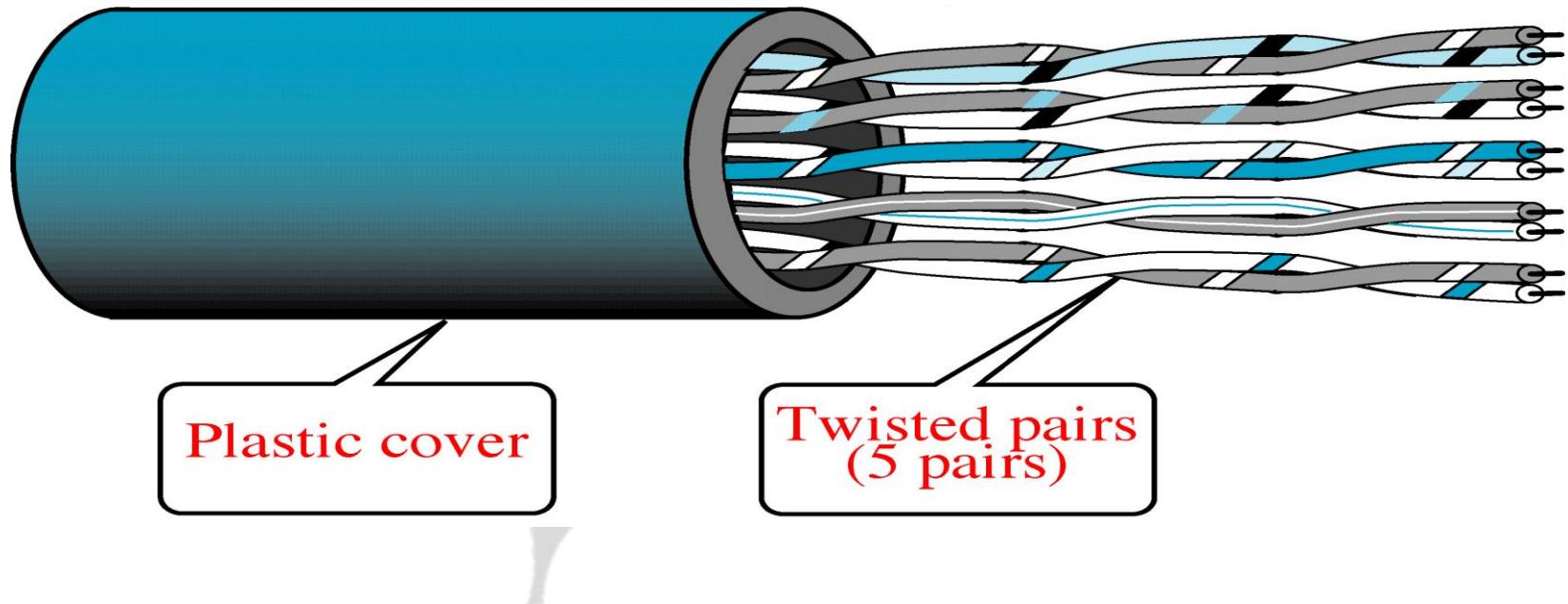
Effect of Noise on Parallel Lines



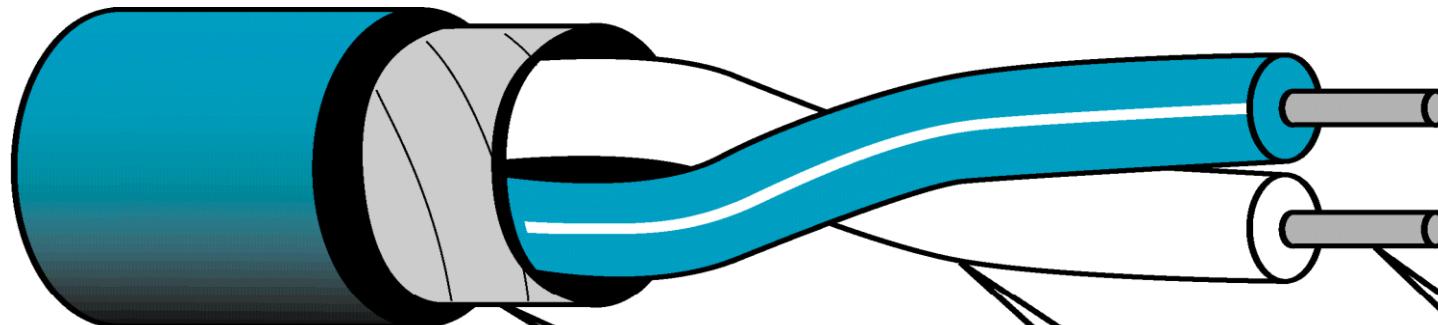
Noise on Twisted-Pair Lines



Unshielded Twisted-Pair Cable



Shielded Twisted-Pair Cable



Plastic cover

Metal shield

Insulation

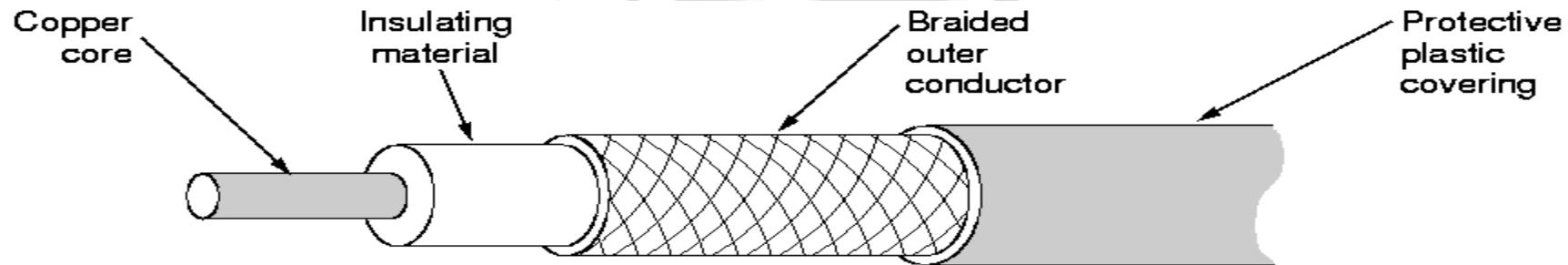
Copper

Wired Transmission Media

- Coaxial Cable
 - Most versatile medium
 - LANs, Cable TV, Long-distance telephones, VCR-to-TV connections
 - Noise immunity is good
 - Very high channel capacity
 - few 100 MHz / few 100 Mbps
 - Need repeater/amplifier every few kilometer or so (about the same as with twisted pair)
- Has an inner conductor surrounded by a braided mesh
- Both conductors share a common center axial, hence the term “co-axial”

Coaxial cable

- Signal and ground wire
 - Solid center conductor running coaxially inside a solid (usually braided) outer circular conductor.
 - Center conductor is shielded from external interference signals.



Properties of coaxial cable

- Better shielding allows for longer cables and higher transfer rates.
- 100 m cables
 - 1 to 2 Gbps feasible (modulation used)
 - 10 Mbps typical
- Higher bandwidth
 - 400 to 600Mhz
 - up to 10,800 voice conversations
- Can be tapped easily: stations easily added (pros and cons)
- Much less susceptible to interference than twisted pair
- Used for long haul routes by Phone Co.
 - Mostly replaced now by optical fiber.
- High attenuation rate makes it expensive over long distance
- Bulky
- *Baseband vs. broadband coax.*

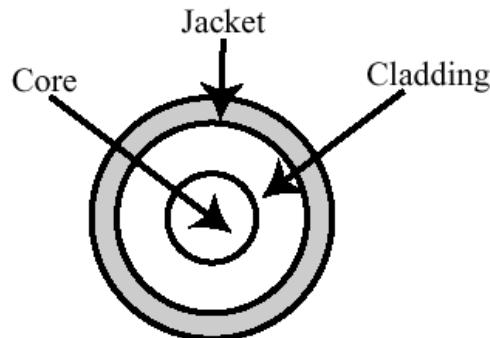
Wired Transmission Media

- Optical Fiber

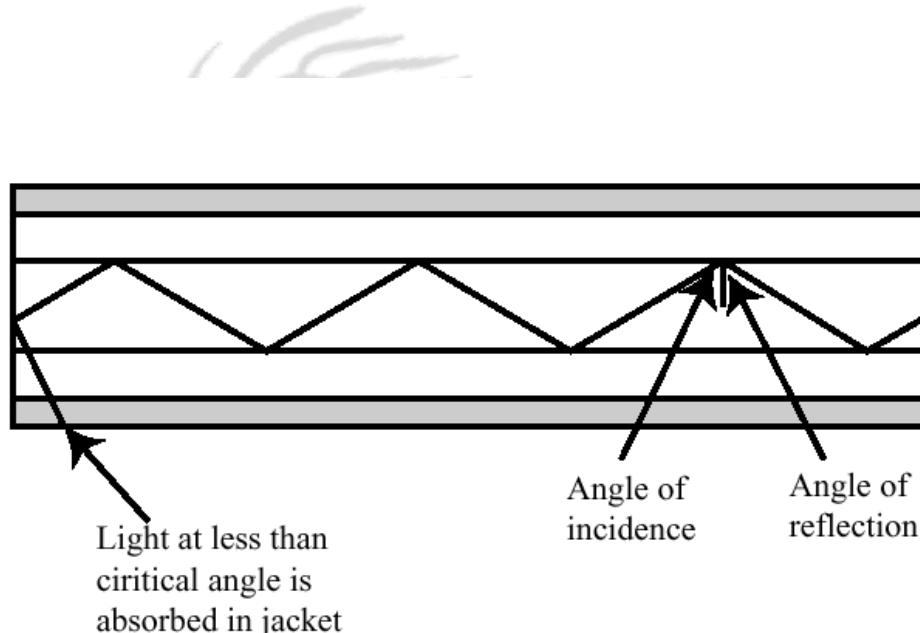
- Flexible, thin (few to few hundred μm), very pure glass/plastic fiber capable of conducting optical rays
- Extremely high bandwidth : capable of $\geq 2 \text{ Gbps}$
- Very high noise immunity, resistant to electromagnetic interference
- Does not radiate energy/cause interference
- Very light
- Need repeaters only 10's or 100 km apart
- Very difficult to tap : Better security but multipoint not easy
- Require a light source with injection laser diode (ILD) or light-emitting diodes (LED)

Wired Transmission Media

- Need optical-electrical interface (more expensive than electrical interface)



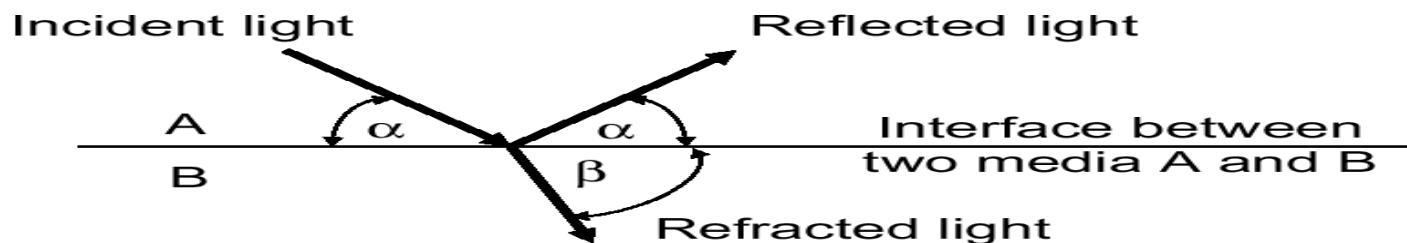
- Glass or plastic core
- Laser or light emitting diode
- Specially designed jacket
- Small size and weight



(c) Optical Fiber

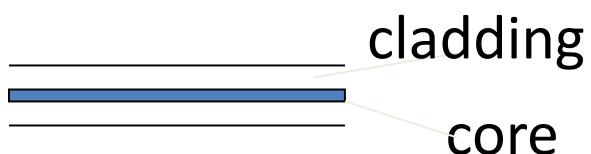
Wired Transmission Media

- Principle of optical fiber transmission: Based on the principle of total internal reflection
- If $\beta > \alpha$, medium B (water) has a higher optical density than medium A (air)
- In case the index of refraction < 1 ($\alpha > \beta$), if α is less than a certain critical angle, there is no refracted light i.e., all the light is reflected. This is what makes fiber optics work



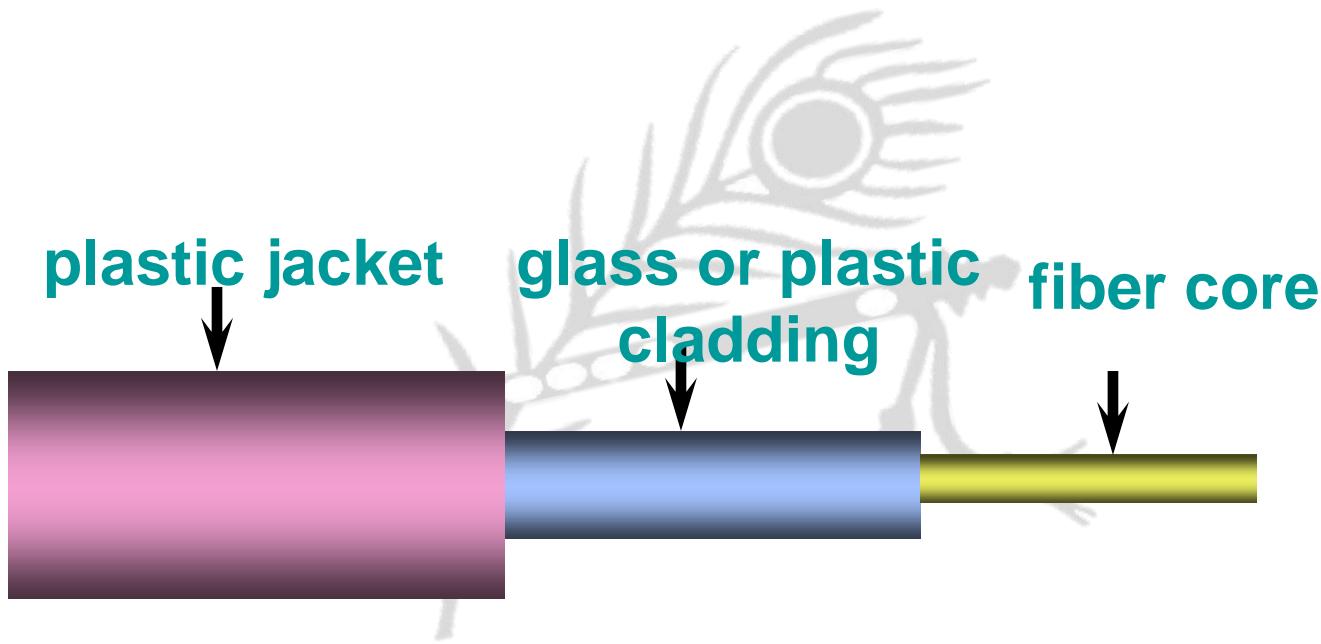
Fiber optics & Physics 101

- Refractive index_{material} = (Speed of light in vacuum)/(Speed of light in material)
- Light is bent as it passes through a surface where the refractive index changes. This bending depends on the angle and refractive index. Frequency does not change, but because it slows down, the wave length gets shorter, causing wave to bend.
- In case of fiber optic media, refractive index of core > refractive index of cladding thereby causing internal reflection.



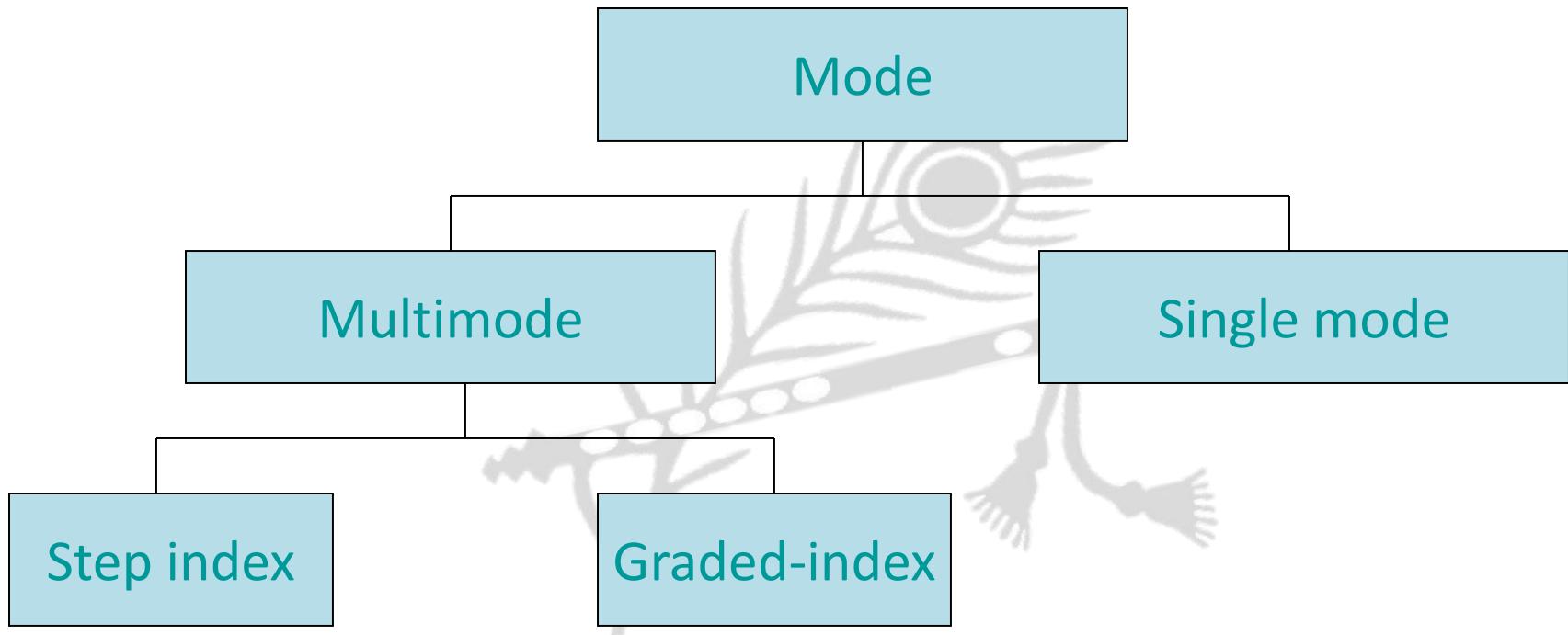
Fiber Optic Layers

- consists of three concentric sections



Modes of fiber

- Fiber consists of two parts: the *glass core* and *glass cladding* with a lower refractive index.
- Light propagates in 1 of 3 ways depending on the type and width of the core material.
 - **Multimode stepped index fiber**
 - Both core and cladding have different but uniform refractive index.
 - Relies on total internal reflection; Wide pulse width.
 - **Multimode graded index fiber**
 - Core has variable refractive index (light bends as it moves away from core).
 - Narrow pulse width resulting in higher bit rate.
 - **Singlemode fiber (> 100 Mbs)**
 - Width of core diameter equal to a single wavelength.



Fiber Optic Types

- multimode step-index fiber
 - the reflective walls of the fiber move the light pulses to the receiver
- multimode graded-index fiber
 - acts to refract the light toward the center of the fiber by variations in the density
- single mode fiber
 - the light is guided down the center of an extremely narrow core

Types of optical fiber

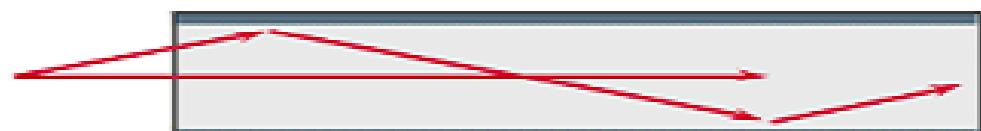
- Modes, bundles of light rays enter the fiber at a particular angle
- Single-mode
 - Also known as mono-mode
 - Only one mode propagates through fiber
 - Higher bandwidth than multi-mode
 - Longer cable runs than multi-mode
 - Lasers generate light signals
 - Used for inter-building connectivity



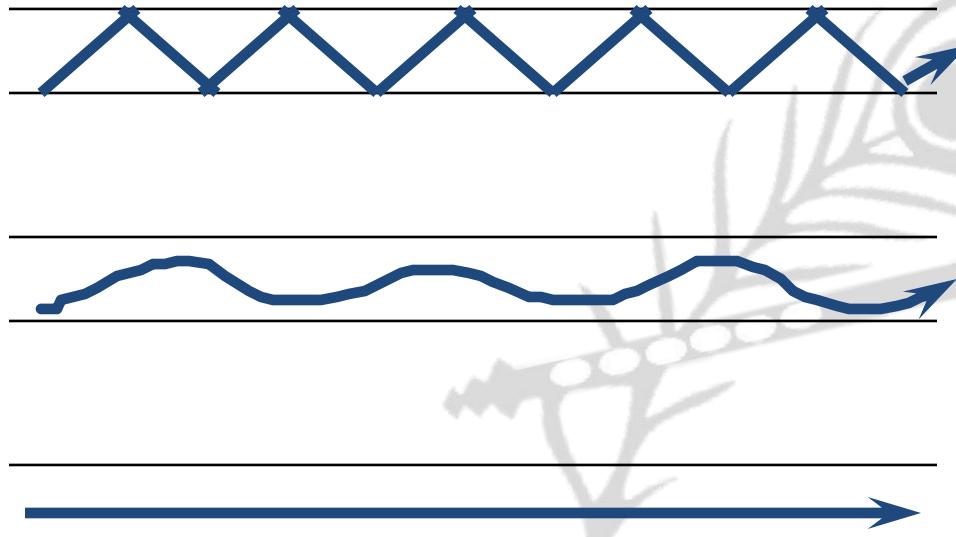
Types of optical fiber

- Multi-mode
 - Multiple modes propagate through fiber
 - Different angles mean different distances to travel
 - Transmissions arrive at different times
 - Modal dispersion
 - LEDs as light source
 - Used for intra-building connectivity

Multimode
"cone" of rays
enters fiber
emitted by LED



Fiber Optic Signals



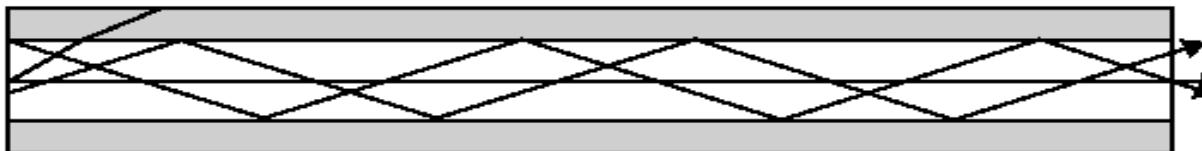
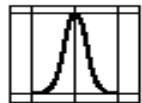
fiber optic multimode
step-index

fiber optic multimode
graded-index

fiber optic single mode

Optical Fiber Transmission Mode

Input pulse

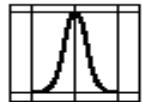


Output pulse

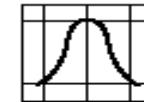


(a) Step-index multimode

Input pulse

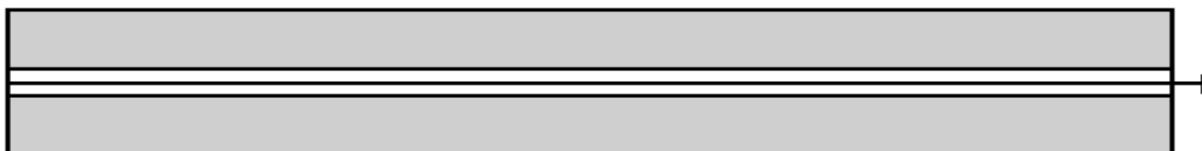
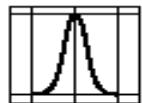


Output pulse

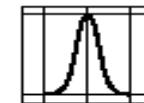


(b) Graded-index multimode

Input pulse



Output pulse



(c) Single mode

Fiber Optic

Advantages

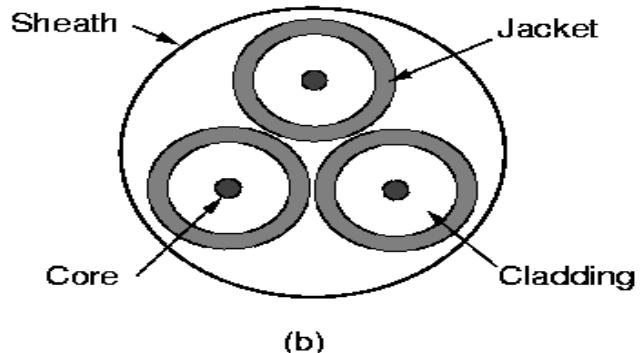
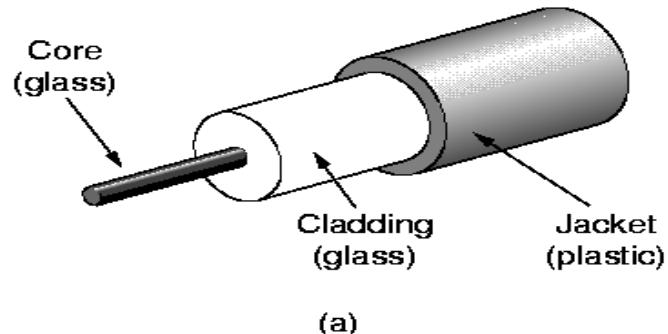
- greater capacity (bandwidth Gbps)
- smaller size and lighter weight
- lower attenuation
- immunity to environmental interference
- highly secure due to tap difficulty and lack of signal radiation

Disvantages

- expensive over short distance
- requires highly skilled installers
- adding additional nodes is difficult

Fiber cables

- Multimode: diameter of core is ~50 microns
 - About the same as a human hair
- Single mode: diameter of core 8-10 microns
- They can be connected by connectors, or by splicing, or by fusion



Fiber vs. copper

- Fiber (pros)
 - Higher bandwidth,
 - Lower attenuation,
 - Immune to electromagnetic noise and corrosive chemicals,
 - Thin and lightweight,
 - Security (does not leak light, difficult to tap).
- Fiber (cons)
 - Not many skilled “fiber engineers,”
 - Inherently unidirectional,
 - Fiber interfaces are expensive.

