GLA UNIVERSITY

COMPUTER NETWORK

By:
Dr. Ankush Agarwal

Outline

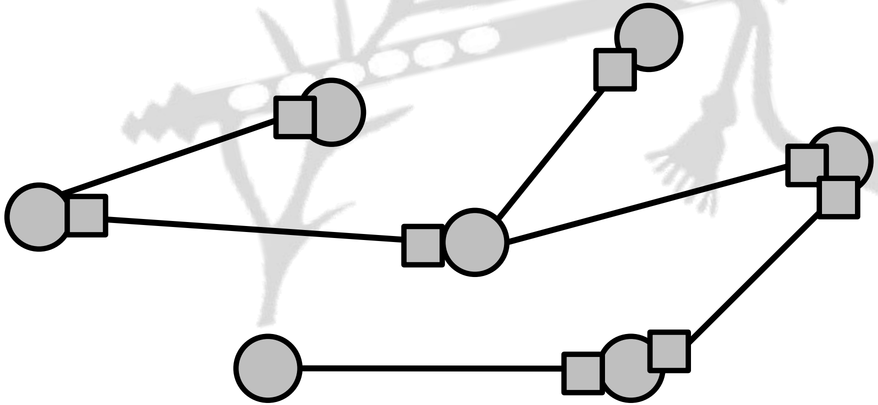
- **Introduction Concepts:**
  - Goals and Applications of networks
  - Network structure and architecture
  - The OSI reference model and services
  - Network topology design
  - Physical Layer Transmission Media
  - Line coding scheme
  - Switching methods (circuit switching, Packet switching)
  -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

Introduction Concepts

Introduction

Network

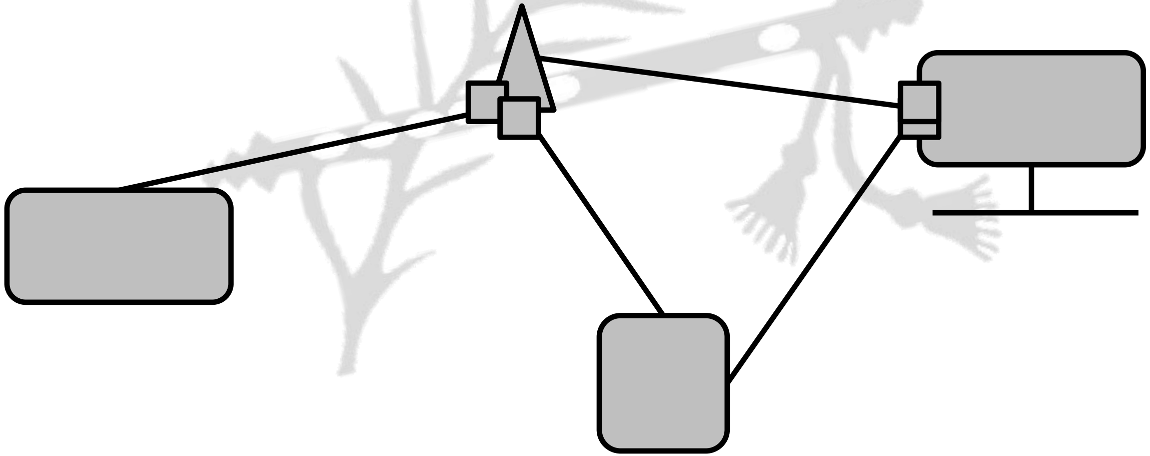
- It is defined as a medium which is responsible for carrying the data from one node to another
- Eg: intranet, internet, PAN, etc



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

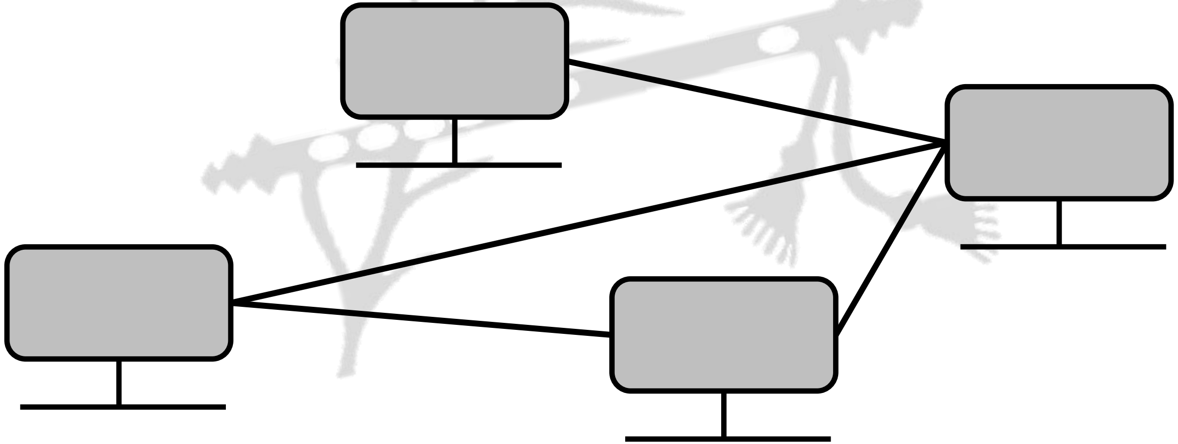
Network architecture

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

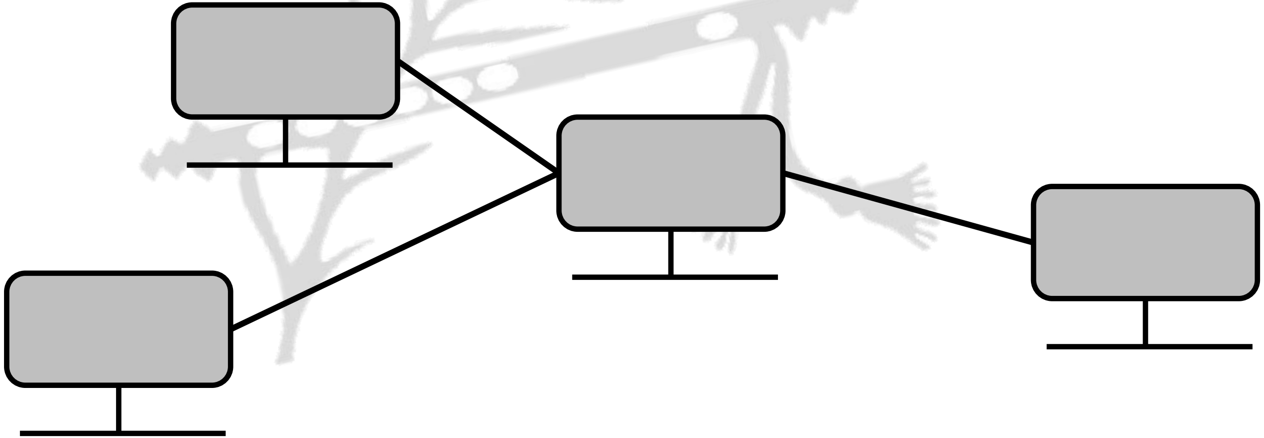
- Less costly as there is no central server
- In case of a node failure, other nodes in the network are not affected
- Installation is quite easy

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

Application Layer

↓

Presentation Layer

↓

Session Layer

↓

Transport Layer

↓

Network Layer

↓

Data link Layer

↓

Physical Layer

OSI reference model and its services

Application Layer

Presentation Layer

Session Layer

Transport Layer

Network Layer

Data link Layer

Physical Layer

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

OSI reference model and its services

- Application Layer
- Presentation Layer
- Session Layer
- Transport Layer
- Network Layer
- Data link Layer
- Physical Layer