Wireless (Unguided Media) Transmission

- transmission and reception are achieved by means of an antenna
- directional
 - transmitting antenna puts out focused beam
 - transmitter and receiver must be aligned
- omnidirectional
 - signal spreads out in all directions
 - can be received by many antennas

Physical media: radio

- signal carried in electromagnetic spectrum
- no physical “wire”
- bidirectional
- propagation environment effects:
 - reflection
 - obstruction by objects
 - interference

Physical media: radio

- Radio link types:
 - microwave
 - e.g. up to 45 Mbps channels
 - LAN (e.g., waveLAN)
 - 2Mbps, 11Mbps, 54 Mbps
 - wide-area (e.g., cellular)
 - e.g. CDPD, 10's Kbps
 - satellite
 - up to 50Mbps channel (or multiple smaller channels)
 - 270 msec end-end delay
 - geosynchronous versus LEOS

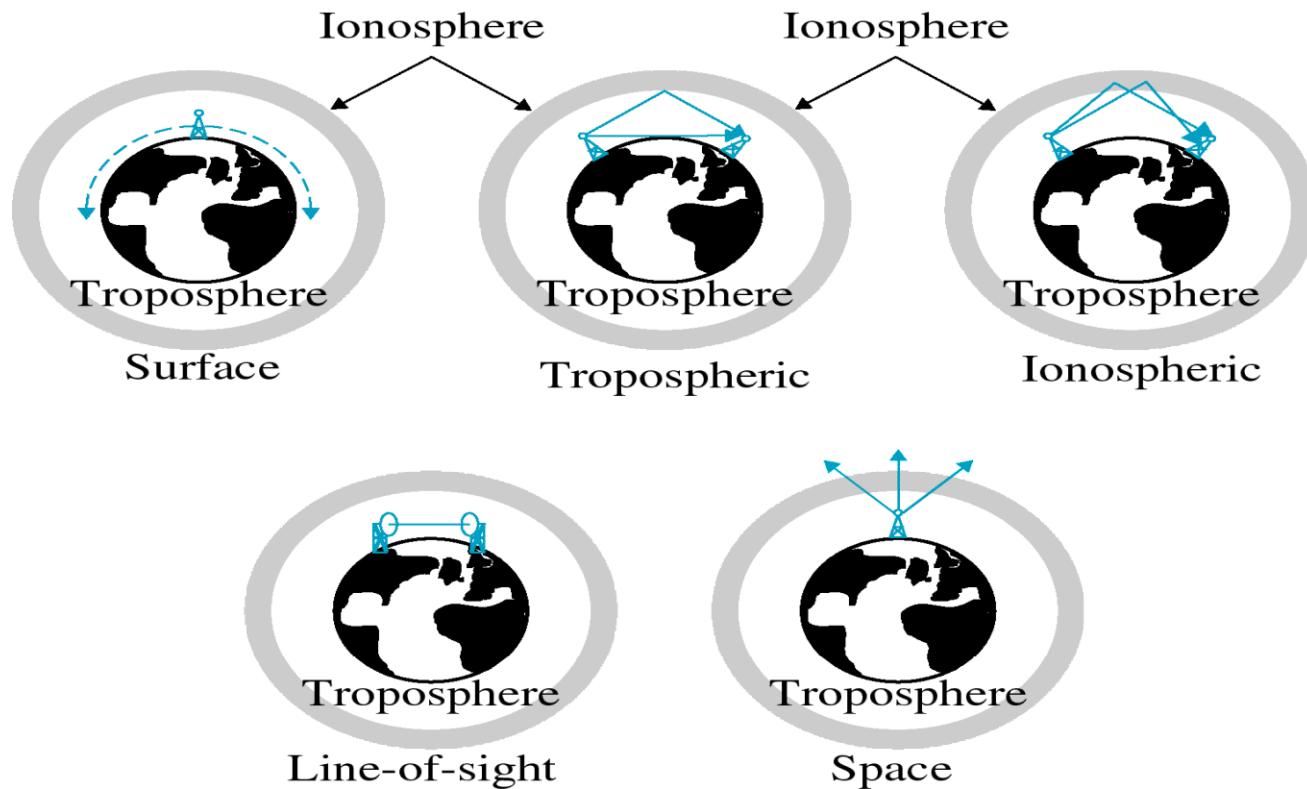
Infrared

- Transceivers must be within line of sight of each other (directly or via reflection)
- Unlike microwaves, infrared does not penetrate walls
- Fairly low bandwidth (4 Mbps)
- Uses wavelengths between microwave and visible light
- Uses transmitters/receivers (transceivers) that modulate noncoherent infrared light
- No frequency allocation issue since not regulated.
- Uses include local building connections, wireless LANs, and new wireless peripherals

Radio Transmission

- Radio waves
 - Easy to generate, travel long distances, and penetrate buildings easily.
 - Omnidirectional.
 - Low frequencies
 - Pass through obstacles well,
 - Quick power drop off (e.g. $1/r^3$ in air).
 - High frequencies
 - Travel in straight lines and bounce off obstacles.
 - Absorbed by rain.
 - Subject to electrical interference

Propagation Types



LINE CODING

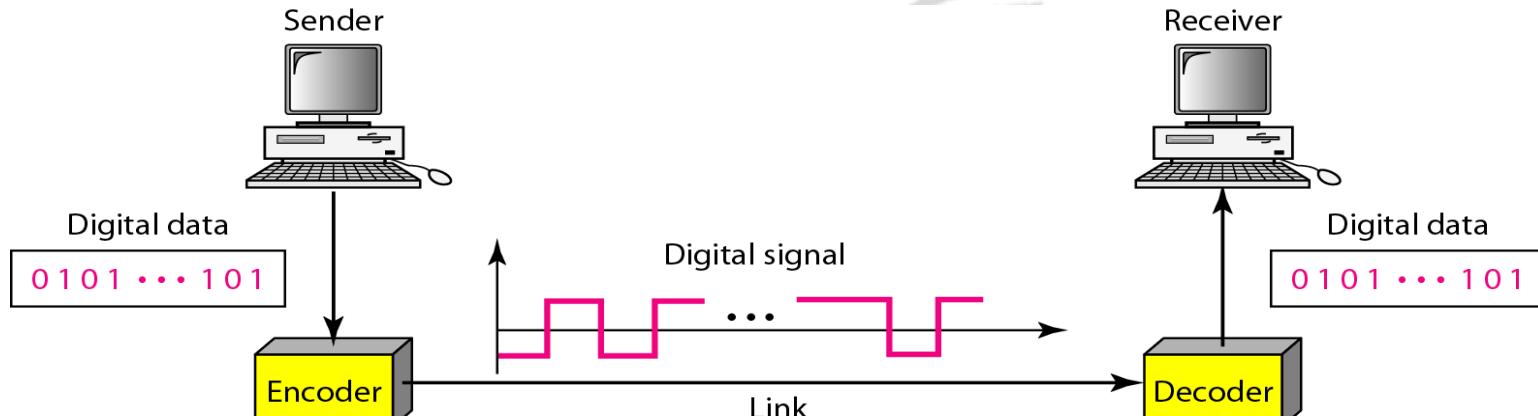
Digital-to-digital conversion

- In this section, we see how we can represent digital data by using digital signals
- The conversion involves three techniques:
 - line coding,
 - block coding, and
 - scrambling.
- Line coding is always needed; block coding and scrambling may or may not be needed

Line Coding

- Converting a string of 1's and 0's (digital data) into a sequence of signals that denote the 1's and 0's
- Eg:
 - a high voltage level (+V) could represent a “1” AND
 - a low voltage level (0 or -V) could represent a “0”

Line coding and decoding



Mapping Data symbols onto Signal levels

- A data symbol can consist of a number of data bits
 - 1, 0 OR
 - 11, 10, 01, etc
- A data symbol can be coded into a single signal element or multiple signal elements
 - 1 → +V, 0 → -V
 - 1 → +V and -V, 0 → -V and +V
- The ratio 'r' is the number of data elements carried by a signal element

Relationship b/w data rate and signal rate

- Data rate
 - the number of bits sent per sec (bps)
 - it is often referred to the bit rate
- Signal rate
 - the number of signal elements sent in a second
 - it is measured in bauds
 - it is also referred to as the modulation rate or baud rate

Relationship b/w data rate and signal rate

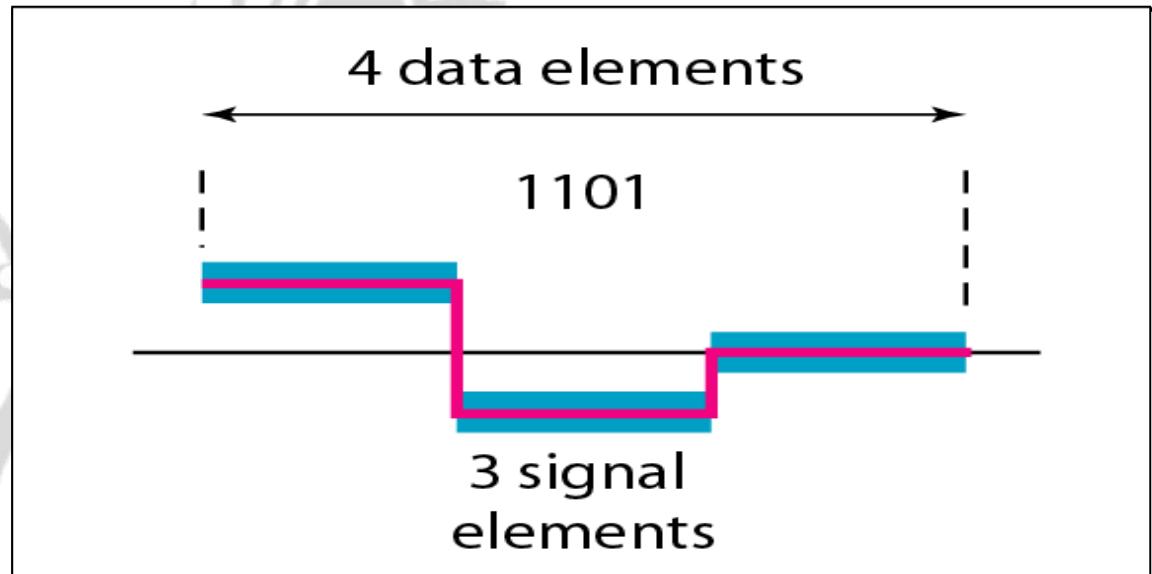
Data

- A data element is the smallest entity that can represent a piece of information (bit)
- Data elements are what we need to send
- Data elements are being carried
- Data rate defines the number of data elements (bits) send in 1s
- Unit is bps

Signal

- A signal element is the shortest unit of the digital signal
- Signal element are what we can send
- Signal elements are the carriers
- Signal rate is the number of signal elements send in 1s
- Unit is baud

Data element vs data element



Baud rate

- The baud or signal rate can be expressed as:

$$S = c \times N \times 1/r \text{ bauds}$$

where,

c is the case factor (worst, best & avg.)

N is data rate

r is the ratio between data element & signal element

Baud rate

- Eg:
 - A signal is carrying data in which one data element is encoded as one signal element ($r = 1$). If the bit rate is 100 kbps, what is the average value of the baud rate if c is between 0 and 1?

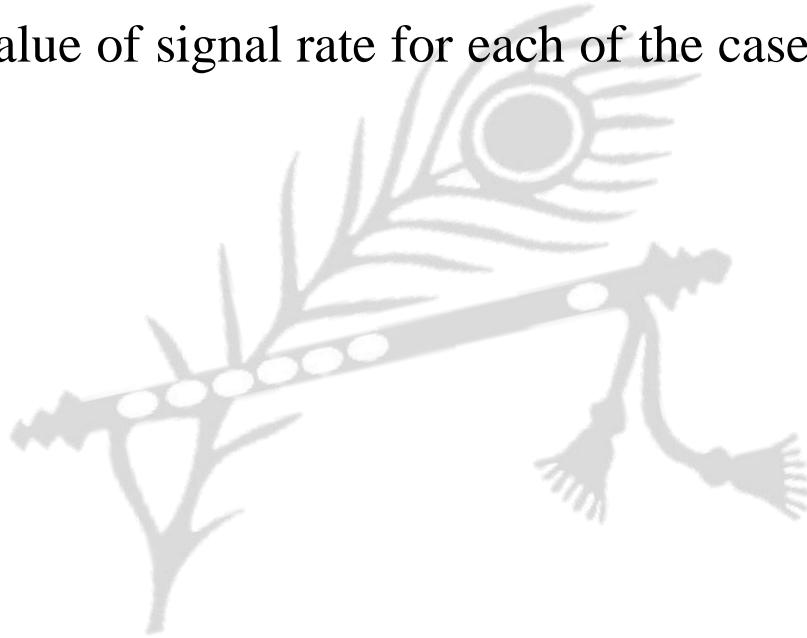
Solution

- We assume that the average value of c is $1/2$. The baud rate is then

$$\begin{aligned}S &= c * N * 1/r \\&= \frac{1}{2} * 100000 * 1 \\&= 50000 \\&= 50k \text{ baud}\end{aligned}$$

Baud rate

- Eg:
 - Calculate the value of signal rate for each of the cases if data rate is 1 Mbps and $c = 1/2$
 - a. $r = 1$
 - b. $r = 1/2$
 - c. $r = 2$
 - d. $r = 4/3$



Line Coding

- Data as well as signals that represents data can either be digital or analog
- Line coding is the process of converting digital data to digital signals
- By this technique we converts a sequence of bits to a digital signal
- At the sender side digital data are encoded into a digital signal and at the receiver side the digital data are recreated by decoding the digital signal

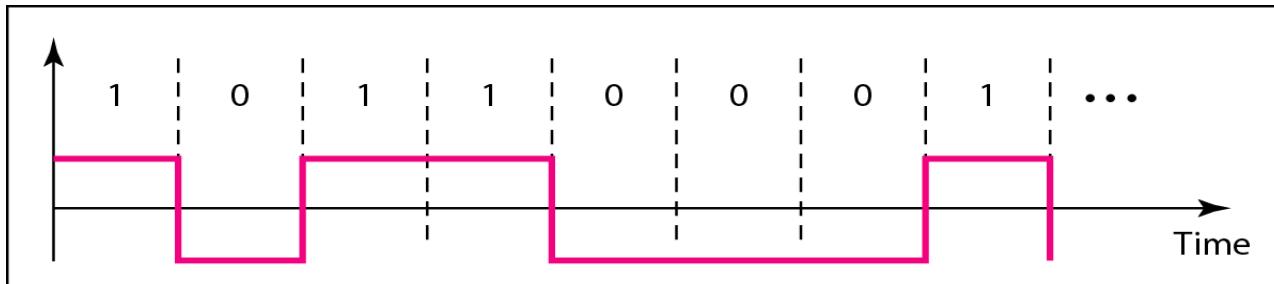
Line Coding

- We can divide line coding schemes into five categories
 - Unipolar (Eg: NRZ scheme)
 - Polar (Eg: NRZ-L, NRZ-I, RZ, and Biphase – Manchester and differential Manchester)
 - Bipolar (Eg: AMI and Pseudoternary).
 - Multilevel
 - Multi-transition

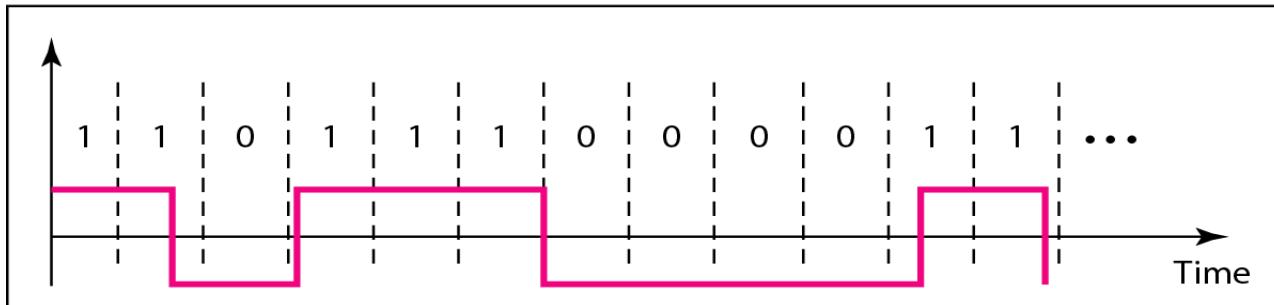
Characteristics of Line Coding techniques

- There should be self-synchronizing i.e., both receiver and sender clock should be synchronized
- There should have some error-detecting capability
- There should be immunity to noise and interference
- There should be less complexity
- There should be no low frequency component, as long distance transfer is not feasible for low frequency component signal
- There should be less base line wandering

Characteristics of Line Coding techniques



a. Sent



b. Received

- Eg:
 - In a digital transmission, the receiver clock is 0.1 percent faster than the sender clock. How many extra bits per second does the receiver receive if the data rate is 1 kbps? How many if the data rate is 1 Mbps?

Solution

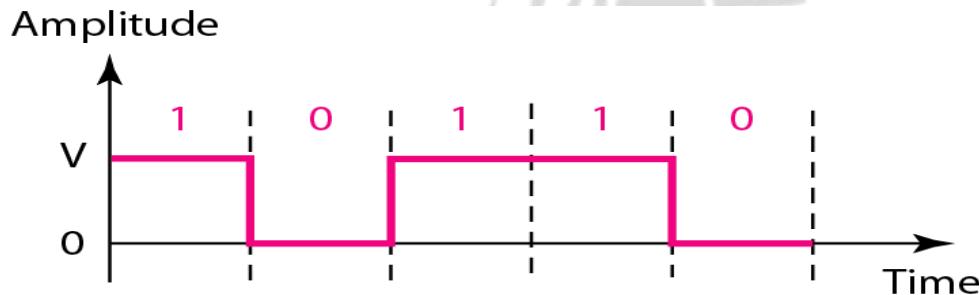
- At 1 kbps, the receiver receives 1001 bps instead of 1000 bps
- At 1 Mbps, the receiver receives 1,001,000 bps instead of 1,000,000 bps

Unipolar Line Coding Scheme

- All signal levels are on one side of the time axis
 - either above or below
 - Eg: NRZ (Non Return to Zero)
- The signal level does not return to zero during a symbol transmission
- The signal will change level at the edge of the time interval and not in between
- Disadvantages
 - Scheme is subject to baseline wandering
 - It has no synchronization or any error detection
 - It is simple but costly in power consumption

Unipolar - NRZ scheme

- Assumption: data element ‘1’ is on positive side of axis and data element ‘0’ is on the axis

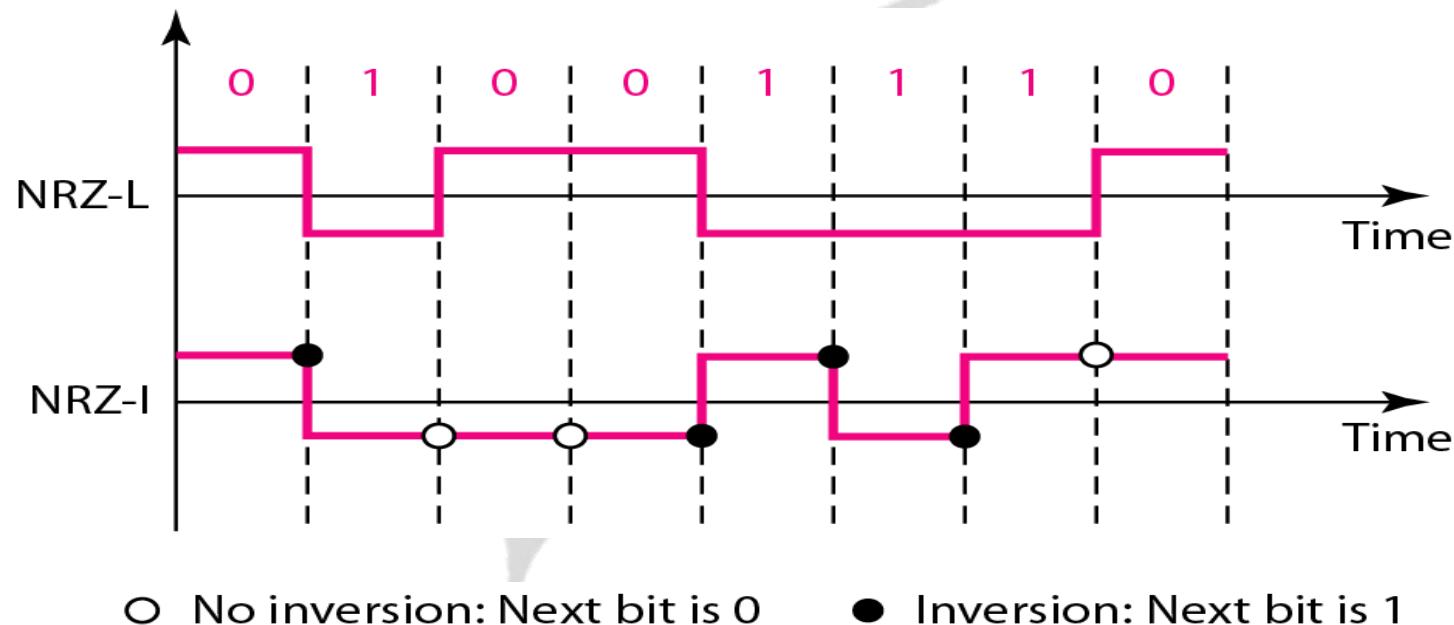


- NOTE: data element ‘1’ is on negative side of axis and data element ‘0’ is on the axis can also be assumed