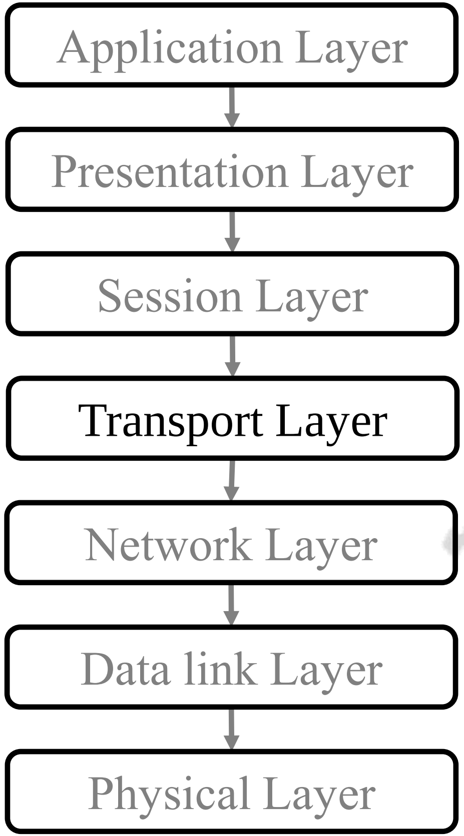
- The data from the application layer is extracted here and converted as per the required format to transmit over the network
- The functions of the presentation layer are :
  - Translation
  - Encryption/ Decryption
  - Compression

OSI reference model and its services

Application Layer
↓
Presentation Layer
↓
Session Layer
↓
Transport Layer
↓
Network Layer
↓
Data link Layer
↓
Physical Layer

- 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

Application Layer

Presentation Layer

Session Layer

Transport Layer

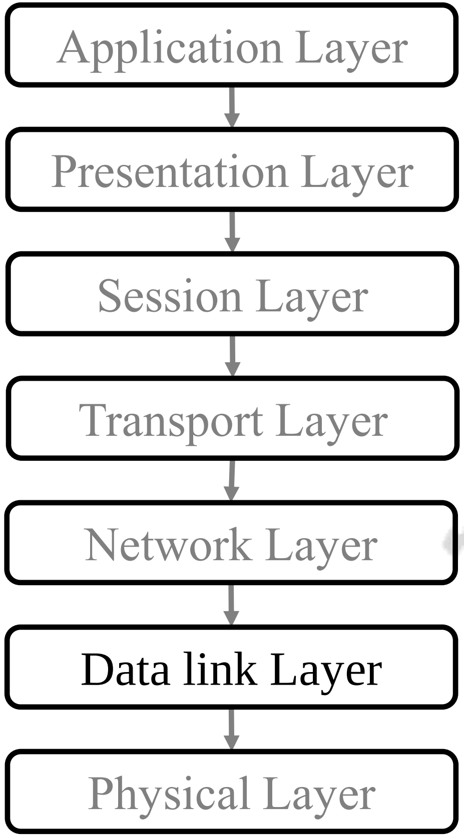
Network Layer

Data link Layer

Physical Layer

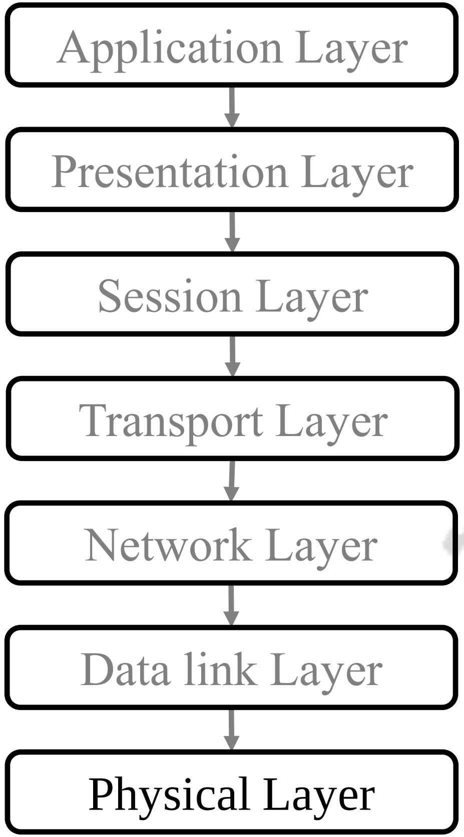
- Network layer works for the transmission of data
- It also takes care of packet routing i.e. selection of the shortest path
- The sender & receiver's IP address are placed in the header by the network layer.

OSI reference model and its services



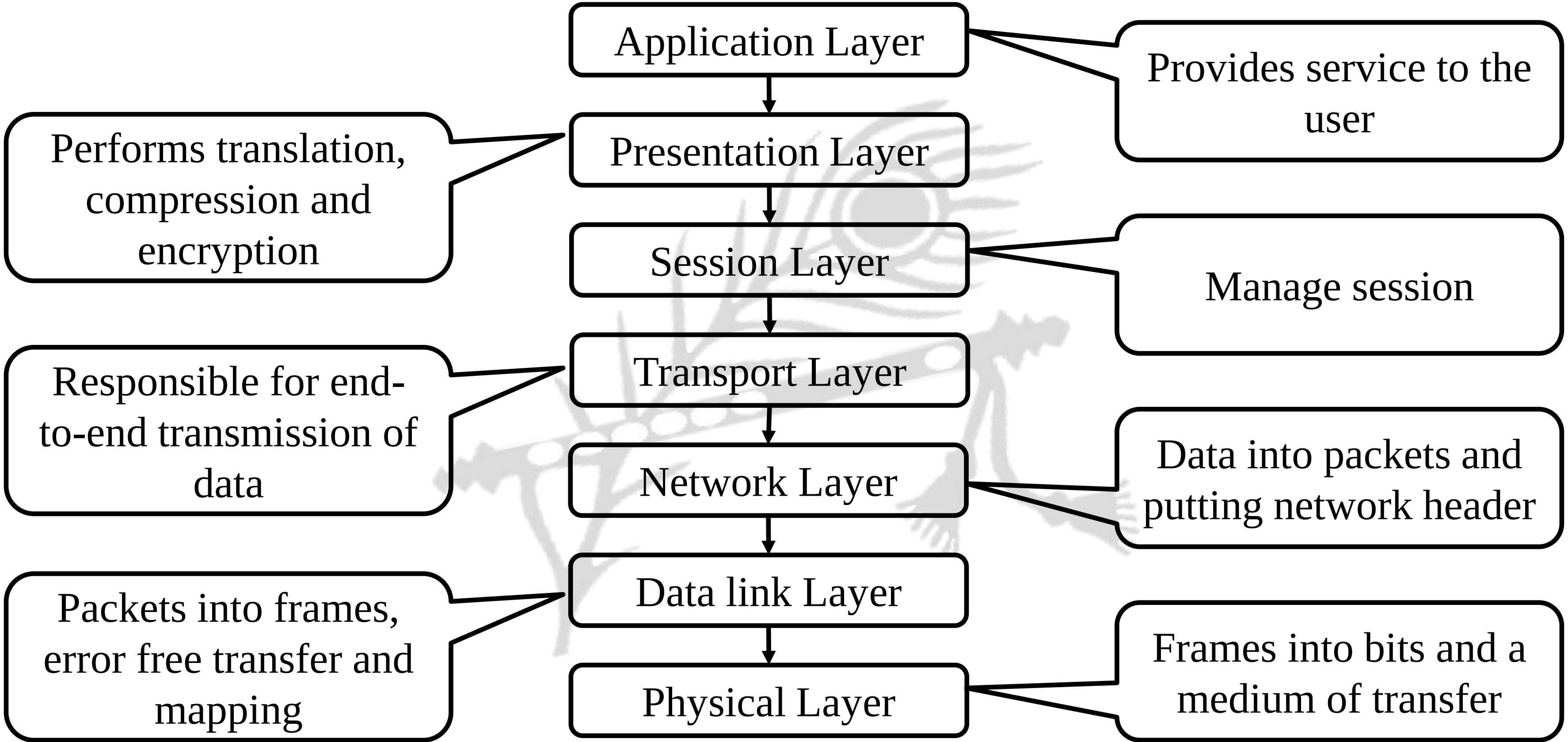
- The main function of this layer is to make sure data transfer is error-free from one node to another, over the physical layer
- When a packet arrives, it is the responsibility of DLL to transmit it to the Host using its MAC address.
- Data Link Layer is divided into two sub layers :
  - Logical Link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