Polar – NRZ Line Coding Scheme

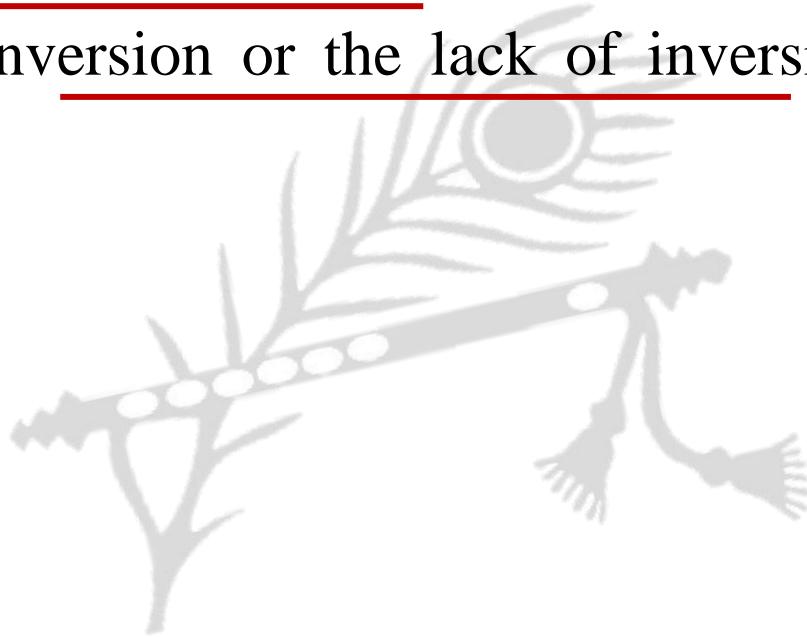
- The voltages are on both sides of the time axis
- The signal level does not return to zero during a symbol transmission
- The signal will change level at the edge of the time interval and not in between
- Polar NRZ scheme can be implemented with two voltages
 - E.g. +V for 1 and -V for 0 or vice versa
- There are two versions:
 - NRZ - Level (NRZ-L) - positive voltage for one symbol and negative for the other
 - NRZ - Inversion (NRZ-I) - the change or lack of change in polarity determines the value of a symbol
 - E.g. a 1 symbol inverts the polarity a 0 does not

Polar NRZ-L and NRZ-I schemes



Polar NRZ-L and NRZ-I schemes

- In NRZ-L the level of the voltage determines the value of the bit
- In NRZ-I the inversion or the lack of inversion determines the value of the bit

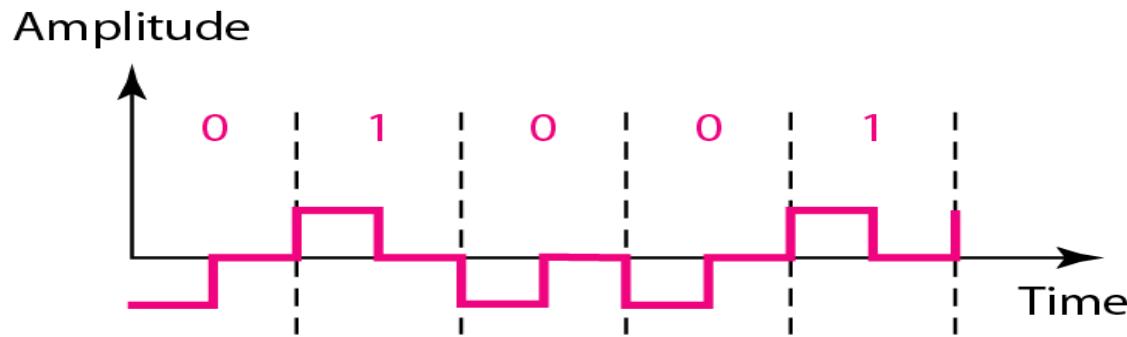


Polar – RZ Scheme

- The Return to Zero (RZ) scheme uses three voltage values
 - +, 0, -
- Each symbol has a transition in the middle
 - Either from high to zero or from low to zero
- The signal will change level in between of the signal element or bit duration
- The signal will not change level at the edge of the time interval
- This scheme has more signal transitions (two per symbol) and therefore requires a wider bandwidth

Polar RZ scheme

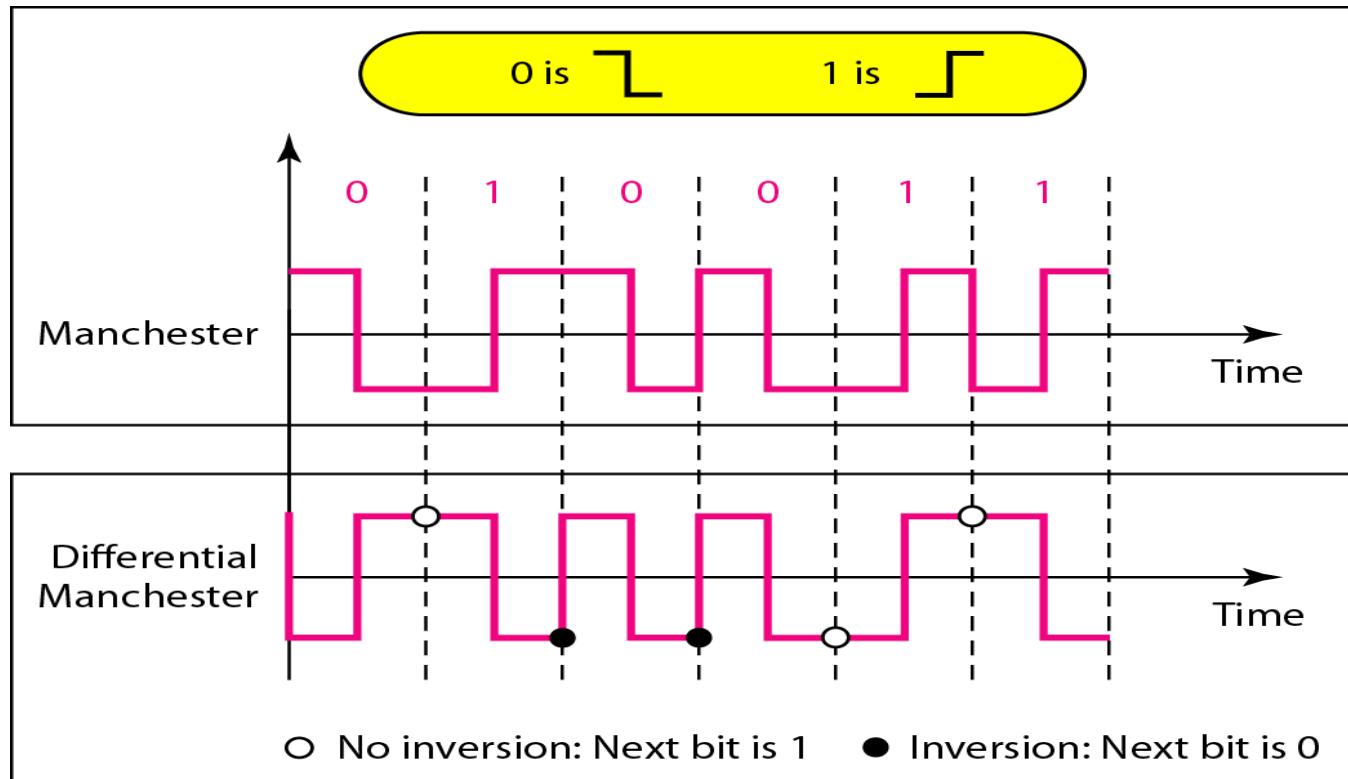
- One bit duration, signal is returning to zero axis during the bit i.e., at the middle of the signal element transmission and not at the edge of the interval



Polar Biphasic

- Manchester coding
 - combining the NRZ-L and RZ schemes
 - Every symbol has a level transition in the middle: from high to low or low to high
 - Uses only two voltage levels
- Differential Manchester coding
 - combining the NRZ-I and RZ schemes
 - Every symbol has a level transition in the middle. But the level at the beginning of the symbol is determined by the symbol value
 - One symbol causes a level change while the other does not

Polar Biphasic



SWITCHING

Switch

- A switch is a device in a computer network that connects other devices together
- Multiple data cables are plugged into a switch to enable communication between different networked devices
- A switch is a device that is used at the Access or OSI Layer 2
- We use switches in circuit-switched and packet-switched networks

Switching Technique

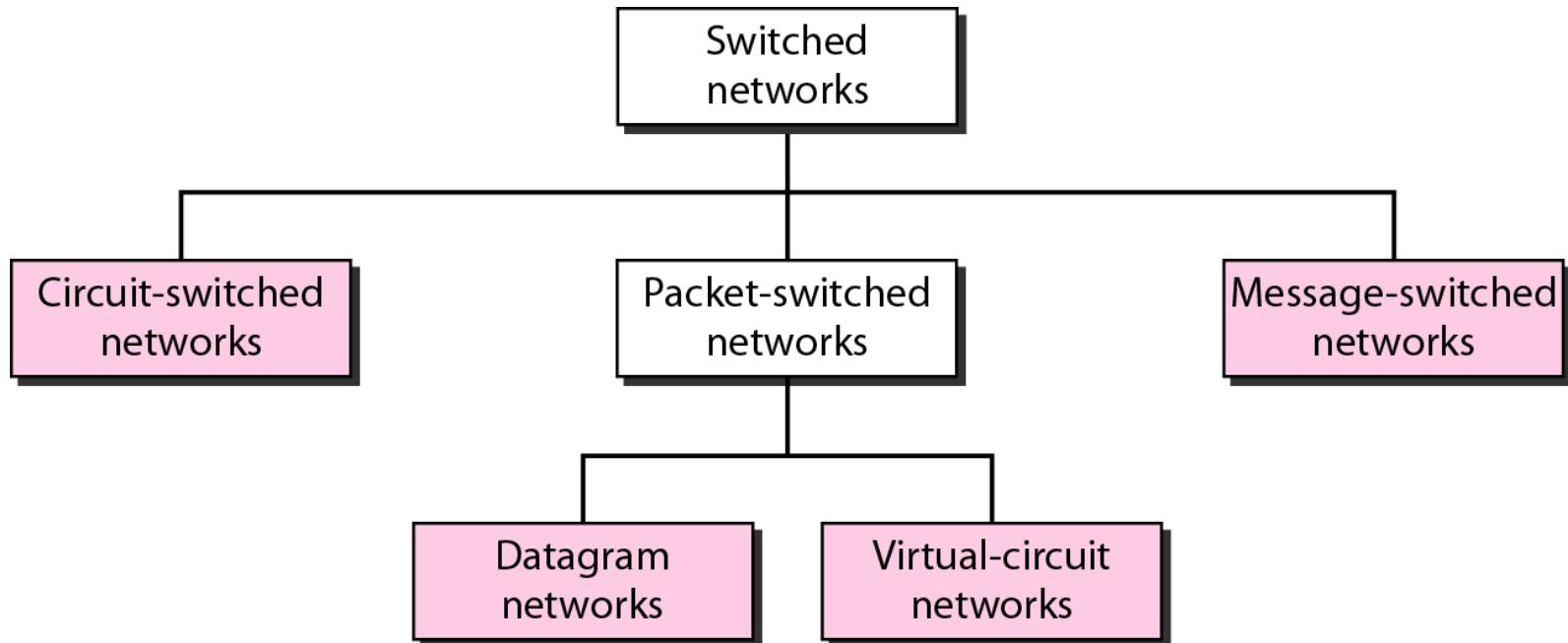
- How 2 devices communicate when there are many devices?
 - One alternative is to establish Point to Point connection between each pair of devices using mesh topology (which is highly complex)
 - The other alternative is to use switching techniques leading to switched connection network

Switching Technique

- There are three typical switching techniques available for digital traffic
 - Circuit Switching
 - Message Switching
 - Packet Switching



Classification of switched networks



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
- Each link is normally divided into n channels by using FDM or TDM
- Routing decisions must be made when the circuit is first established, but there are no decisions made after that time

Circuit Switching

- There are three phases in circuit switching:
 - Establish (Connection Establishment)
 - Transfer (Data Transfer)
 - Disconnect (Connection Release or Tear Down)
- The message arrives in the same order that it was originally sent.

Circuit Switching

Advantages:

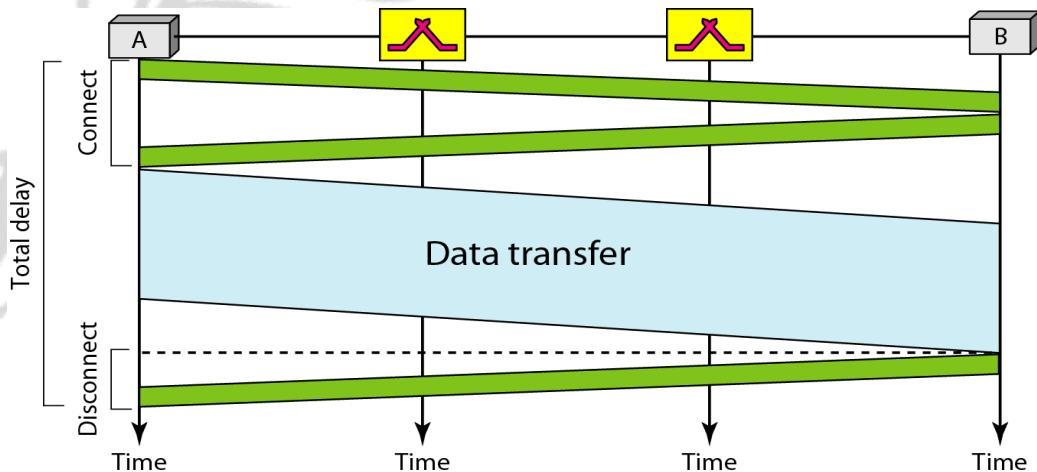
- The communication channel (once established) is dedicated

Disadvantages:

- Possible long wait to establish a connection
- More expensive than any other switching techniques
- Inefficient use of the communication channel

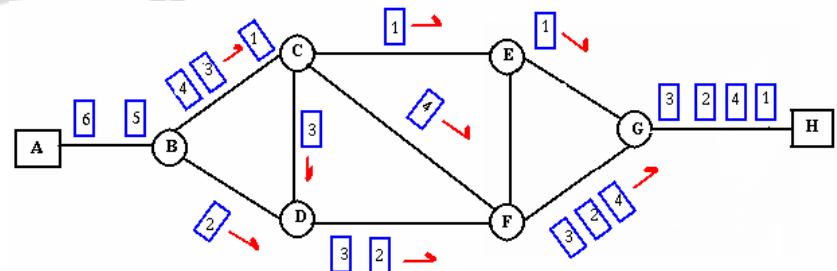
Delay in a circuit-switched network

- Total Delay in a circuit-switched network will be delay for
 - setup and tear down + Propagation delay + Transmission delay
- Total Delay = 3 * Propagation time + 3 * Transmission time + Data Transfer time



Packet Switching

- In packet switching, the message gets broken into small data packets
- These packets travel around the network seeking out the most efficient route to reach to destination
- This does not necessarily mean the shortest route
- Each packet may follow a different route
- There are two methods:
 - Datagram AND
 - virtual circuit packet switching



Packet Switching

Packet Switching

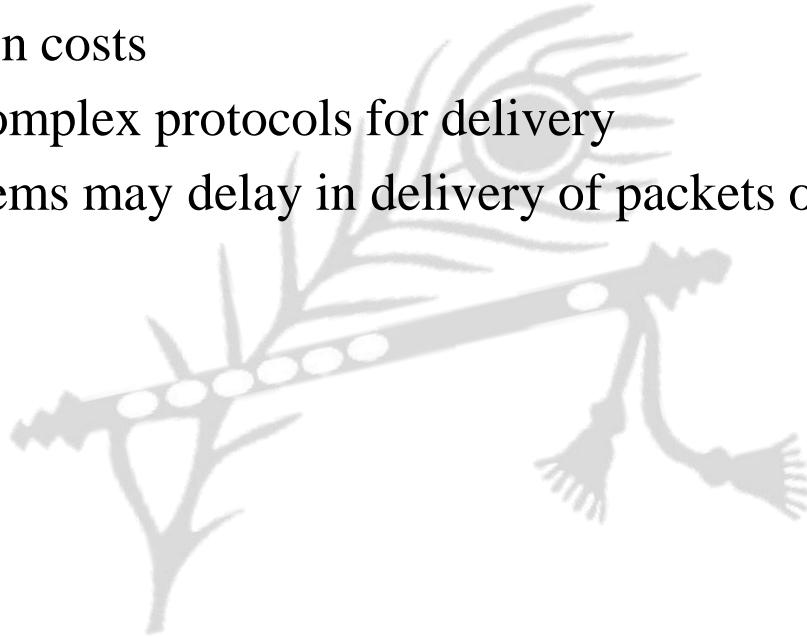
- In both packet switching methods, a message is broken into small parts, called packets
- Each packet is tagged with appropriate source and destination addresses
- Since packets have a strictly defined maximum length, they can be stored in main memory instead of disk
- Packets are generally accepted on a first-come, first-served basis
- If the network becomes overloaded, packets are delayed or discarded

Packet Switching

- Advantages
 - Delay in delivery of packets is less
 - Switching devices don't require massive storage
 - Data delivery can continue even if some parts of the network fails
 - It allows simultaneous usage of the same channel by multiple users
 - It ensures better bandwidth usage

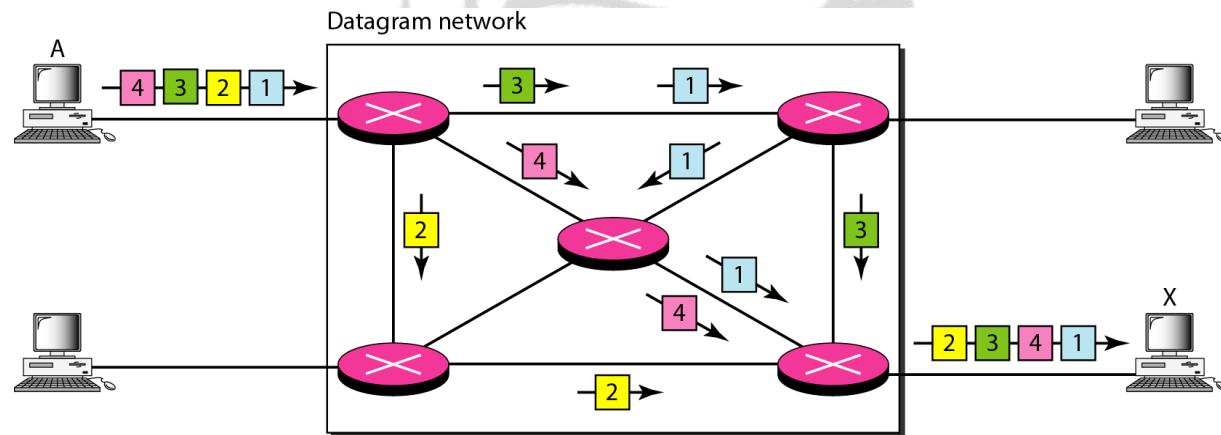
Packet Switching

- Disadvantages
 - High installation costs
 - They require complex protocols for delivery
 - Network problems may delay in delivery of packets or loss of packets



Packet Switching

- In datagram approach, the message is divided into small packets of fixed or variable size
- The size of the packet is determined by the network and the governing protocol

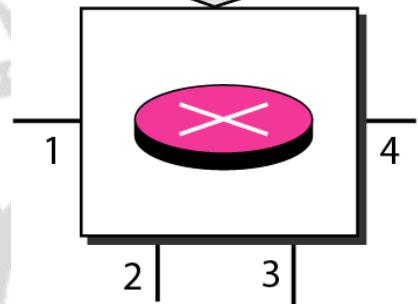


Packet Switching

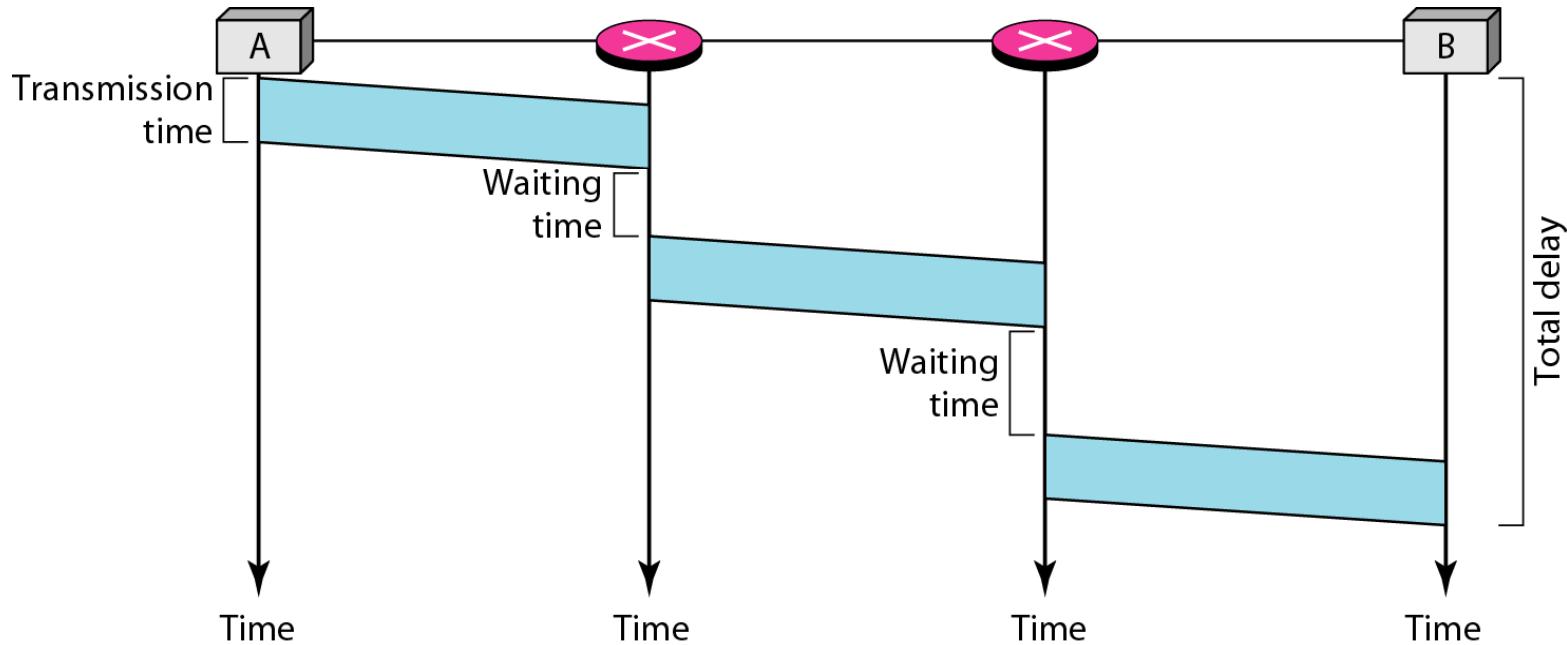
- In a packet-switched network, there is no resource reservation; resources are allocated on demand
- A switch in a datagram network uses a routing table that is based on the destination address
- The destination address in the header of a packet in a datagram network remains the same during the entire journey of the packet

Routing table

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



Delay in network



Datagram switching

- Eg:

Datagram	Path Length	Visited Switches
1	3200 km	1,3,5
2	11,700 km	1,2,5
3	12,200 km	1,2,3,5
4	10,200 km	1,4,5
5	10,700 Km	1,4,3,5

- We assume that the delay for each switch (including waiting and processing) is 3,10, 20, 7, and 20 ms respectively. Assuming that the propagation speed is 2×10^8 m, find the order of arrival at the destination and the delay for each. Ignore any other delays in transmission.

Datagram switching

Solution

We assume that the transmission time is negligible in this case. This means that we suppose all datagrams start at time 0. The arrival timed are calculated as:

First: $(3200 \text{ Km}) / (2 \times 10^8 \text{ m/s}) + (3 + 20 + 20) = 59.0 \text{ ms}$

Second: $(11700 \text{ Km}) / (2 \times 10^8 \text{ m/s}) + (3 + 10 + 20) = 91.5 \text{ ms}$

Third: $(12200 \text{ Km}) / (2 \times 10^8 \text{ m/s}) + (3 + 10 + 20 + 20) = 114.0 \text{ ms}$

Fourth: $(10200 \text{ Km}) / (2 \times 10^8 \text{ m/s}) + (3 + 7 + 20) = 81.0 \text{ ms}$

Fifth: $(10700 \text{ Km}) / (2 \times 10^8 \text{ m/s}) + (3 + 7 + 20 + 20) = 103.5 \text{ ms}$

The order of arrival is: **3 → 5 → 2 → 4 → 1**

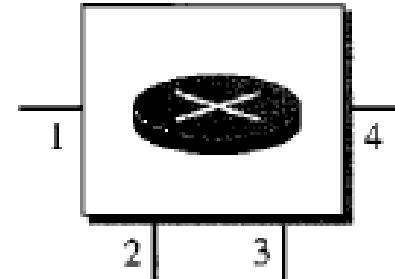
Datagram switching

- Eg:

- Figure shows the switch in a datagram network. Find the output port for packets with the following destination address.
- Packet 1: 7176
- Packet 2: 1233
- Packet 3: 8766
- Packet 4: 9144

Packet 1: 2
 Packet 2: 3
 Packet 3: 3
 Packet 4: 2

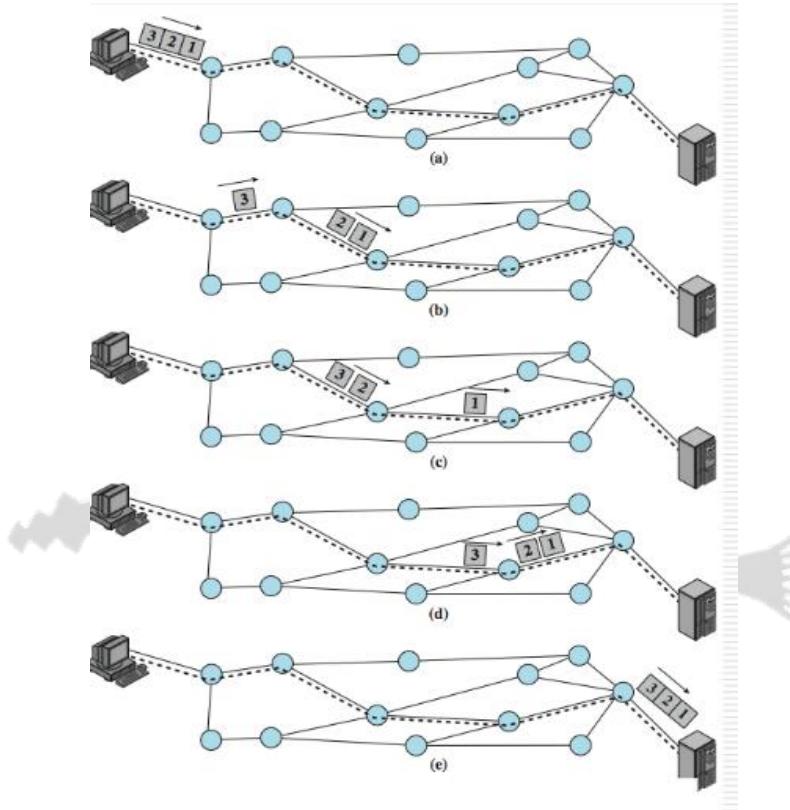
Destination address	Output port
1233	3
1456	2
3255	1
4470	4
7176	2
8766	3
9144	2



Virtual circuit switched networks

- A virtual-circuit network is a mixture of circuit switched network and a datagram network
- Virtual-Circuit network guarantees that
 - the packets sent arrive in the order sent
 - with no duplicates or omissions
 - with no errors (with high probability)
 - regardless of how they are implemented internally

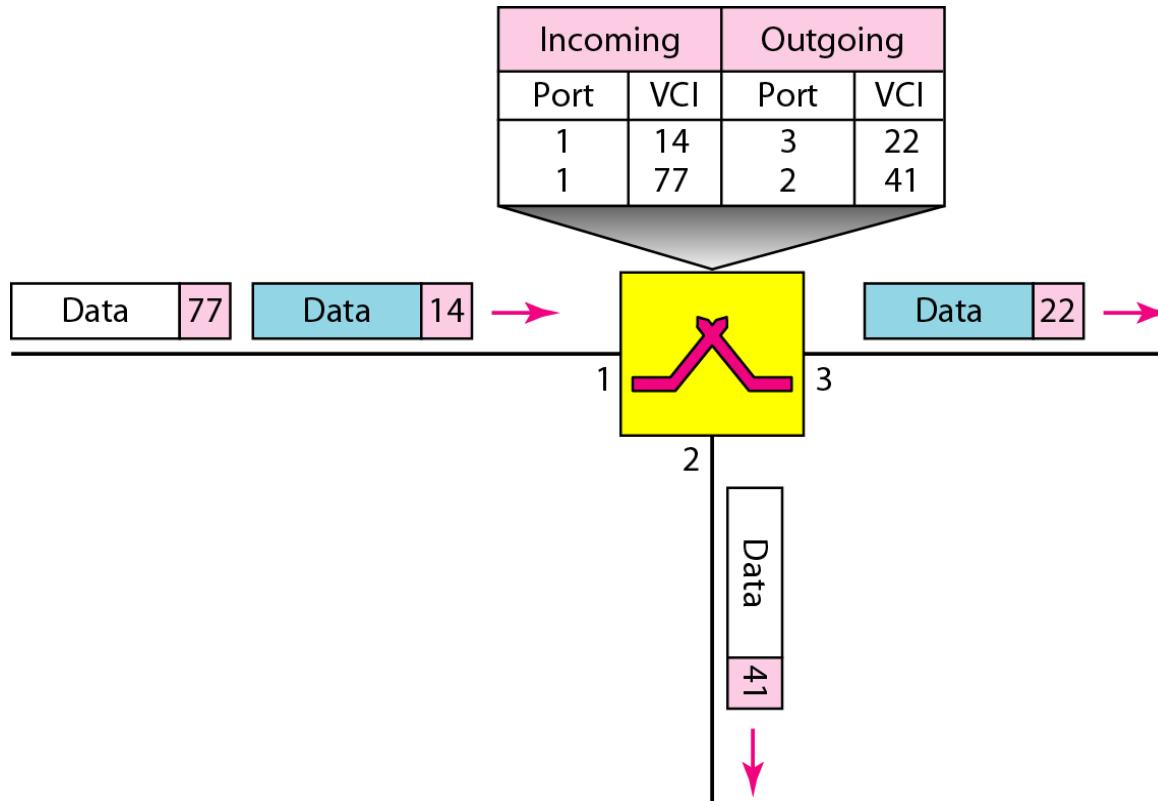
Virtual circuit switched networks



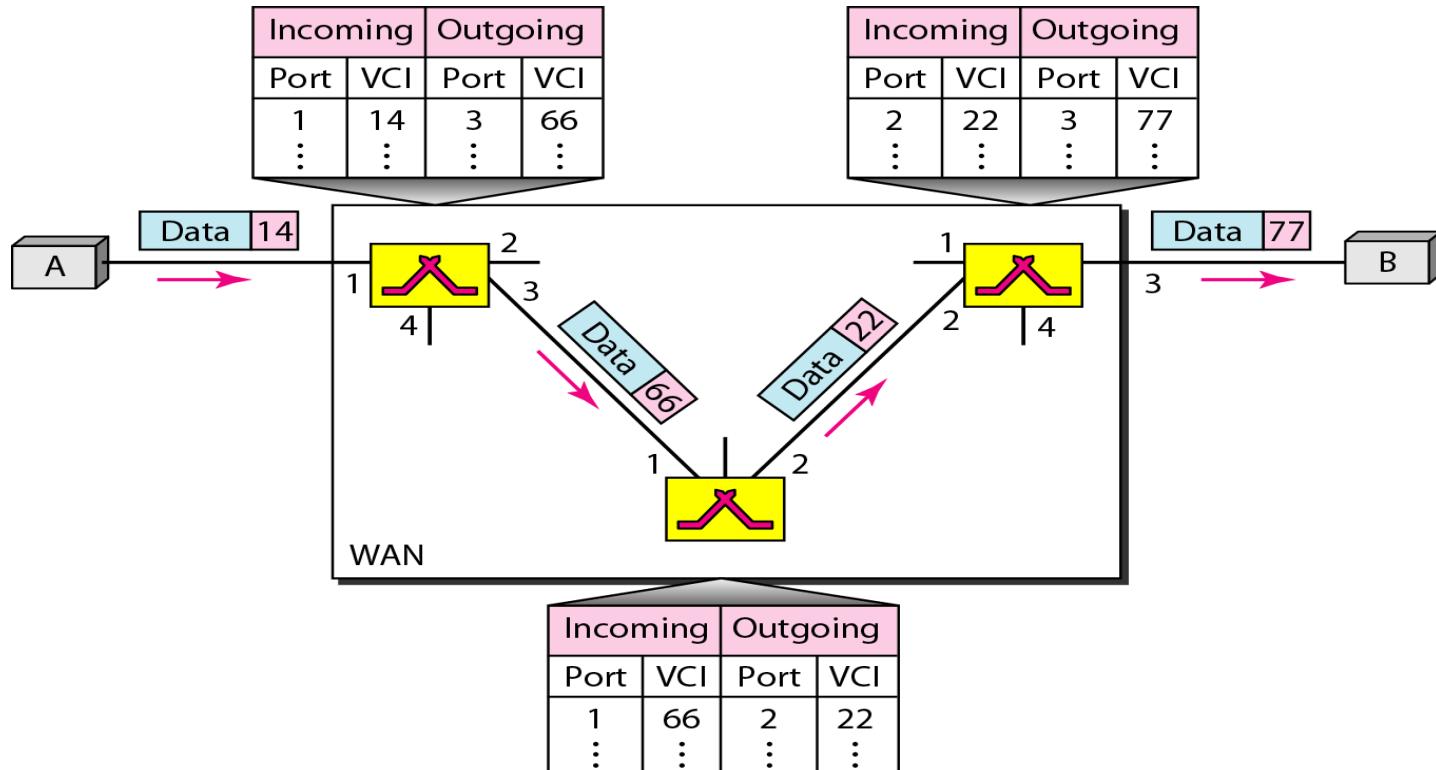
Virtual circuit switched networks

- How it is implemented ?
 - Addressing:
 - In a virtual-circuit network, two types of addressing are involved: global and local (virtual-circuit identifier)
 - Global Addressing:
 - A source or a destination IP address is considered to be global address
 - Virtual-Circuit Identifier:
 - The identifier that is actually used for data transfer is called the virtual-circuit identifier (VCI)
 - A VCI is a small number that has only switch scope
 - It is used by a frame between two switches
 - When a frame arrives at a switch, it has a VCI; when it leaves, it has a different VCI

Switch and tables in a virtual-circuit network



Data transfer in a virtual-circuit network



Virtual circuit switched networks

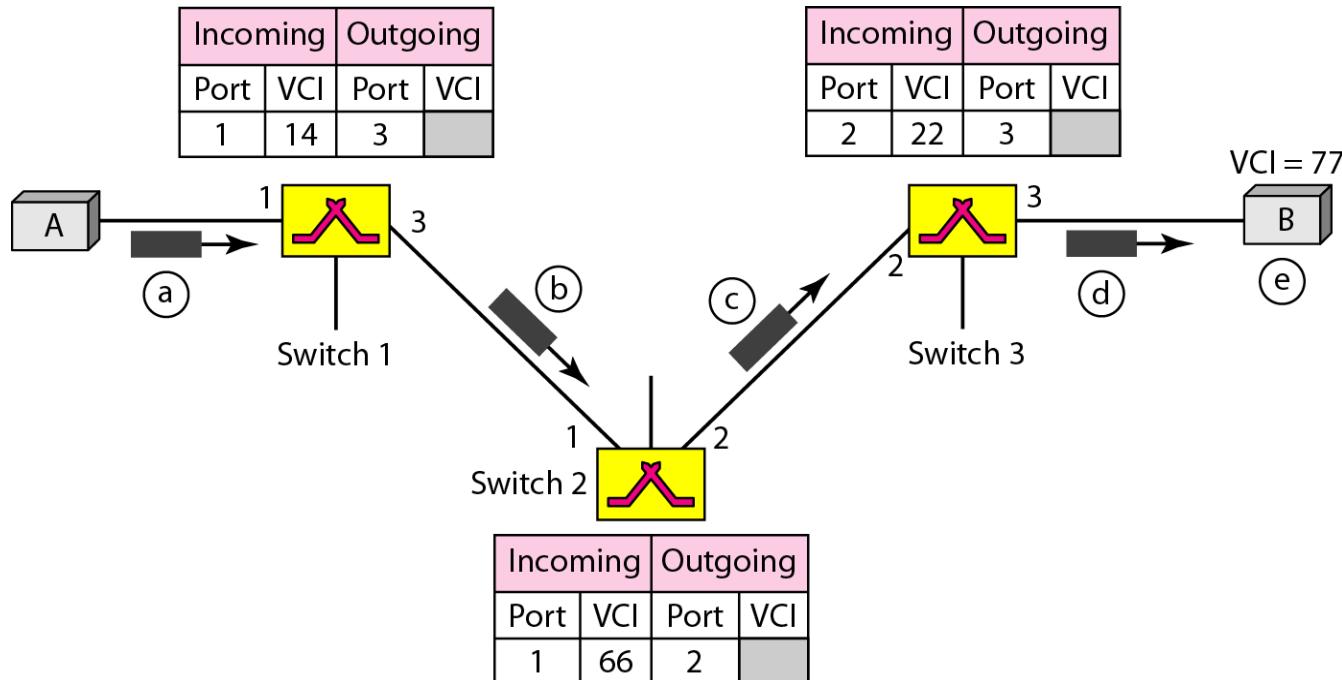
How Virtual Circuit is Established ?

- A source and destination need to go through three phases:
 - Setup phase:
 - the source and destination use their global addresses to help switches make table entries for the connection
 - Data transfer
 - Teardown phase:
 - the source and destination inform the switches to delete the corresponding entry

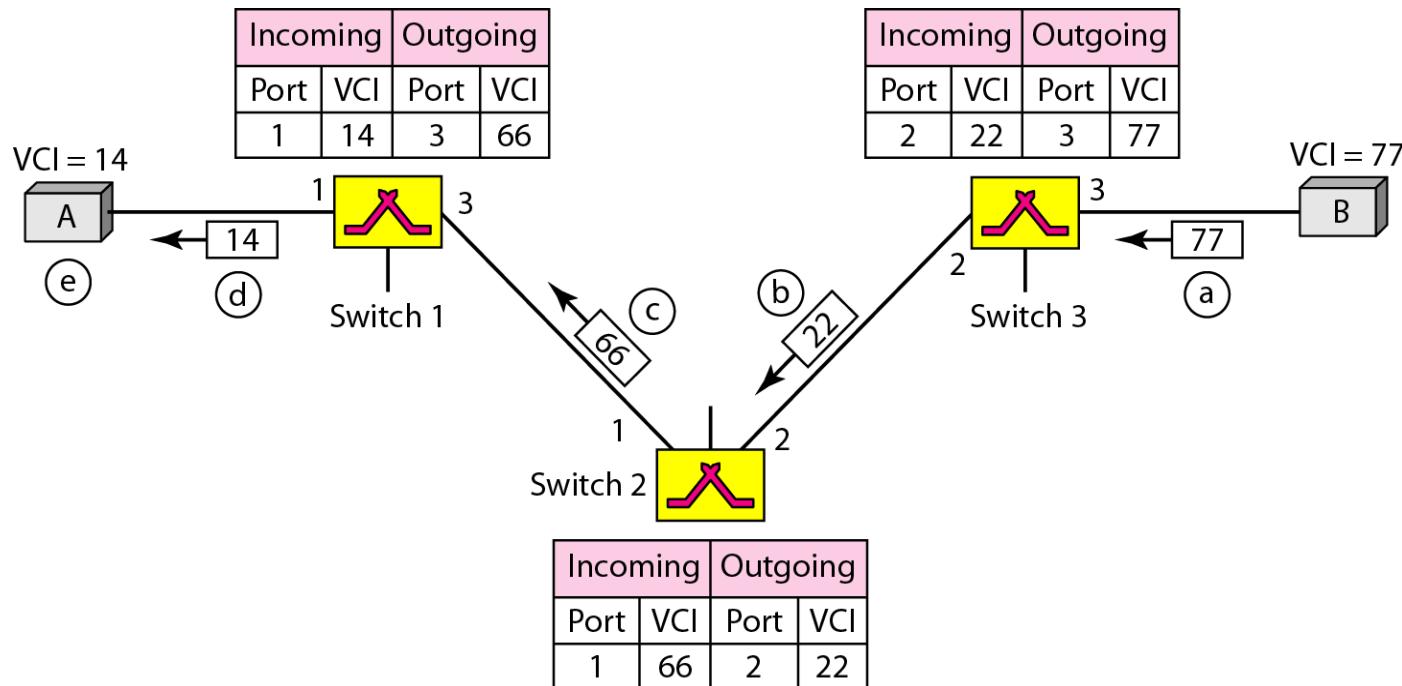
Virtual circuit switched networks

- Setup Phase:
 - Suppose source A needs to create a virtual circuit to B.
 - Two steps are required:
 - the setup request and
 - the acknowledgment
- Setup Request:
 - A setup request frame is sent from the source to the destination
- Acknowledgment:
 - A special frame, called the acknowledgment frame, completes the entries in the switching tables

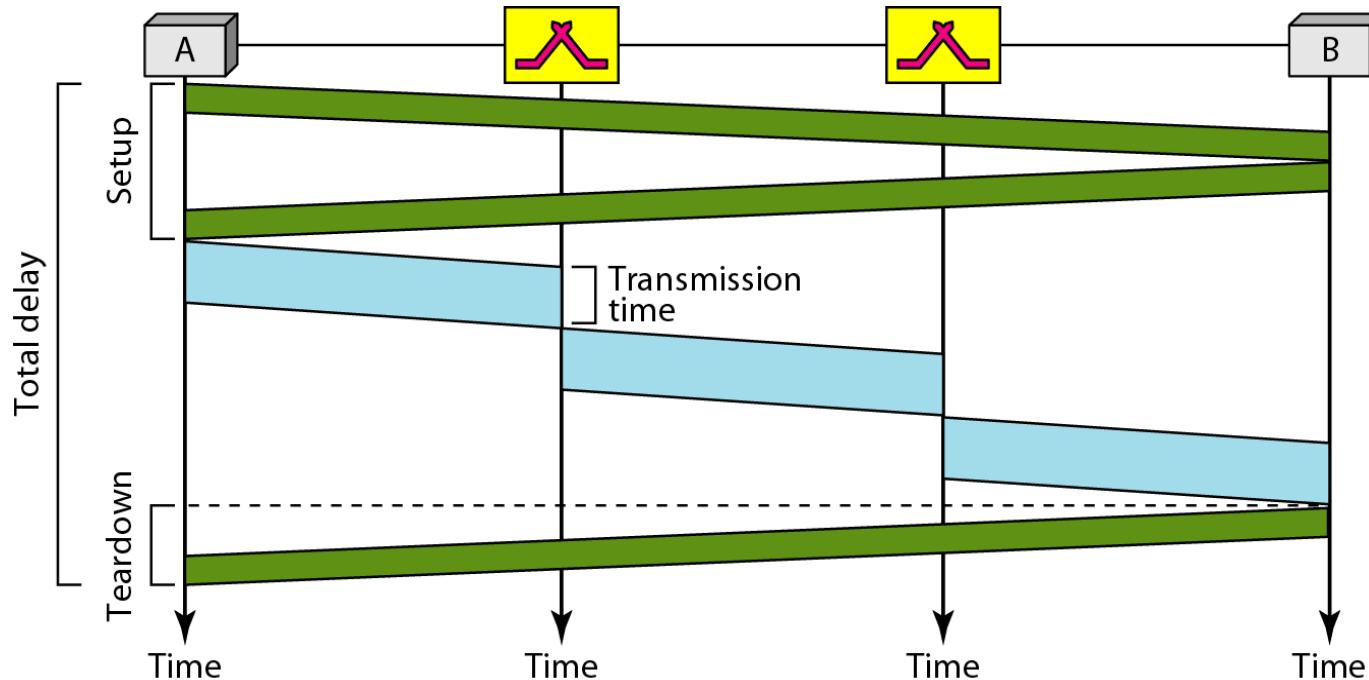
Virtual circuit switched networks



Virtual circuit switched networks



Delay in a virtual-circuit network



Virtual circuit switched networks

- Eg:
 - Find the output port and the output VCI for packet with the following input port and input VCI addresses:
 - Packet 1: 3, 78
 - Packet 2: 2, 92
 - Packet 3: 4, 56
 - Packet 4: 2, 71

Incoming		Outgoing	
Port	VCI	Port	VCI
1	14	3	22
2	71	4	41
2	92	1	45
3	58	2	43
3	78	2	70
4	56	3	11

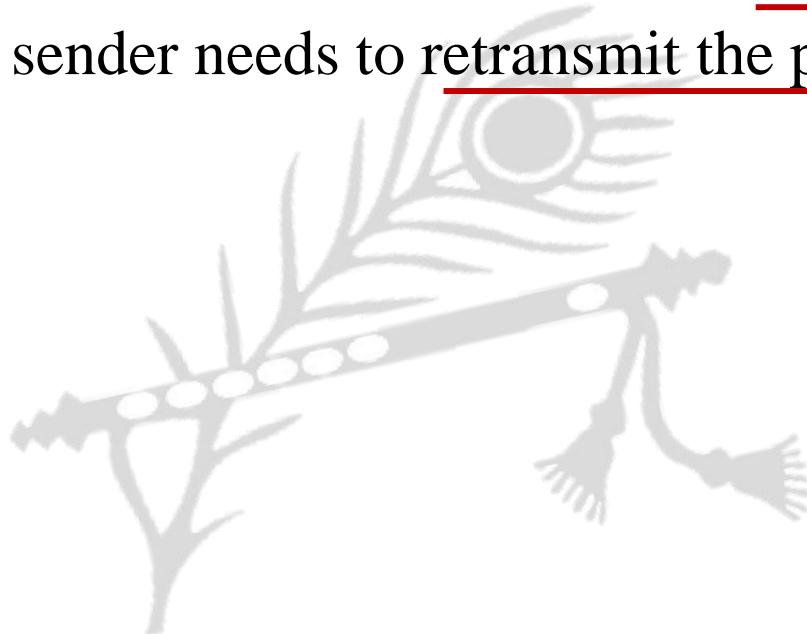
Packet 1: **2, 70**
 Packet 2: **1, 45**
 Packet 3: **3, 11**
 Packet 4: **4, 41**