OSI reference model and its services



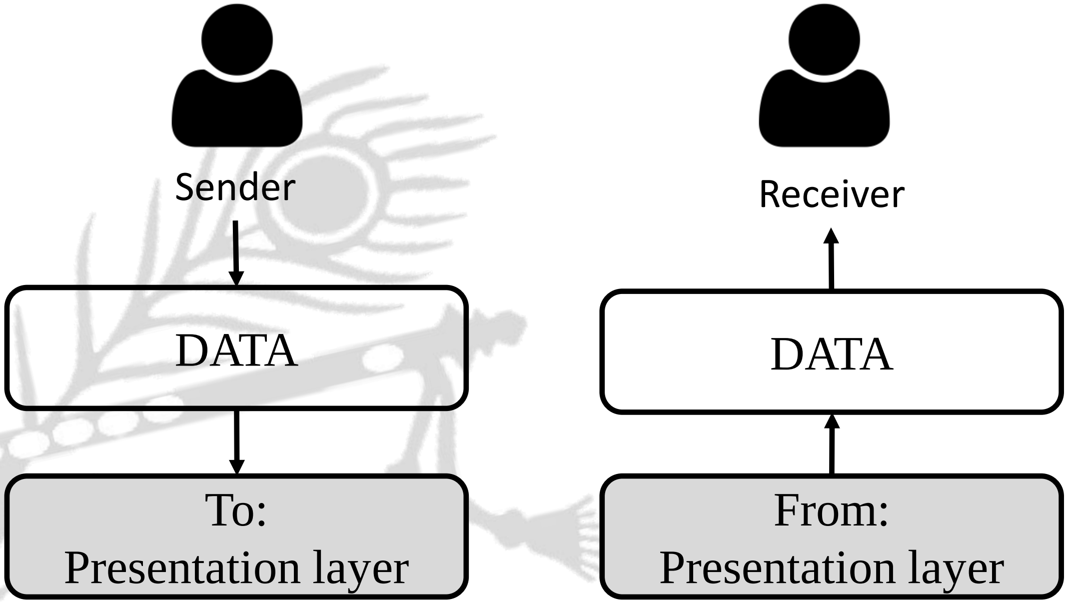
- It is responsible for the actual physical connection between the devices
- The physical layer contains information in the form of bits
- It is responsible for transmitting individual bits
- When receiving data, this layer will get the signal and convert it into 0s and 1s and send them to the Data Link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

OSI reference model and its services (in brief)



OSI reference model and its services (review)

Application Layer



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)

Application Layer

Presentation Layer

Sender

From: Application layer

Encode, Encrypt, Compress

To: Session layer

Receiver

From: Session layer

Decode, Decrypt, Decompress

To: Application layer

OSI reference model and its services (review)

Application Layer

↓

Presentation Layer

- 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)

Application Layer

↓

Presentation Layer

↓

Session Layer

Sender	Receiver
From: Presentation layer	To: Presentation layer
↓	↑
Sync and recovery	Sync and recovery
↓	↑
To: Transport layer	From: Transport layer

OSI reference model and its services (review)

Application Layer

↓

Presentation Layer

↓

Session Layer

- 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)

Application Layer

Presentation Layer

Session Layer

Transport Layer

Sender

From:
Session layer

Break data into segments

To:
Network layer

Receiver

To:
Session layer

Merge segments to form data

From:
Network layer

DATA				
DS1	DS2	DS3	…	DSn

OSI reference model and its services (review)

Application Layer
↓
Presentation Layer
↓
Session Layer
↓
Transport Layer

Sender	Receiver
From: Session layer	To: Session layer
↓	↑
Break data into segments	Merge segments to form data
↓	↑
To: Network layer	From: Network layer

Two protocols used in this layer:

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

OSI reference model and its services (review)

Application Layer

↓

Presentation Layer

↓

Session Layer

↓

Transport Layer

Sender	Receiver
From: Session layer	To: Session layer
↓	↑
Break data into segments	Merge segments to form data
↓	↑
To: Network layer	From: Network layer

Function of this layer:

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

OSI reference model and its services (review)

Application Layer

↓

Presentation Layer

↓

Session Layer

↓

Transport Layer

- 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)

Application Layer

Presentation Layer

Session Layer

Transport Layer

Network Layer

Sender	Receiver
From: Transport layer	To: Transport layer
Break segments into packets	Merge packets to form segments
To: DLL	From: DLL

DS1				
DSP1	DSP2	DSP3	…	DSPn

Protocol used:

- IP

OSI reference model and its services (review)

Application Layer
↓
Presentation Layer
↓
Session Layer
↓
Transport Layer
↓
Network Layer

- 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 a new for each packet, to reflect the current network load
  - Congestion: Controls the number 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)

Application Layer

Presentation Layer

Session Layer

Transport Layer

Network Layer

Data link Layer

Sender	Receiver
From: Network layer	To: Network layer
Break packets into frames	Merge frames to form packets
To: Physical layer	From: Physical layer

DSP1				
DSPF1	DSPF2	DSPF3	…	DSPFn

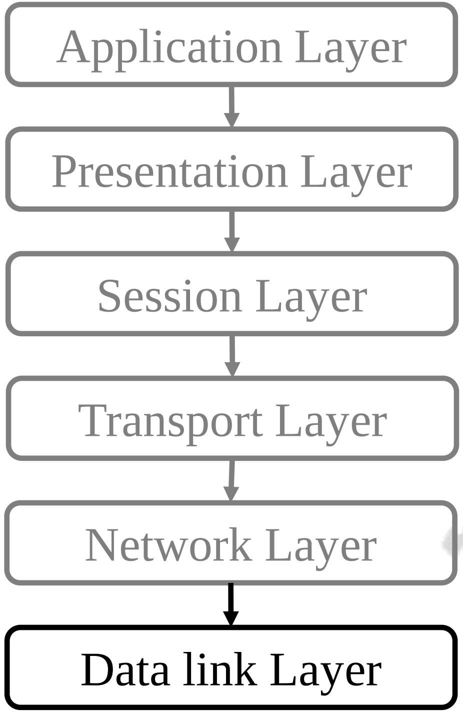
OSI reference model and its services (review)

Application Layer
↓
Presentation Layer
↓
Session Layer
↓
Transport Layer
↓
Network Layer
↓
Data link Layer

It contains two sub-layers:

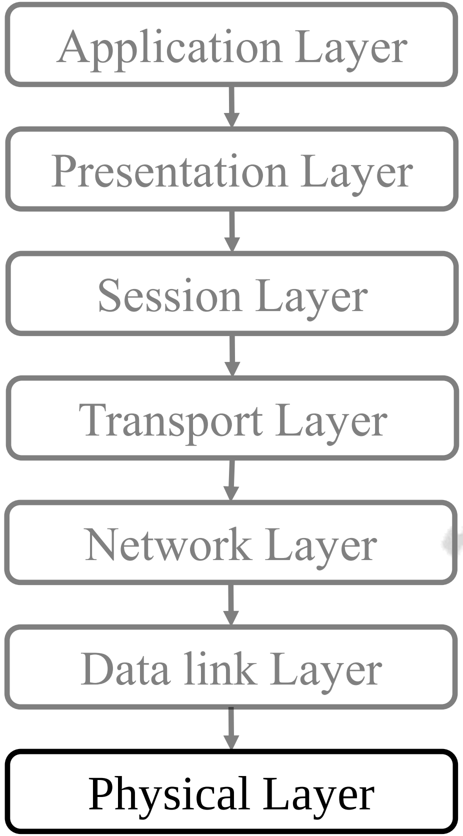
- Logical Link Control Layer
  – It identifies the address of the network layer protocol from the header
  – It also provides flow control
- Media Access Control Layer
  – A Media access control layer is a link between the Logical Link Control layer and the network's physical layer