Advantages of packet switching

- Packet switching is cost effective
- Packet switching offers improved delay
- Packet can be rerouted if there is any problem, such as busy or disabled links
- Many network users can share the same channel at the same time
- Packet switching can maximize link efficiency by making optimal use of link bandwidth

Disadvantages of packet switching

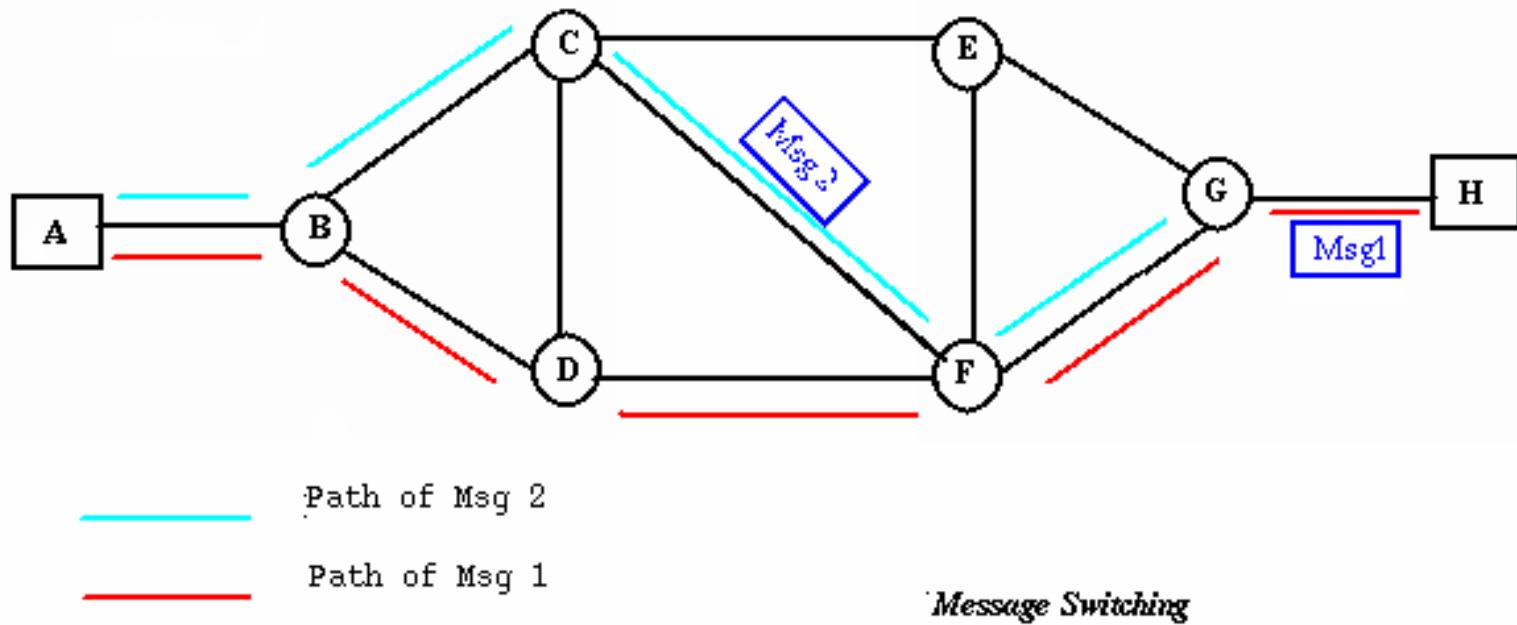
- Protocols for packet switching are typically more complex
- If packet is lost, sender needs to retransmit the packet



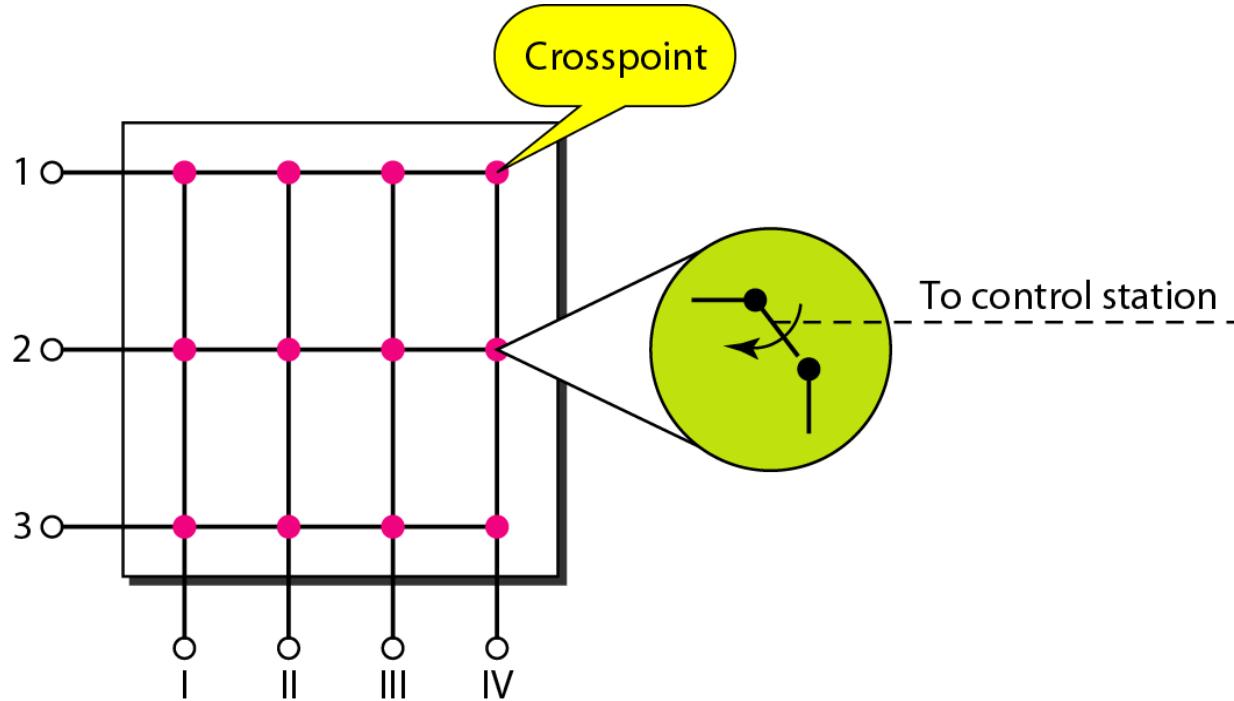
Message Switching

- With message switching there is no need to establish a dedicated path between source and destination
- When a station sends a message, the destination address is appended to the message
- Each node receives the entire message, stores it on disk, and then transmits the message to the next node
- This type of network is called a store-and-forward network
- A time delay is introduced using this type of scheme due to store-and-forward time, plus the time required to find the next node in the transmission path

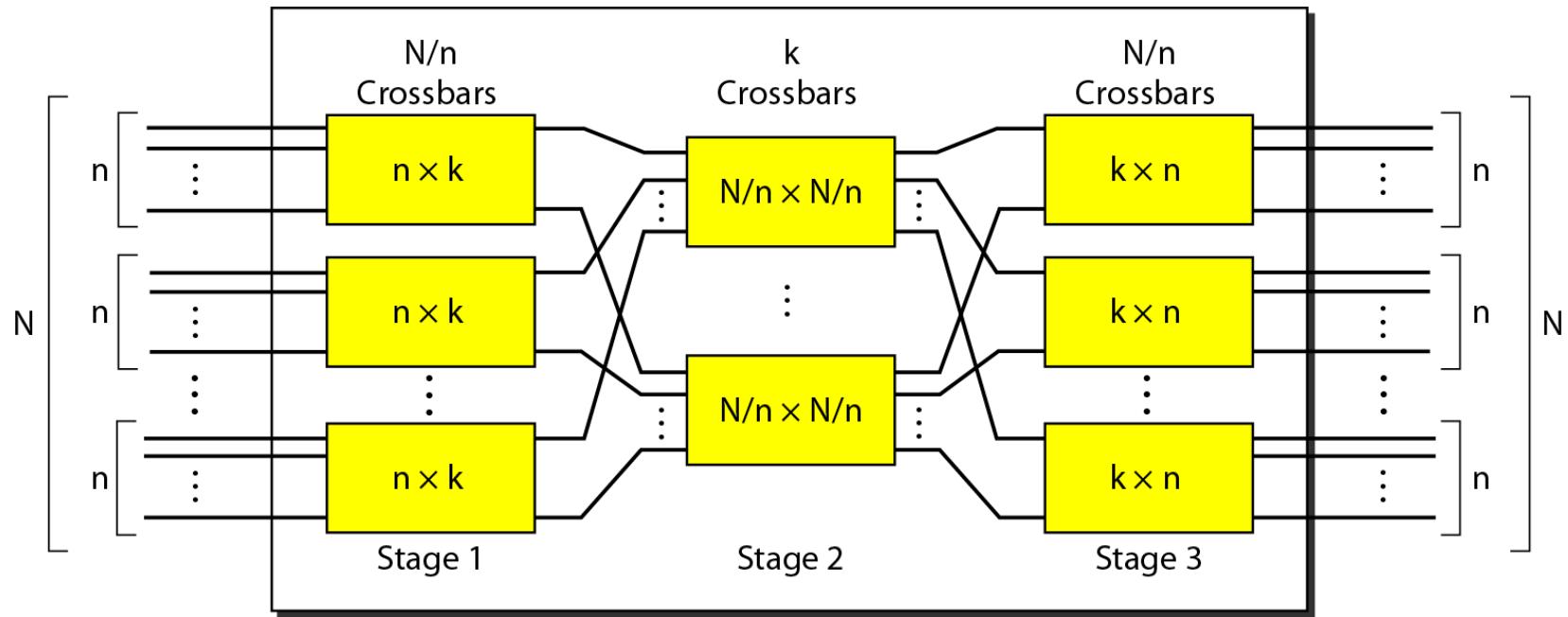
Message Switching



Crossbar switch with three inputs and four outputs



Multistage switch



Multistage switch

- In a three-stage switch, the total number of cross points is

$$2kN + k(N/n)^2$$

which is much smaller than the number of cross points in a single-stage switch (N^2)

Multistage switch

- Eg:
 - Design a three-stage, 200×200 switch ($N = 200$) with $k = 4$ and $n = 20$

Solution

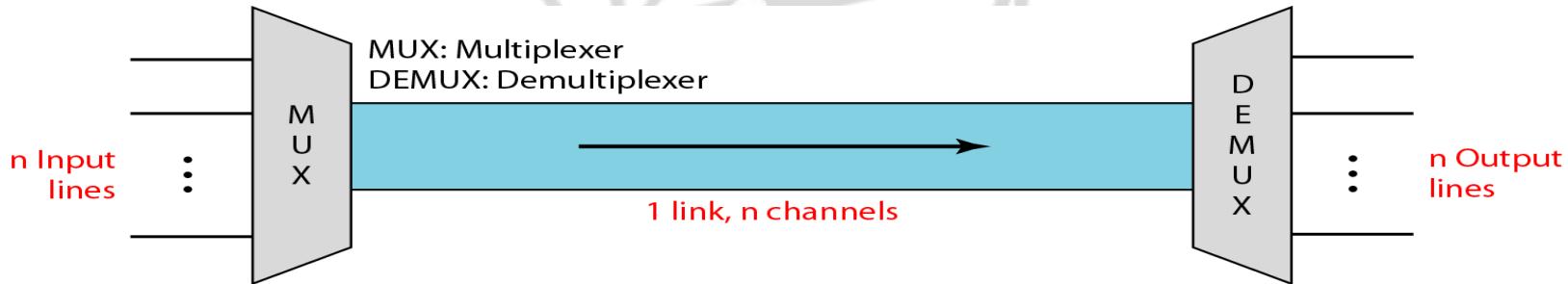
- In the first stage we have $N/n = 10$ crossbars, each of size 20×4
- In the second stage, we have 4 crossbars, each of size 10×10
- In the third stage, we have 10 crossbars, each of size 4×20
- The total number of cross points is $2kN + k(N/n)^2$, or 2000 cross points
- This is 5% of the number of cross points in a single-stage switch ($200 \times 200 = 40,000$)

Multiplexing

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

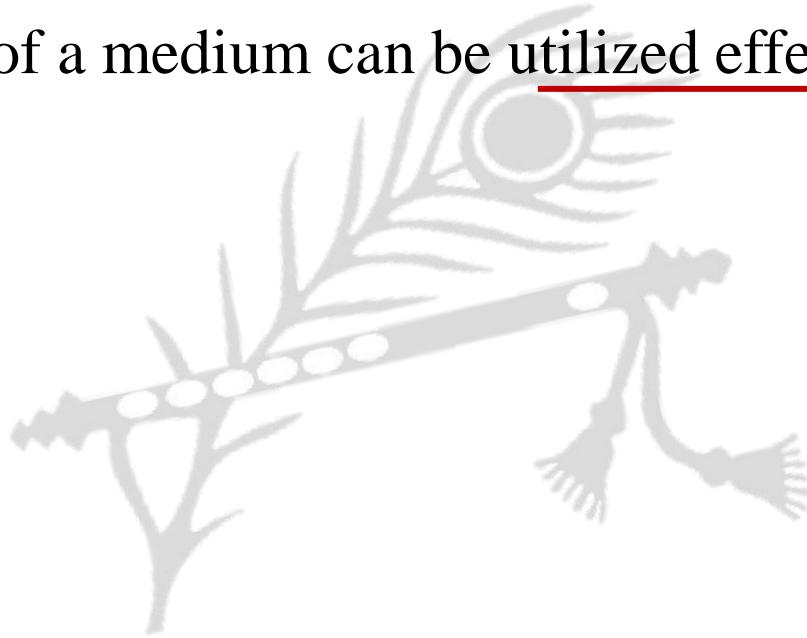
Multiplexing

- A Multiplexer (MUX) is a device that combines several signals into a single signal
- A Demultiplexer (DEMUX) is a device that performs the inverse operation

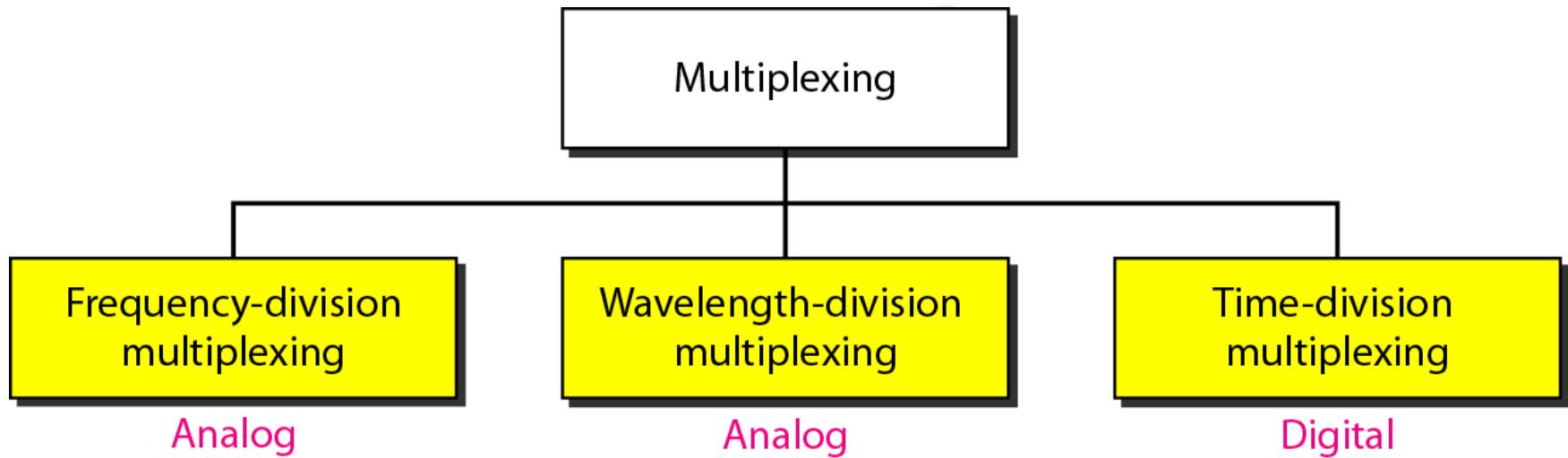


Advantages of Multiplexing

- More than one signal can be sent over a single medium
- The bandwidth of a medium can be utilized effectively

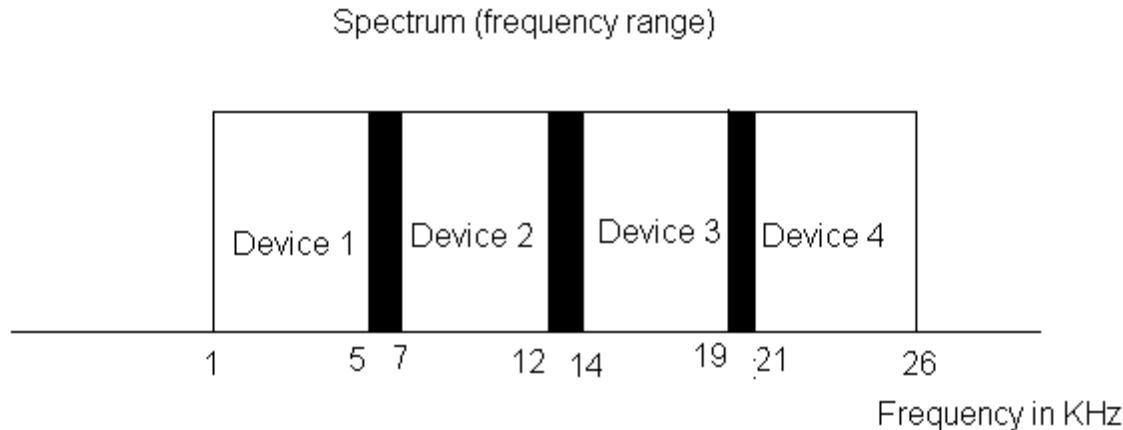


Categories of multiplexing



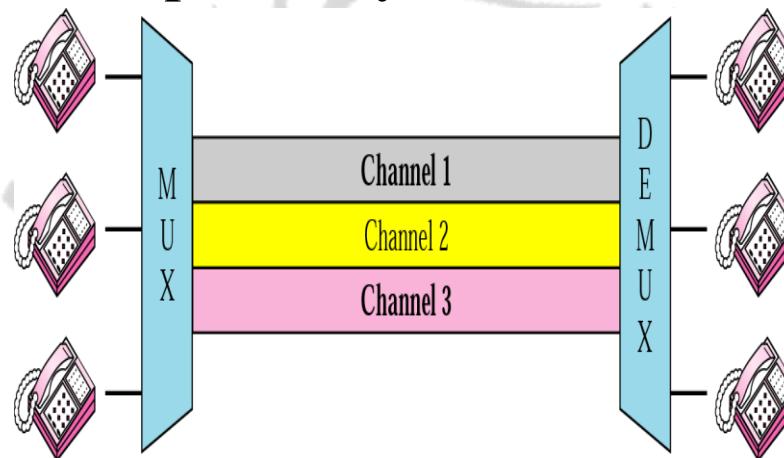
Frequency division multiplexing (FDM)

- FDM is an analog technique that can be applied when the bandwidth of a link is greater than the combined bandwidths of the signals to be transmitted



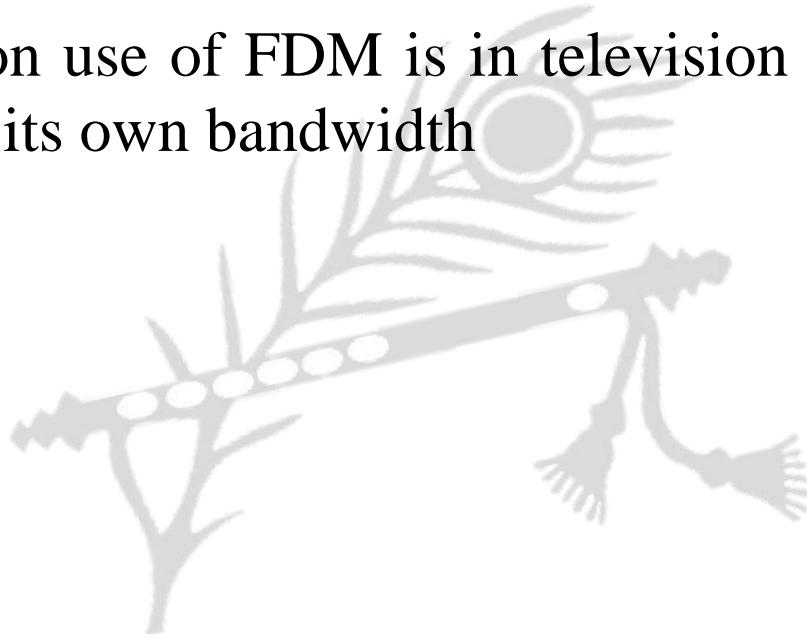
FDM

- In FDM signals generated by each device modulate different carrier frequencies
- These modulated signals are combined into a single composite signal that can be transported by the link



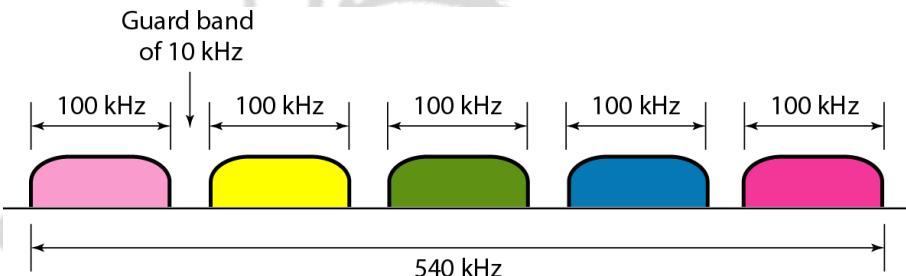
Applications of FDM

- A very common application of FDM is FM radio broadcasting
- Another common use of FDM is in television broadcasting. Each TV channel has its own bandwidth



FDM

- Eg:
 - 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?

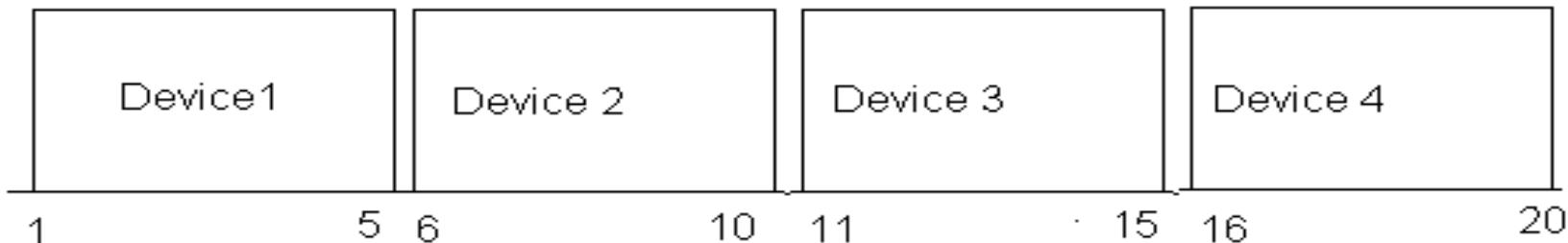


Solution

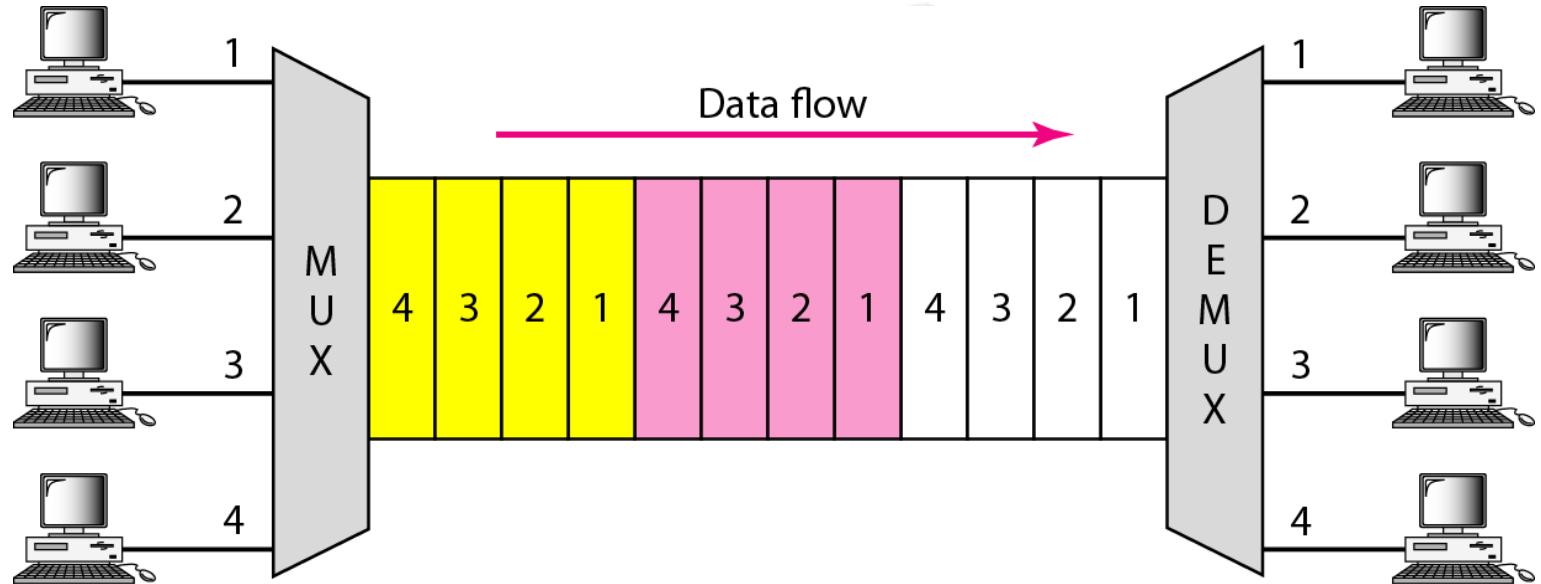
- For five channels, we need at least four guard bands. This means that the required bandwidth is at least
- $5 \times 100 + 4 \times 10 = 540 \text{ kHz}$

Time division multiplexing (TDM)

- TDM is a digital process that can be applied when the data rate capacity of the transmission medium is greater than the data rate required by the sending and receiving devices



TDM



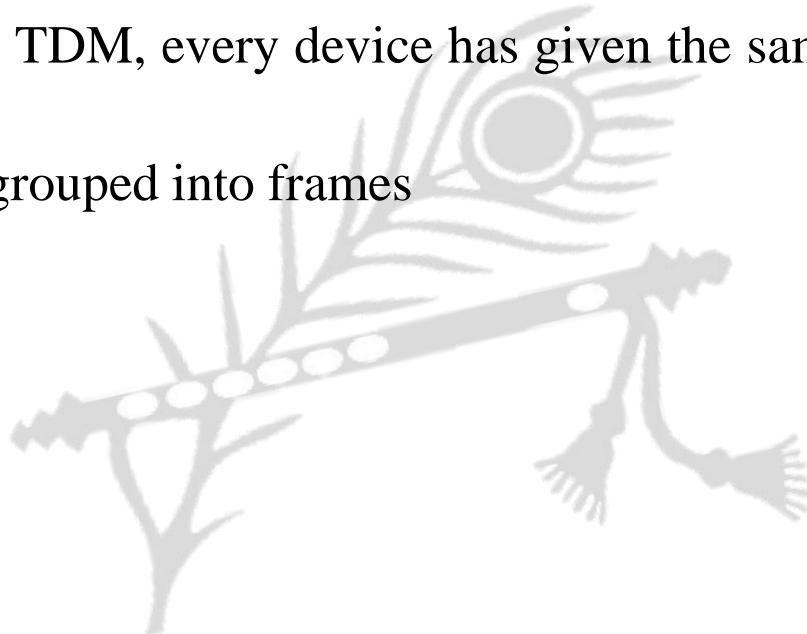
TDM

- TDM can be implemented in two ways
 - Synchronous TDM
 - Asynchronous TDM



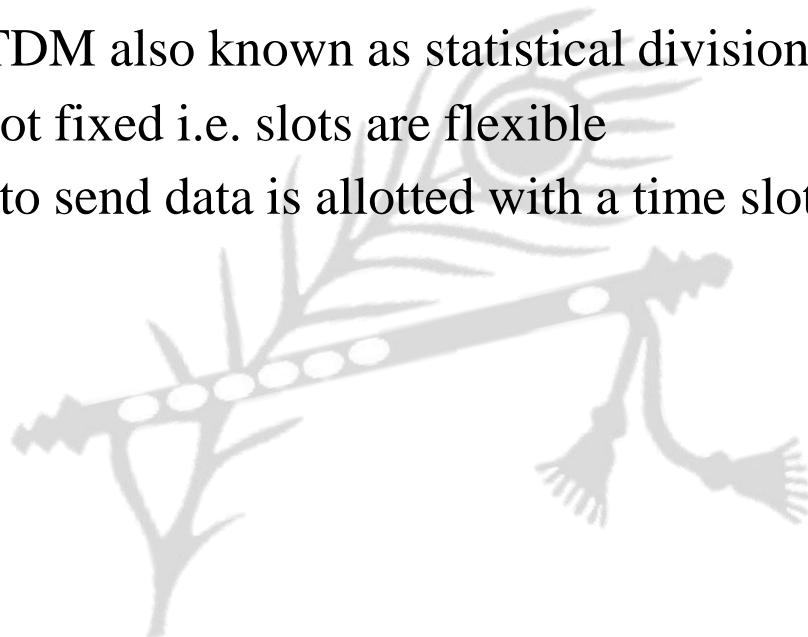
TDM

- Synchronous TDM
 - In synchronous TDM, every device has given the same time slot to transmit data
 - Time slots are grouped into frames



TDM

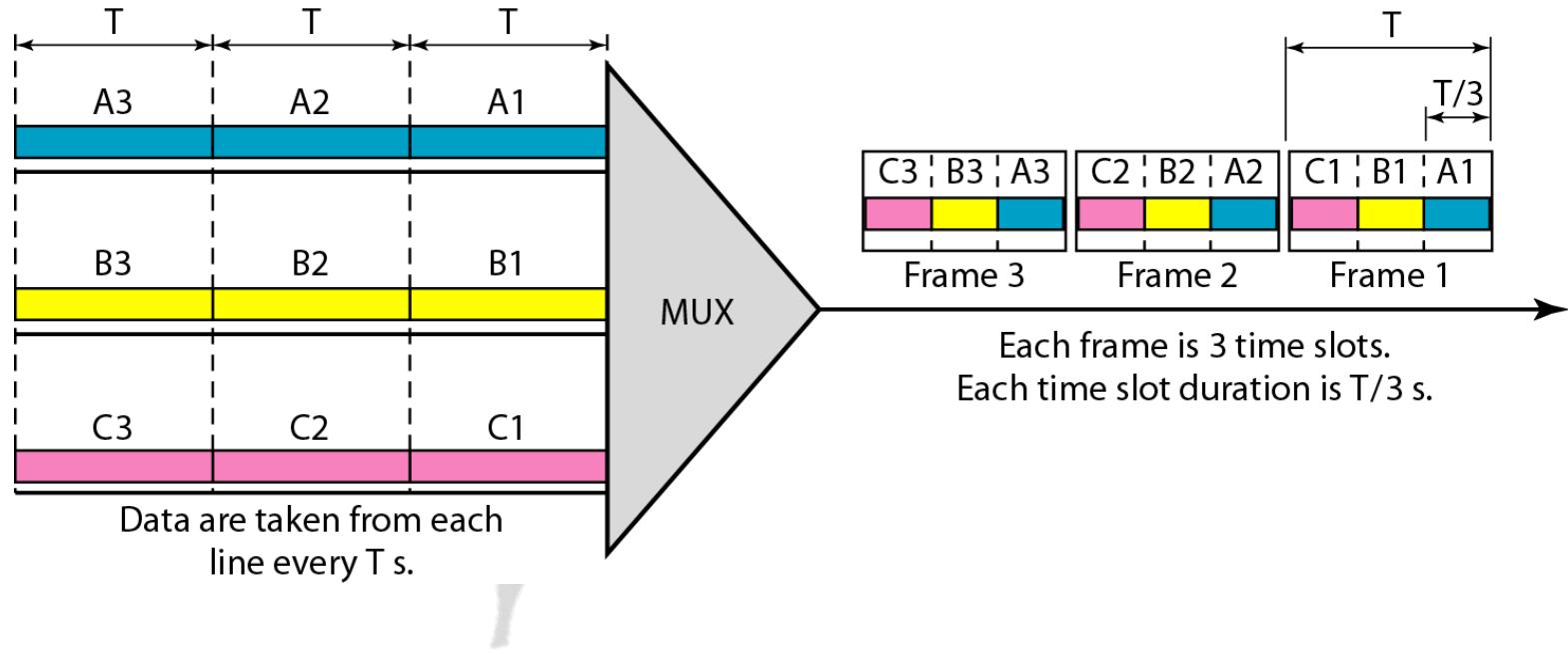
- Asynchronous TDM
 - asynchronous TDM also known as statistical division multiplexing
 - time-slots are not fixed i.e. slots are flexible
 - a device wants to send data is allotted with a time slot



Application of TDMA

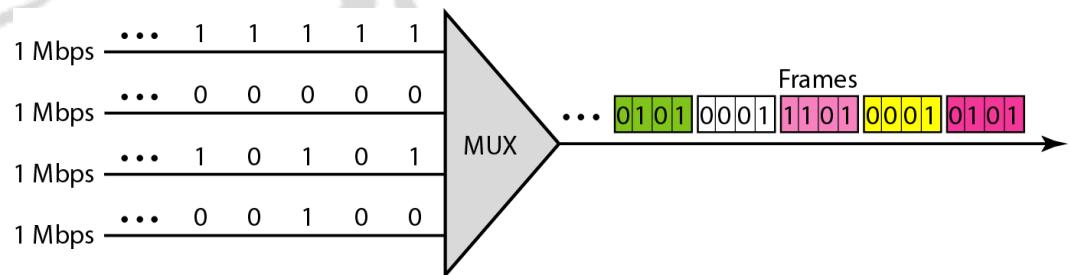
- It used in ISDN (Integrated Services Digital Network) telephone lines
- It is used in PSTN (Public Switched Telephone Network)
- It is used for some telephone system
- Note: It can be used to multiplex both digital and analog signals but mainly used to multiplex digital signals

Synchronous TDM



Synchronous TDM

- Eg:
 - Given 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
 - (d) the output frame rate



Synchronous TDM

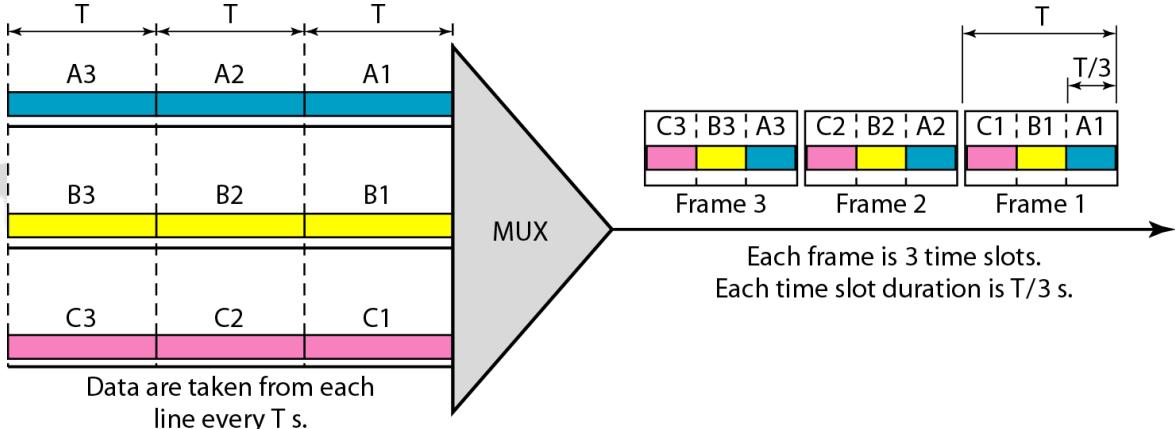
Solution

- (a)
 - The input bit duration is the inverse of the bit rate, Here bit rate = 1 Mbps
 - So the input bit duration = $1/1 \text{ Mbps} = 1 \mu\text{s}$
- (b)
 - The output bit duration is one-fourth of the input bit duration (four slot in a frame) = $\frac{1}{4} \mu\text{s}$
- (c)
 - The output bit rate is the inverse of the output bit duration = $1/(1/4 \mu\text{s}) = 4 \text{ Mbps}$
 - This can also be deduced from the fact that the output rate is 4 times as fast as any input rate; so the output rate = $4 \times 1 \text{ Mbps} = 4 \text{ Mbps}$
- (d)
 - The frame rate is always the same as any input rate
 - So the frame rate is 1,000,000 (as $1 \text{ Mbps} = 10^6 \text{ bps}$) frames per second

Synchronous TDM

- Eg:

- In given figure, the data rate for each input connection is 1 kbps. If 1 bit at a time is multiplexed (a unit is 1 bit), what is the duration of
 - Each input slot
 - Each output slot
 - Each frame



Synchronous TDM

Solution

- (a)
 - The input bit duration is the inverse of the bit rate
 - This means that the bit duration is $1/1000$ s or 1 ms
- (b)
 - The duration of each output time slot is one-third of the input time slot
 - This means that the duration of the output time slot is $1/3$ ms
- (c)
 - Each frame carries three output time slots. So the duration of a frame is $3 \times 1/3$ ms, or 1 ms
 - The duration of a frame is the same as the duration of an input unit

Synchronous TDM

- Eg:

- Four 1 Kbps connections are multiplexed together. A unit is 1 bit. Find
 - (a) The duration of 1 bit before multiplexing
 - (b) The transmission rate of the link
 - (c) The duration of a time slot
 - (d) The duration of a frame

Synchronous TDM

Solution

- (a)
 - The duration of 1 bit before multiplexing is $1/1 \text{ Kbps}$, or 0.001 s (1 ms)
- (b)
 - The rate of the link is 4 times the rate of a connection, or 4 Kbps
- (c)
 - The duration of each time slot is one-fourth of the duration of each bit before multiplexing, or $1/4 \text{ ms}$ or $250 \mu\text{s}$
- (d)
 - The duration of a frame is always the same as the duration of a unit before multiplexing, or 1 ms
 - Each frame in this case has four time slots. So the duration of a frame is 4 times $250 \mu\text{s}$, or 1 ms

Wavelength Division Multiplexing (WDM)

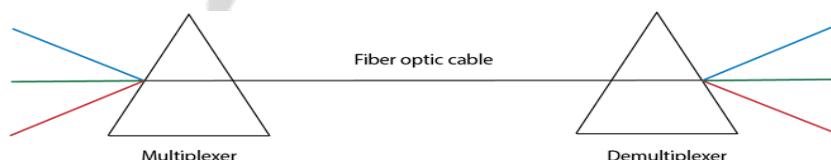
- Wavelength Division Multiplexing is same as FDM except that the optical signals (electromagnetic signal) are transmitted through the fiber optic cable
- WDM is used on fiber optics to increase the capacity of a single fiber
- It is an analog multiplexing technique
- Optical signals from different source are combined to form a wider band of light with the help of multiplexer
- At the receiving end, de-multiplexer separates the signals to transmit them to their respective destinations

WDM

- Note: Light has the property that keeps it from mixing and allows it to be separated into its color like this prism
- Multiplexing and Demultiplexing can be achieved by using a prism
- Prism can perform a role of multiplexer by combining the various optical signals to form a composite signal, and the composite signal is transmitted through a fibre optical cable
- Prism also performs a reverse operation, i.e., demultiplexing the signal

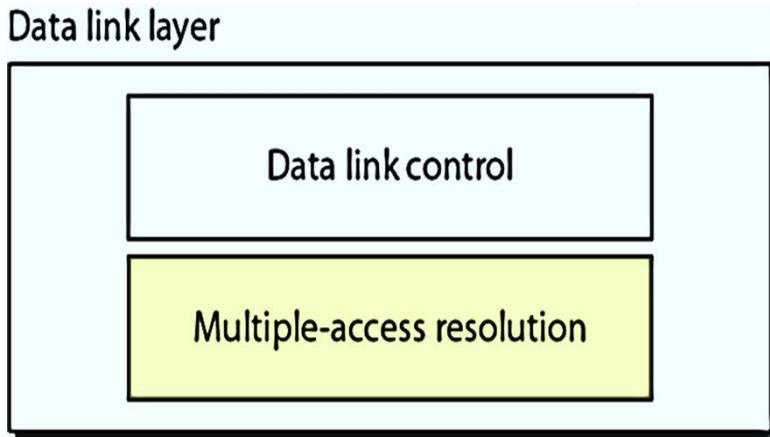
WDM

- The technology of WDM is widely used in Optical Transport Networks
- This technology can be used in Synchronous optical networking. SONET is a communication protocol that is used to transmit a large amount of data over relatively large distances using optical fiber. With SONET, multiple digital data streams are transferred at the same time over the optical fiber
- This technology is used for up gradation of broadband



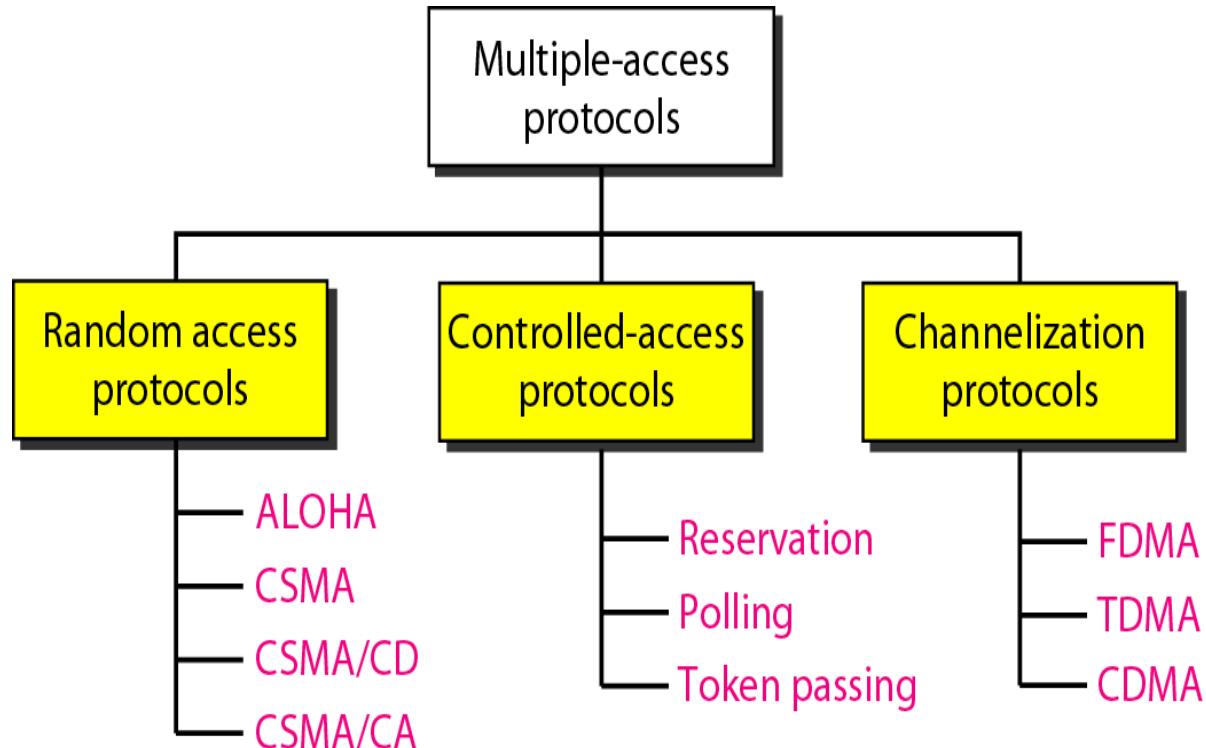
Multiple Access

- Data link layer divided into two functionality-oriented sublayers



- The upper sublayer is responsible for data link control, and the lower sublayer is responsible for resolving access to the shared media.
- If the channel is dedicated, we do not need the lower sublayer

Multiple Access



Random Access

- In random access or contention methods, no station is superior to another station and none is assigned the control over another
- At each instance, a station that has data to send, uses a procedure defined by the protocol to make a decision on whether or not to send

Aloha

- There are two different versions of Aloha
 - Pure Aloha
 - Slotted Aloha



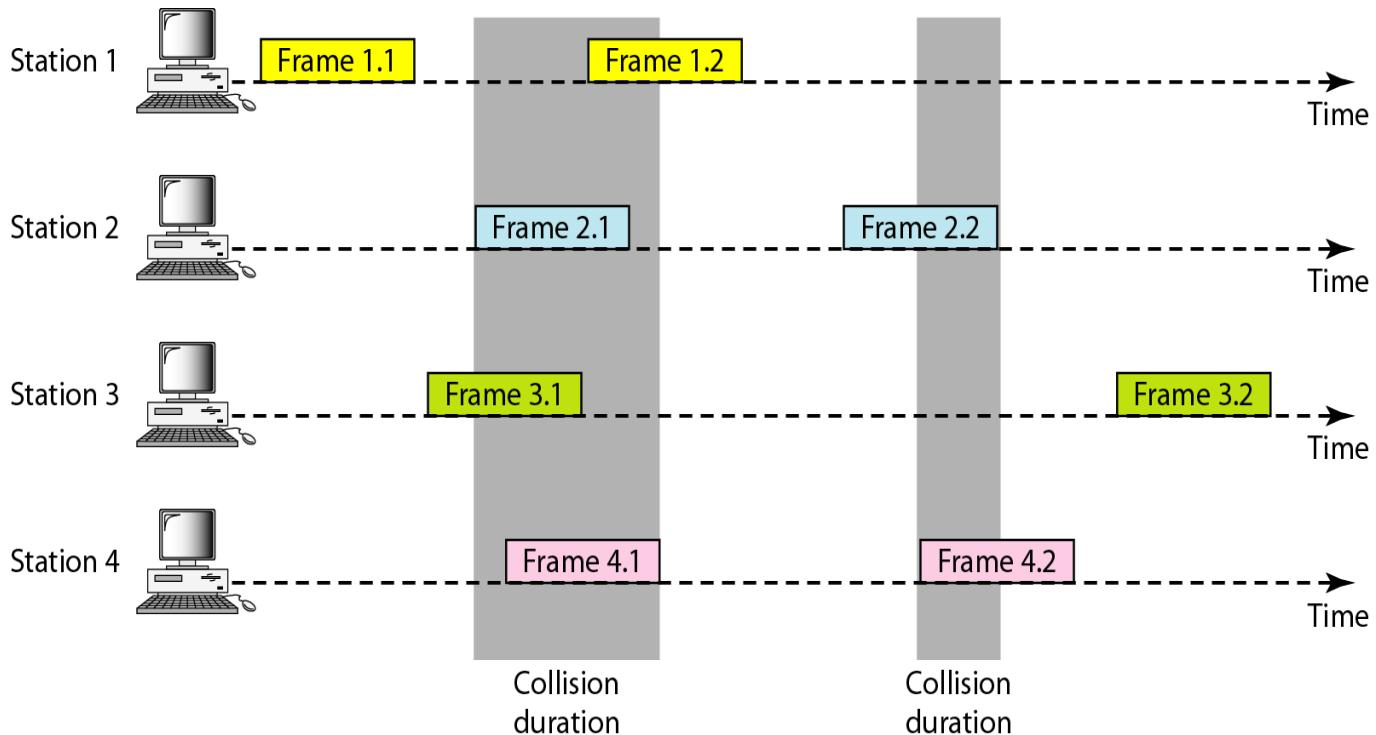
Pure Aloha

- It allows the stations to transmit data at any time whenever they want
- After transmitting the data packet, station waits for some time
- The following two cases are possible
 - Case-01: Transmitting station receives an acknowledgement
 - Assumption: the transmission is successful
 - Case-02: Transmitting station does not receive any acknowledgement within specified time
 - Assumption: the transmission is unsuccessful

Pure Aloha

- Frame time:
 - The time required to send a frame is called frame time
- Vulnerable time:
 - It is the time during which no transmission should be done to avoid any collision
 - In case of Pure Aloha vulnerable time is $2T$

Pure Aloha



Pure Aloha

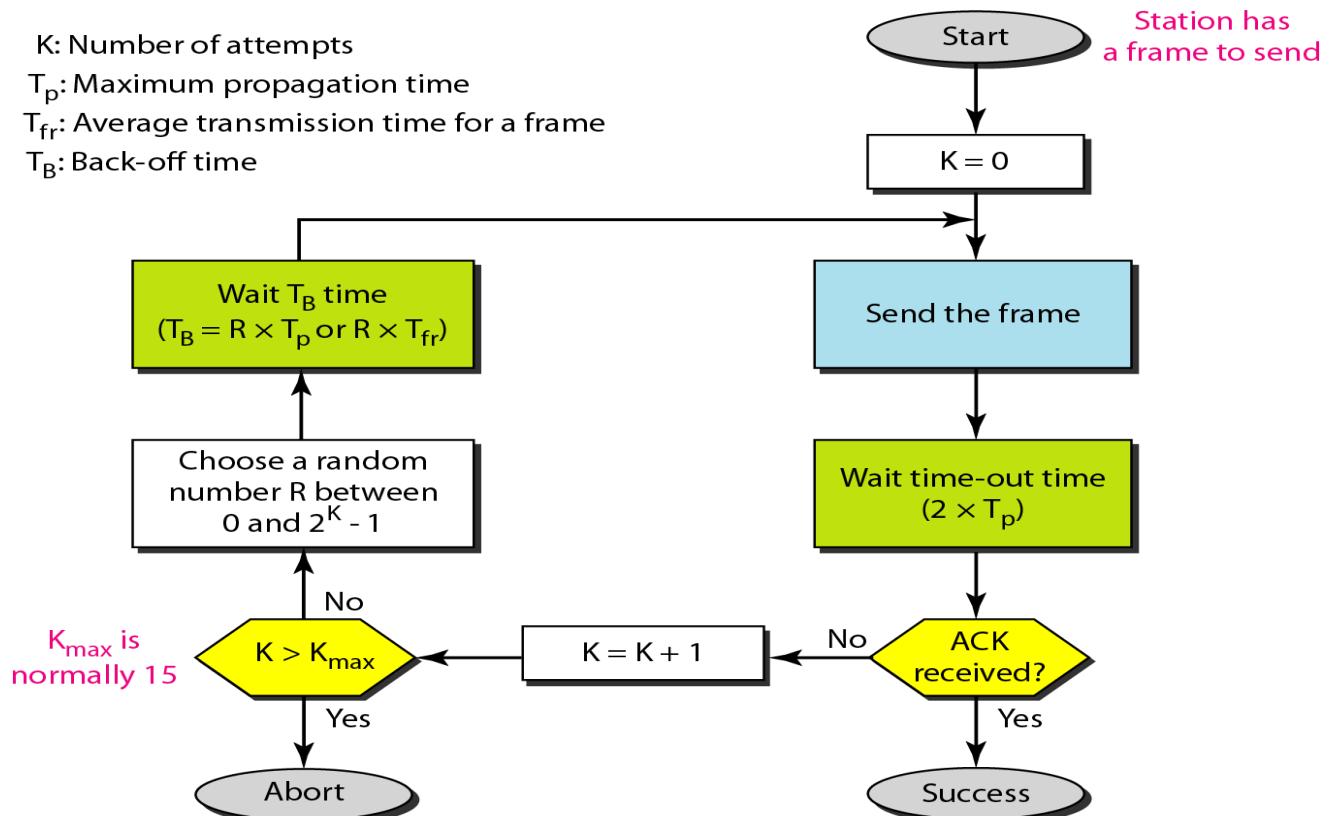
- Methodology

K: Number of attempts

T_p : Maximum propagation time

T_{fr} : Average transmission time for a frame

T_B : Back-off time



K_{max} is normally 15

Pure Aloha

- Eg:
 - The stations on a wireless ALOHA network are a maximum of 600 km apart. If we assume that signals propagate at 3×10^8 m/s, we find
- Solution

$$T_p = (600 \times 10^3) / (3 \times 10^8) = 2 \text{ ms}$$

- Now we can find the value of T_B for different values of K
 - For $K = 1$, the range is $\{0, 1\}$. The station needs to generate a random number with a value of 0 or 1.
 - This means that T_B is either 0 ms (0×2) or 2 ms (1×2), based on the outcome of the random variable

Pure Aloha

- The throughput for pure ALOHA is

$$S = G * e^{-2G}$$

where,

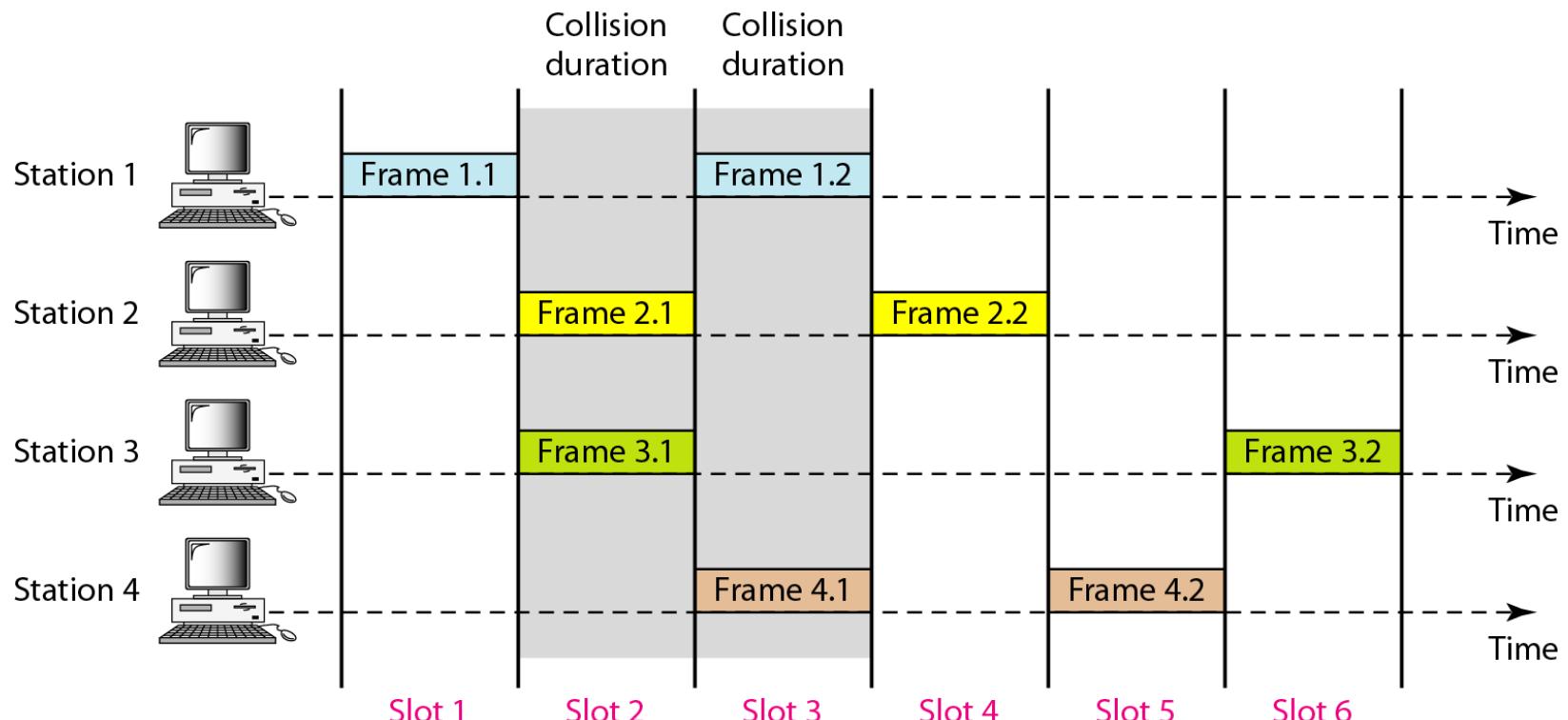
G is load



Slotted Aloha

- Slotted Aloha divides the time of shared channel into discrete intervals called as time slots
- Any station can transmit its data in any time slot
- The only condition is that station must start its transmission from the beginning of the time slot
- If the beginning of the slot is missed, then station has to wait until the beginning of the next time slot
- A collision may occur if two or more stations try to transmit data at the beginning of the same time slot
- However, the vulnerable time is now reduced to half, i.e. equals to T_f

Slotted Aloha



Slotted Aloha

- The throughput for slotted ALOHA is

$$S = G * e^{-G}$$

where,

G is load



Pure and Slotted Aloha

- Eg:
 - A pure ALOHA network transmits 200-bit frames on a shared channel of 200 kbps. What is the requirement to make this frame collision free

Solution

- Average frame transmission time

$$\begin{aligned} T_{fr} &= 200 \text{ bits}/200 \text{ kbps} \\ &= 1 \text{ ms} \end{aligned}$$

- Vulnerable time

$$\begin{aligned} &= 2 * T_{fr} \\ &= 2 \times 1 \\ &= 2 \text{ ms} \end{aligned}$$

Pure and Slotted Aloha

- Eg:
 - A pure ALOHA network transmits 200-bit frames on a shared channel of 200 kbps. What is the throughput if the system (all stations together) produces 1000 frames per second

Solution

$$\begin{aligned} T_{fr} &= 200 \text{ bit}/200 \text{ kbps} \\ &= 1 \text{ ms} \end{aligned}$$

- If the system creates 1000 frames per second, i.e. 1 frame per millisecond, then load = 1

$$\begin{aligned} \text{Throughput (S)} &= G * e^{-2G} \\ S &= 0.135 \text{ (13.5 %)} \end{aligned}$$

$$\begin{aligned} \text{Overall throughput} &= 1000 * 0.135 \\ &= 135 \text{ frames} \end{aligned}$$

- Only 135 frames out of 1000 will probably survive

Pure and Slotted Aloha

- Eg:
 - A pure ALOHA network transmits 200-bit frames on a shared channel of 200 kbps. What is the throughput if the system (all stations together) produces 500 frames per second

Solution

$$\begin{aligned} T_{fr} &= 200 \text{ bit}/200 \text{ kbps} \\ &= 1 \text{ ms} \end{aligned}$$

- If the system creates 500 frames per second, i.e. 1/2 frame per millisecond, then load = 1/2

$$\begin{aligned} \text{Throughput (S)} &= G * e^{-2G} \\ S &= 0.184 \text{ (18.4 %)} \end{aligned}$$

$$\begin{aligned} \text{Overall throughput} &= 500 * 0.184 \\ &= 92 \text{ frames} \end{aligned}$$
- Only 92 frames out of 500 will probably survive

Pure and Slotted Aloha

- Eg:
 - A slotted ALOHA network transmits 200-bit frames using a shared channel with a 200-kbps bandwidth. Find the throughput if the system (all stations together) produces 1000 frames per second

Solution

$$T_{fr} = \frac{200 \text{ bit}}{200 \text{ kbps}} \\ = 1 \text{ ms}$$

- If the system creates 1000 frames per second, i.e. 1 frame per millisecond, then load = 1

$$\text{Throughput (S)} = G * e^{-G} \\ S = 0.368 \text{ (36.8 %)}$$

$$\text{Overall throughput} = 1000 * 0.368 \\ = 368 \text{ frames}$$

- Only 368 frames out of 1000 will probably survive

Pure and Slotted Aloha

- Eg:
 - A slotted ALOHA network transmits 200-bit frames using a shared channel with a 200-kbps bandwidth. Find the throughput if the system (all stations together) produces 500 frames per second

Solution

$$\begin{aligned} T_{fr} &= 200 \text{ bit}/200 \text{ kbps} \\ &= 1 \text{ ms} \end{aligned}$$

- If the system creates 500 frames per second, i.e. 1/2 frame per millisecond, then load = 1/2

$$\begin{aligned} \text{Throughput (S)} &= G * e^{-G} \\ S &= 0.303 \text{ (30.3 %)} \end{aligned}$$

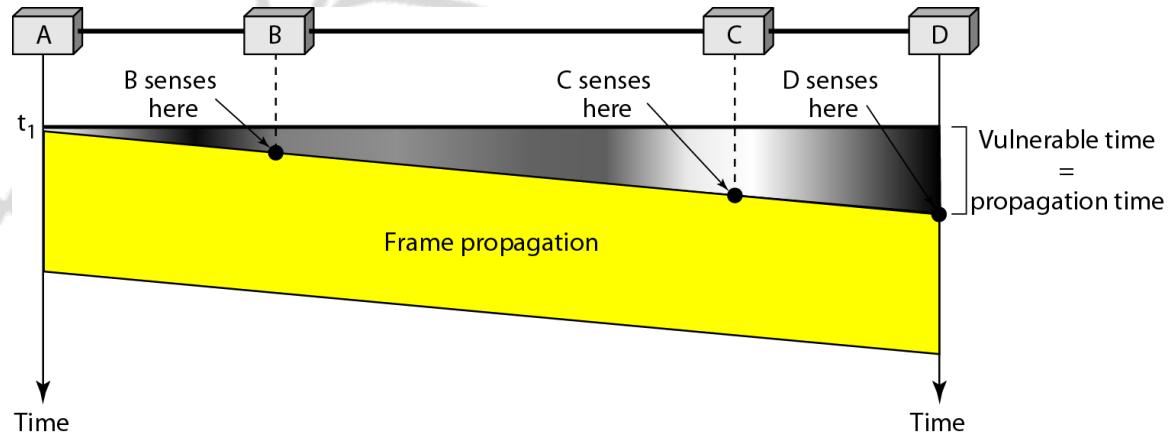
$$\begin{aligned} \text{Overall throughput} &= 500 * 0.303 \\ &= 151 \text{ frames} \end{aligned}$$
- Only 151 frames out of 500 will probably survive

Carrier Sense Multiple Access (CSMA)

- This method was developed to decrease the chances of collisions when two or more stations start sending their data
- CSMA requires that each station first check the state of the medium before sending
- CSMA is based on the principle “sense before transmit”
- CSMA can reduce the possibility of collision, but it cannot eliminate it

Carrier Sense Multiple Access (CSMA)

- Vulnerable Time
 - The vulnerable time for CSMA is the propagation time T_p
 - This is the time needed for a signal to propagate from one end of the medium to the other
 - When a station sends a frame, and any other station tries to send a frame during this time, a collision will result



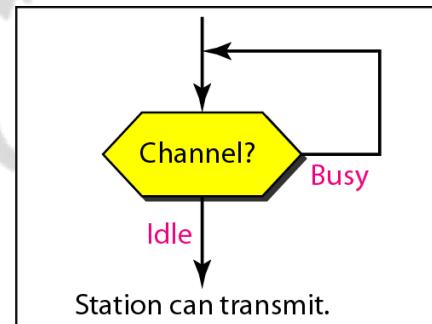
Types of CSMA

- There are three types
 - 1-Persistent CSMA
 - Non-Persistent CSMA
 - P-Persistent CSMA



1-Persistent CSMA

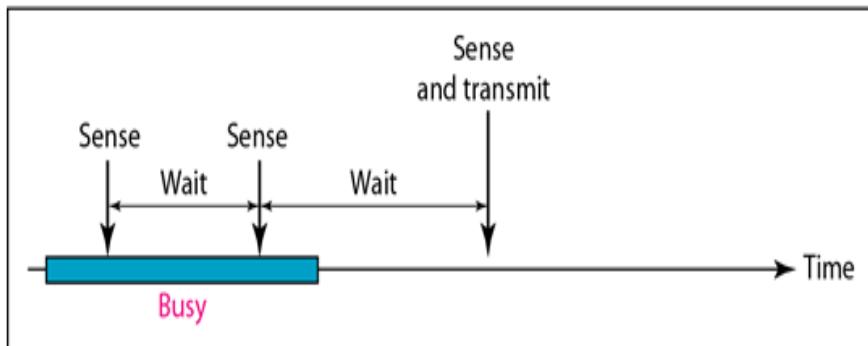
- If a station wants to transmit data, continuously senses the channel to check whether the channel is idle or busy
- If the channel is busy, the station waits until it becomes idle
- When the station detects an idle-channel, it immediately transmits the frame with probability 1
- Hence it is called 1-persistent CSMA



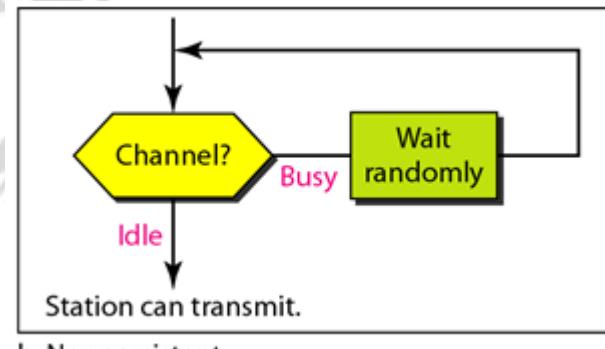
a. 1-persistent

Non-Persistent CSMA

- A station that has a frame to send senses the channel
- If the channel is idle, it sends immediately
- If the channel is busy, it waits a random amount of time and then senses the channel again
- In non-persistent CSMA the station does not continuously sense the channel



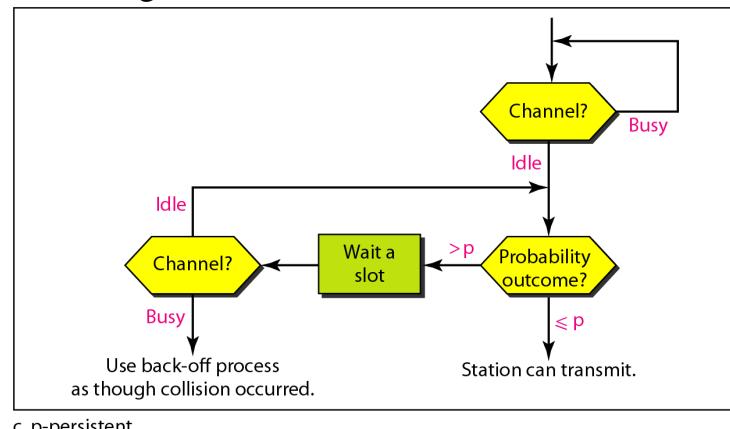
b. Nonpersistent



b. Nonpersistent

P-Persistent CSMA

- The p-persistent approach combines the advantages of the other two strategies. It reduces the chance of collision and improves efficiency
- In this method, if the station finds the line idle, it follows these steps:
 - With probability p , the station sends its frame
 - The station waits for the beginning of the next time slot and checks the line again
 - If the line is idle, it goes to step 1
 - If the line is busy, it acts as though a collision has occurred and uses the back off procedure



c. p-persistent

CSMA/CD

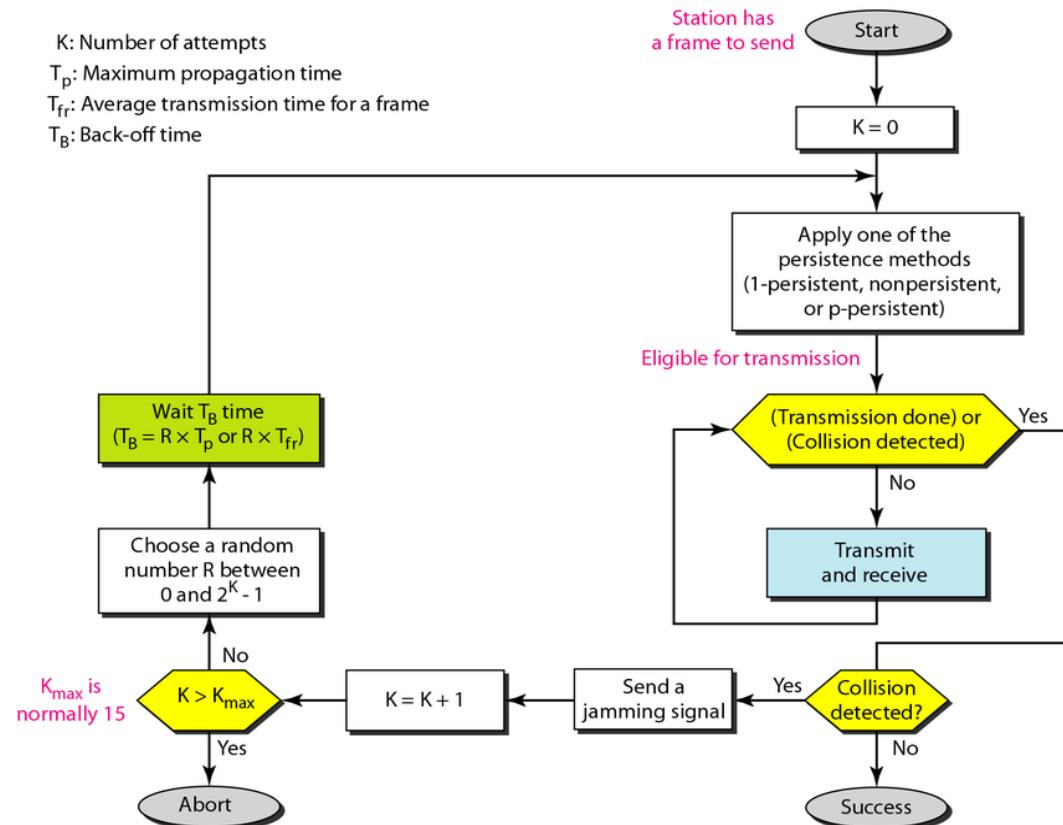
- CSMA/CD (Carrier Sense Multiple Access/ Collision Detection) is a media-access control method
- Consider a scenario where there are ‘n’ stations on a link and all are waiting to transfer data through that channel. In this case all ‘n’ stations would want to access the link/channel to transfer their own data. Problem arises when more than one station transmits the data at the moment. In this case, there will be collisions in the data from different stations
- CSMA/CD is one such technique where different stations that follow this protocol agree on some terms and collision detection measures for effective transmission. This protocol decides which station will transmit so that data reaches the destination without corruption

How CSMA/CD works?

- Step 1:
 - Check if the sender is ready for transmitting data packets
- Step 2:
 - Check if the transmission link is idle?
 - Sender has to keep on checking if the transmission link is idle. For this it continuously senses transmissions from other nodes. Sender sends dummy data on the link. If it does not receive any collision signal, this means the link is idle. it sends the data. otherwise not
- Step 3:
 - Transmit the data & check for collisions
 - Sender transmits its data on the link. CSMA/CD does not use ‘acknowledgement’ system. It checks for the successful and unsuccessful transmissions through collision signals. During transmission, if collision signal is received by the node, transmission is stopped. The station then transmits a jam signal onto the link and waits for random time interval before it resends the frame. After some random time, it again attempts to transfer the data and repeats above process.
- Step 4:
 - If no collision was detected in propagation, the sender completes its frame transmission

How CSMA/CD works?

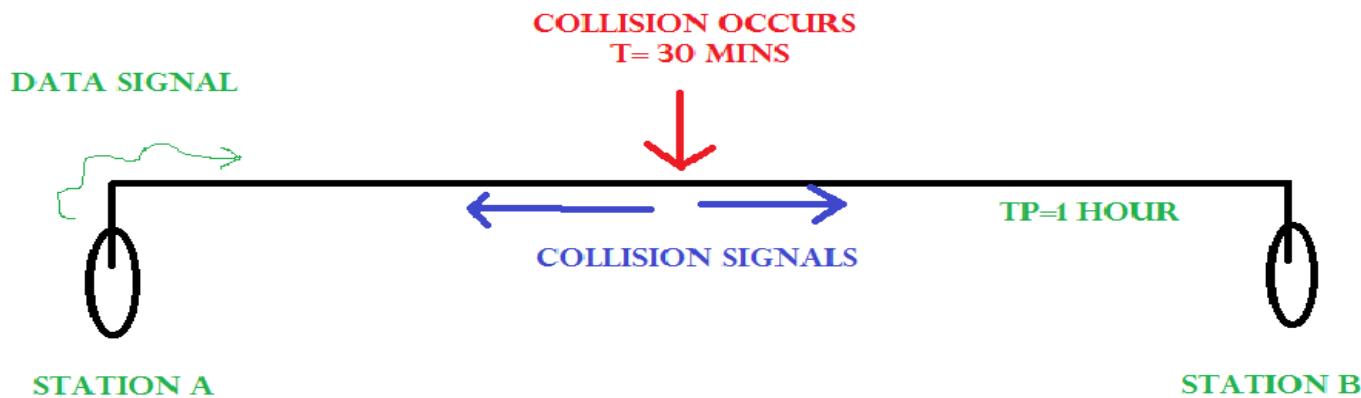
K : Number of attempts
 T_p : Maximum propagation time
 T_{fr} : Average transmission time for a frame
 T_B : Back-off time



Collision Detection in CSMA/CD

- How a station knows if its data collides?
 - Consider the situation for two stations, A and B
 - Propagation Time: $T_p = 1 \text{ hr}$
 - At time $t = 0$, A transmits its data
 - At $t = 30 \text{ mins.}$: Collision occurs
 - After collision occurs, a collision signal is generated and sent to both A & B to inform the stations about collision. Since the collision happened midway, the collision signal also takes 30 minutes to reach A & B
 - Therefore, $t = 1 \text{ hr}$: A & B receive collision signals. This collision signal is received by all the stations on that link

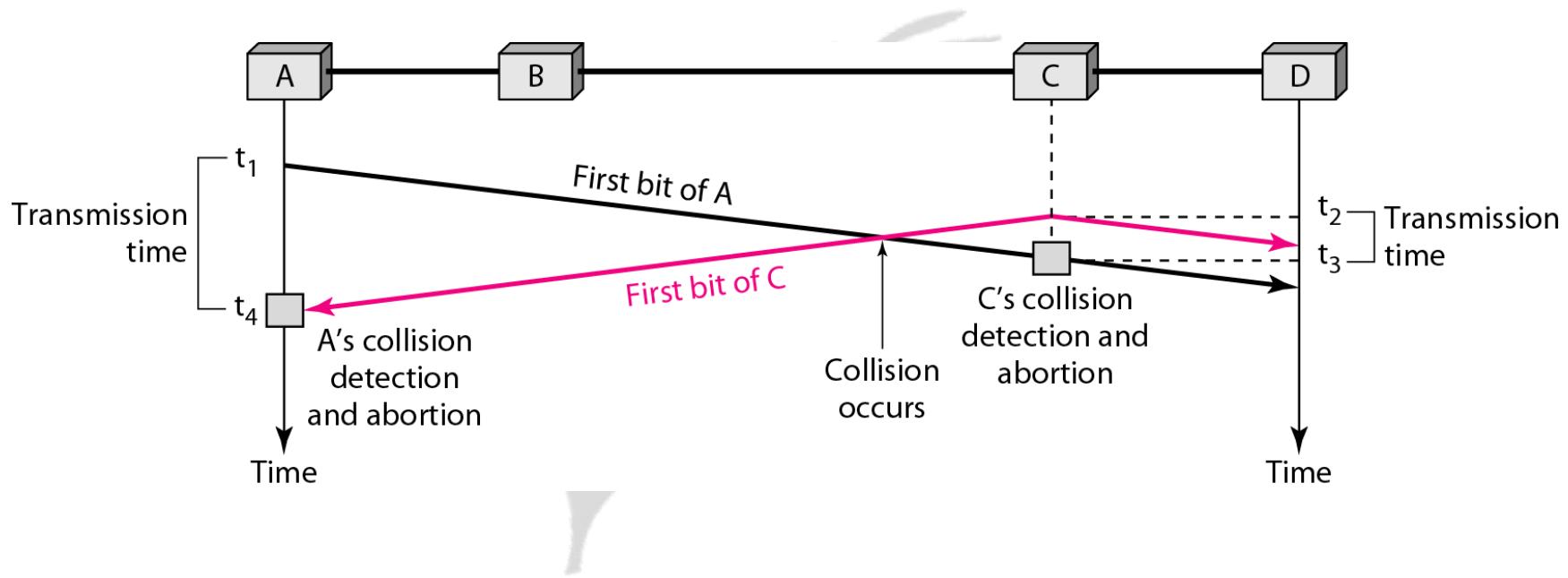
Collision Detection in CSMA/CD



Collision Detection in CSMA/CD

- How a station knows if its data collides?
 - Consider another situation for two stations, A and B
 - At time $t = 0$, A transmits its data
 - At $t = 59:59$ mins: Collision occurs
 - This collision occurs just before the data reaches B. Now the collision signal takes 59:59 minutes again to reach A. Hence, A receives the collision information approximately after 2 hours, that is, after $2 * T_p$
 - This is the maximum collision time that a system can take to detect if the collision was of its own data
 - Length of the packet = $2 * T_p * \text{Bandwidth of the link}$

Collision Detection in CSMA/CD



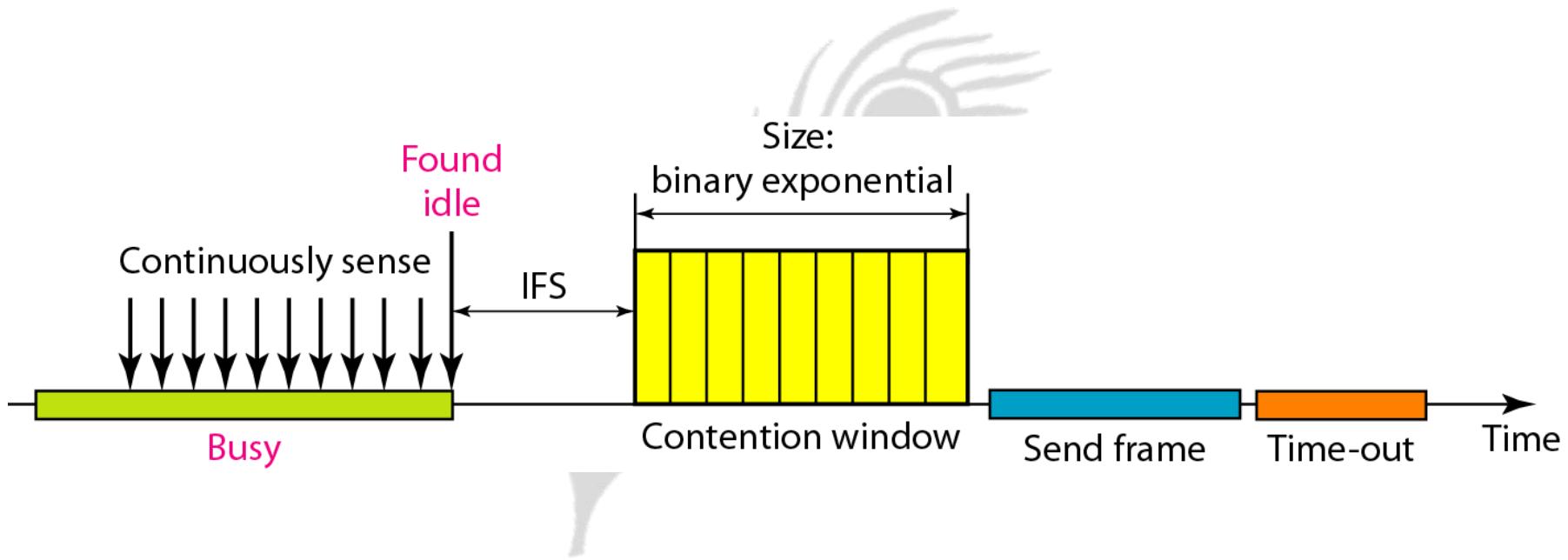
CSMA/CA

- Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)
- In contrast to CSMA/CD that deals with collisions after their occurrence, CSMA/CA prevents collisions prior to their occurrence
- The basic idea behind CSMA/CA is that the station should be able to receive while transmitting, to detect a collision from different stations
- In wired networks, if a collision has occurred then the energy of received signal almost doubles and the station can sense the possibility of collision
- In case of wireless networks, most of the energy is used for transmission and the energy of received signal increases by only 5 – 10 % if a collision occurs. It can't be used by the station to sense collision. Therefore CSMA/CA has been specially designed for wireless networks

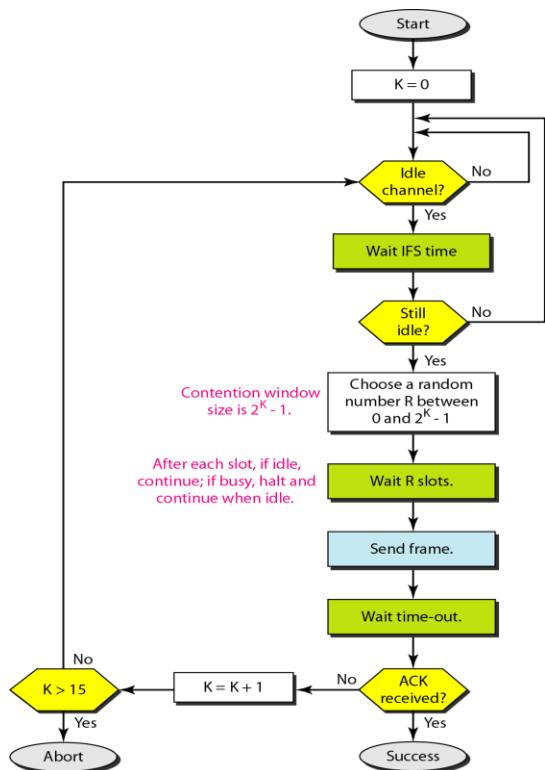
CSMA/CA

- These are three types of strategies:
 - Inter Frame Space (IFS):
 - The concept of an interframe space allows wireless systems to implement a simple priority system. Systems with high priority data to send have shorter IFS times, so whenever the medium is clear they will be the first to send
 - Contention Window:
 - It is the amount of time divided into slots. A station which is ready to send frames chooses random number of slots as wait time
 - Acknowledgements:
 - The positive acknowledgements and time-out timer can guarantee a successful transmission of the frame

CSMA/CA



CSMA/CA



Channel idle? Don't transmit yet!
Wait IFS time

Still idle after IFS? Don't transmit yet!
Now in Contention Window.
Choose random number and wait that many slots

CSMA/CA

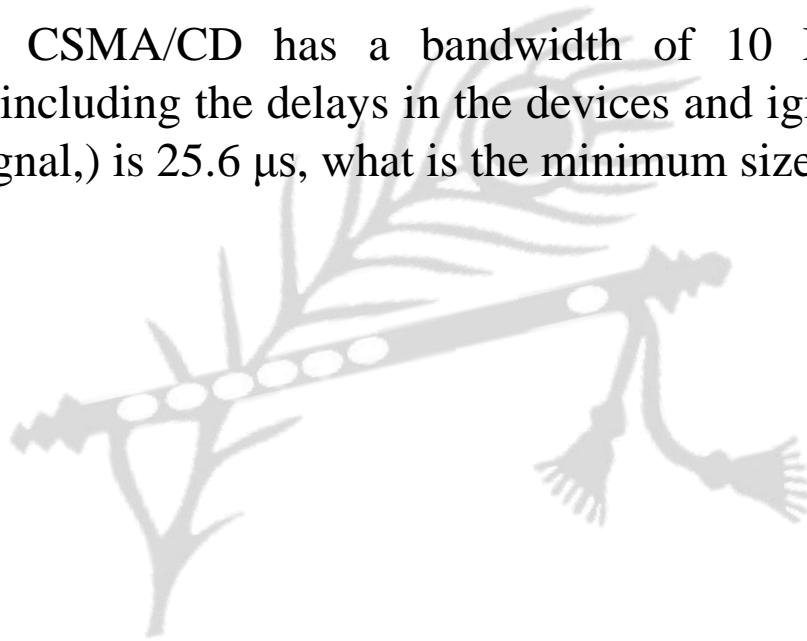
- Algorithm for CSMA/CA

- When a frame is ready, the transmitting station checks whether the channel is idle or busy
- If the channel is busy, the station waits until the channel becomes idle
- If the channel is idle, the station waits for an Inter-frame gap (IFG) amount of time and then sends the frame
- After sending the frame, it sets a timer
- The station then waits for acknowledgement from the receiver. If it receives the acknowledgement before expiry of timer, it marks a successful transmission
- Otherwise, it waits for a back-off time period and restarts the algorithm

CSMA/CD - CA

- Eg:

- A network using CSMA/CD has a bandwidth of 10 Mbps. If the maximum propagation time (including the delays in the devices and ignoring the time needed to send a jamming signal,) is 25.6 μ s, what is the minimum size of the frame?



CSMA/CD - CA

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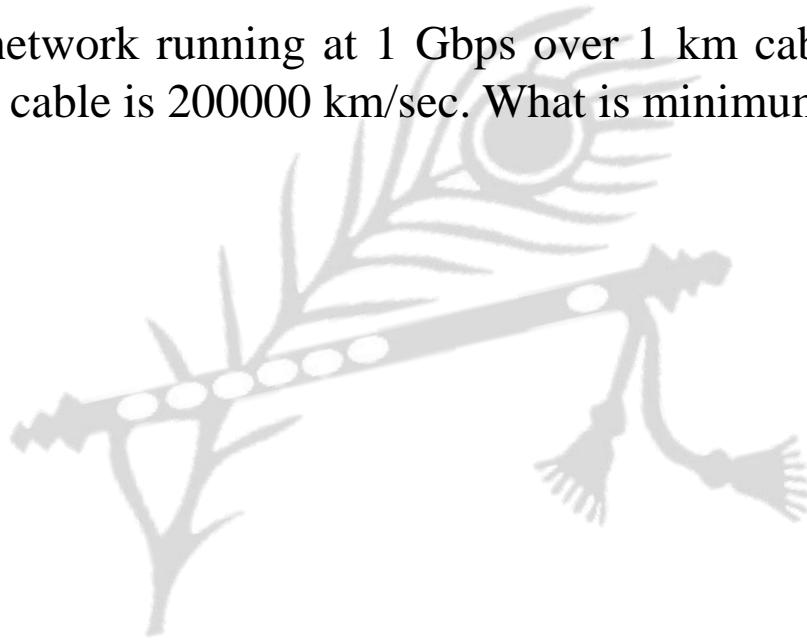
Solution

$$\begin{aligned}\text{size of frame} &= 2 * \text{propagation delay} * \text{bandwidth} \\ &= 2 * (25.6 * 10^{-6}) * 10 * 10^6 \\ &= 512 \text{ bits or } 64 \text{ bytes}\end{aligned}$$

CSMA/CD - CA

- Eg:

- In a CSMA/CD, network running at 1 Gbps over 1 km cable with no repeaters, the signal speed in the cable is 200000 km/sec. What is minimum frame size?



CSMA/CD - CA

- Eg:
 - In a CSMA/CD, network running at 1 Gbps over 1 km cable with no repeaters, the signal speed in the cable is 200000 km/sec. What is minimum frame size?

Solution

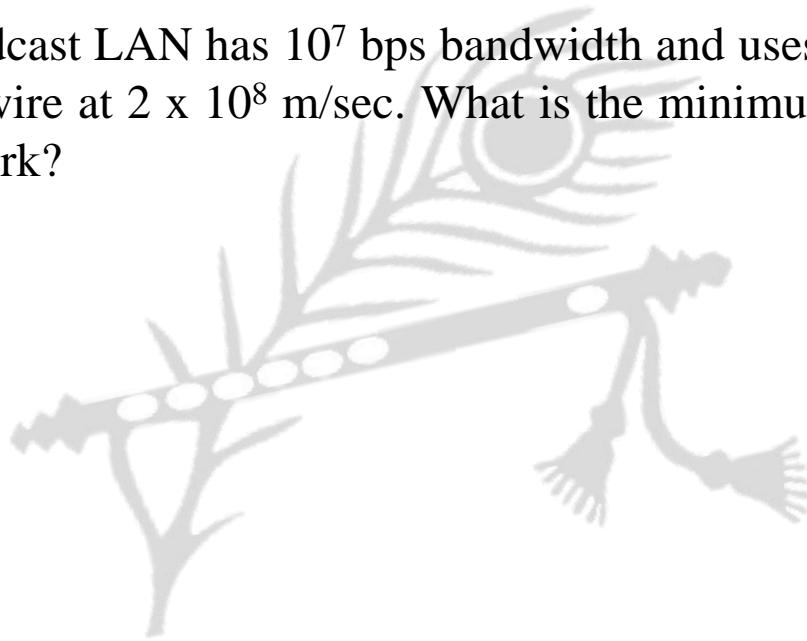
$$\begin{aligned}
 \text{Propagation delay } (T_p) &= \text{Distance/Propagation speed} \\
 &= 1 \text{ km} / (200000 \text{ km/sec}) \\
 &= 0.5 * 10^{-5} \text{ sec} \\
 &= 5 * 10^{-6} \text{ sec}
 \end{aligned}$$

$$\begin{aligned}
 \text{Frame size} &= 2 * \text{Propagation delay} * \text{Bandwidth} \\
 &= 2 * 5 * 10^{-6} * 10^9 \\
 &= 10000 \text{ bits}
 \end{aligned}$$

CSMA/CD - CA

- Eg:

- A 2 km long broadcast LAN has 10^7 bps bandwidth and uses CSMA / CD. The signal travels along the wire at 2×10^8 m/sec. What is the minimum packet size that can be used on this network?



CSMA/CD - CA

- Eg:

- A 2 km long broadcast LAN has 10^7 bps bandwidth and uses CSMA / CD. The signal travels along the wire at 2×10^8 m/sec. What is the minimum packet size that can be used on this network?

Solution

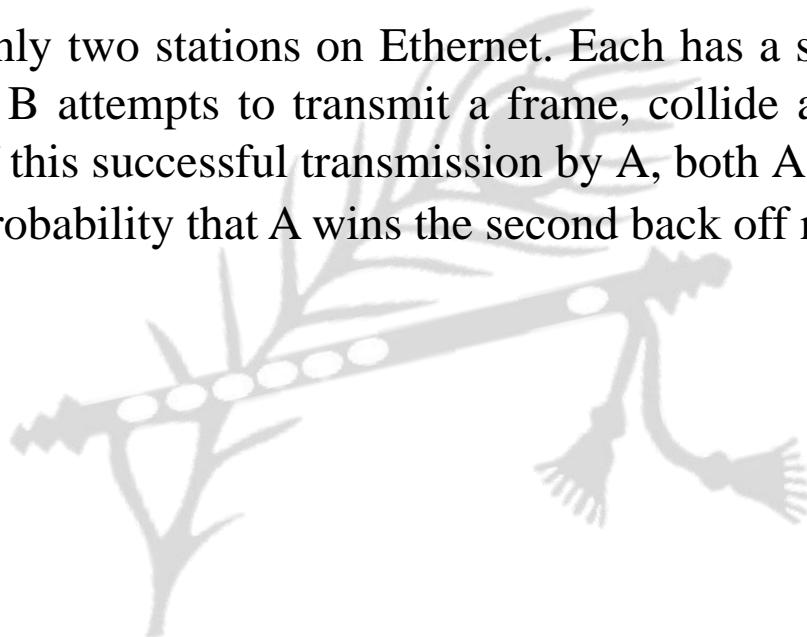
$$\begin{aligned}\text{Propagation delay } (T_p) &= \text{Distance/Propagation speed} \\ &= 2 \text{ km} / (2 * 10^8 \text{ m/sec}) \\ &= 10^{-5} \text{ sec}\end{aligned}$$

$$\begin{aligned}\text{Frame size} &= 2 * \text{Propagation delay} * \text{Bandwidth} \\ &= 2 * 10^{-5} * 10^7 \\ &= 200 \text{ bits}\end{aligned}$$

CSMA/CD - CA

- Eg:

- A and B are the only two stations on Ethernet. Each has a steady queue of frames to send. Both A and B attempts to transmit a frame, collide and A wins first back off race. At the end of this successful transmission by A, both A and B attempt to transmit and collide. The probability that A wins the second back off race is ___ ?



CSMA/CD - CA

- Eg:

- A and B are the only two stations on Ethernet. Each has a steady queue of frames to send. Both A and B attempts to transmit a frame, collide and A wins first back off race. At the end of this successful transmission by A, both A and B attempt to transmit and collide. The probability that A wins the second back off race is ____ ?

Solution

In 1st Transmission Attempt:

Both the stations A and B attempts to transmit a frame

A collision occurs

Back Off Algorithm runs

Station A wins and successfully transmits its 1st data packet

CSMA/CD - CA

- Eg:
 - A and B are the only two stations on Ethernet. Each has a steady queue of frames to send. Both A and B attempts to transmit a frame, collide and A wins first back off race. At the end of this successful transmission by A, both A and B attempt to transmit and collide. The probability that A wins the second back off race is ____ ?

Solution

In 2nd Transmission Attempt:

Station A attempts to transmit its 2nd data packet

Station B attempts to retransmit its 1st data packet

A collision occurs

CSMA/CD - CA

- Eg:
 - A and B are the only two stations on Ethernet. Each has a steady queue of frames to send. Both A and B attempts to transmit a frame, collide and A wins first back off race. At the end of this successful transmission by A, both A and B attempt to transmit and collide. The probability that A wins the second back off race is ____ ?

Solution

Now, We have to find the probability of station A to transmit its 2nd data packet successfully after 2nd collision

After the 2nd collision,

At Station A:

2nd data packet of station A undergoes collision for the 1st time

So, collision number for the 2nd data packet of station A = 1

Now, station A randomly chooses a number from the range $[0, 2^1-1] = [0, 1]$

Then, station A waits for back off time and then attempts to retransmit its data packet

At Station B:

1st data packet of station B undergoes collision for the 2nd time

So, collision number for the 1st data packet of station B = 2

Now, station B randomly chooses a number from the range $[0, 2^2-1] = [0, 3]$

Then, station B waits for back off time and then attempts to retransmit its data packet

CSMA/CD - CA

- Eg:

- A and B are the only two stations on Ethernet. Each has a steady queue of frames to send. Both A and B attempts to transmit a frame, collide and A wins first back off race. At the end of this successful transmission by A, both A and B attempt to transmit and collide. The probability that A wins the second back off race is ____ ?

Solution

Following 8 cases are possible



From here,

Probability of A winning the 2nd back off race = $5 / 8 = 0.625$

Station A	Station B	Remark
0	0	Collision
0	1	A wins
0	2	A wins
0	3	A wins
1	0	B wins
1	1	Collision
1	2	A wins
1	3	A wins