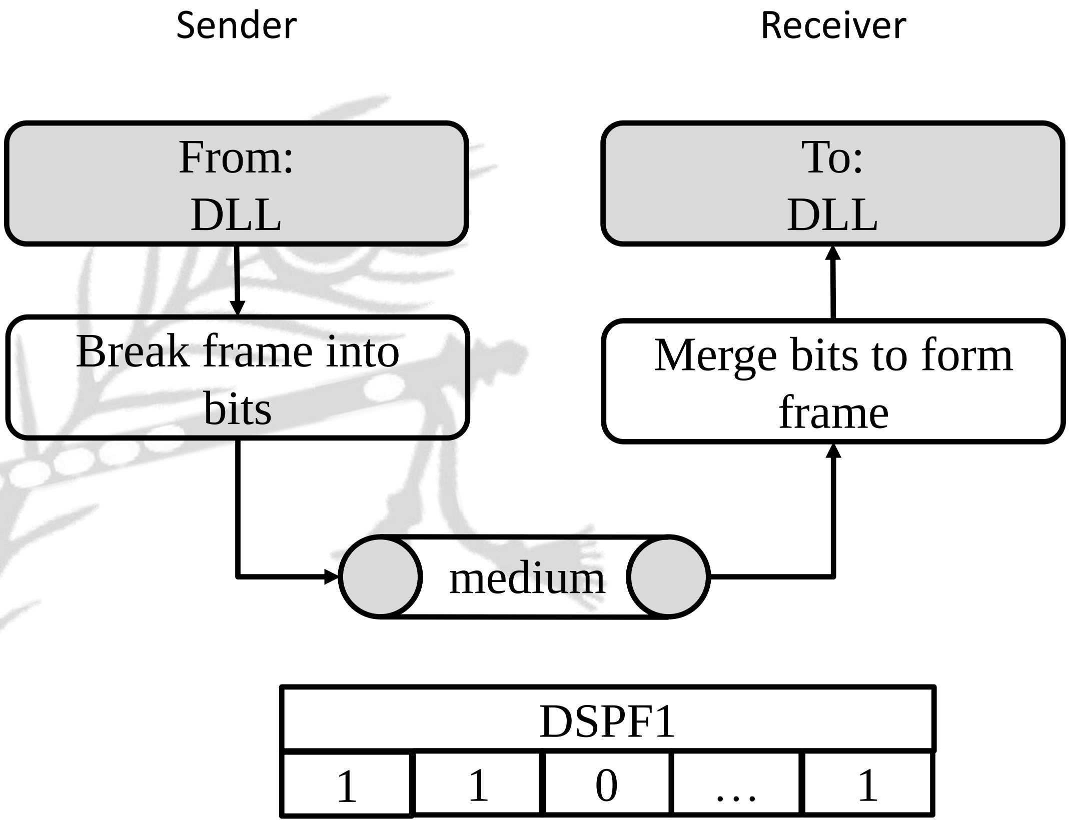
OSI reference model and its services (review)



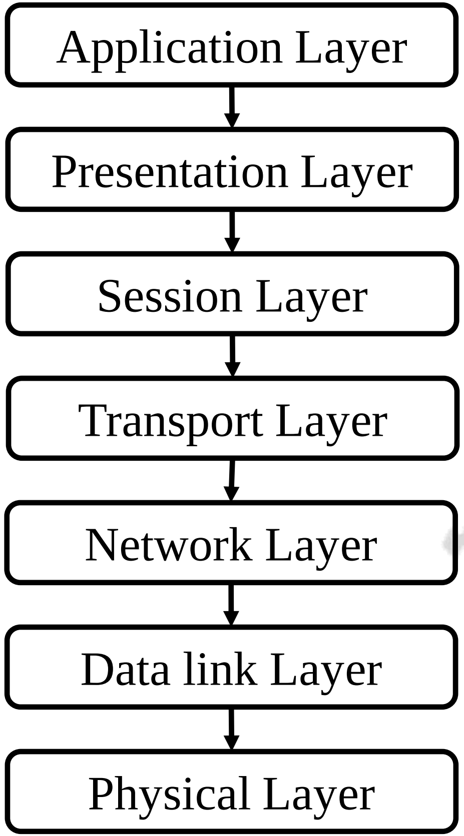
- Purpose
  - Transform a raw transmission line into a line that appears free of undetected transmission errors to the networks layer
- Concerns
  - Framing: Breaks apart input data into frames and transmit the frames sequentially
  - Error handling: if the service is reliable, the receiver confirms 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)



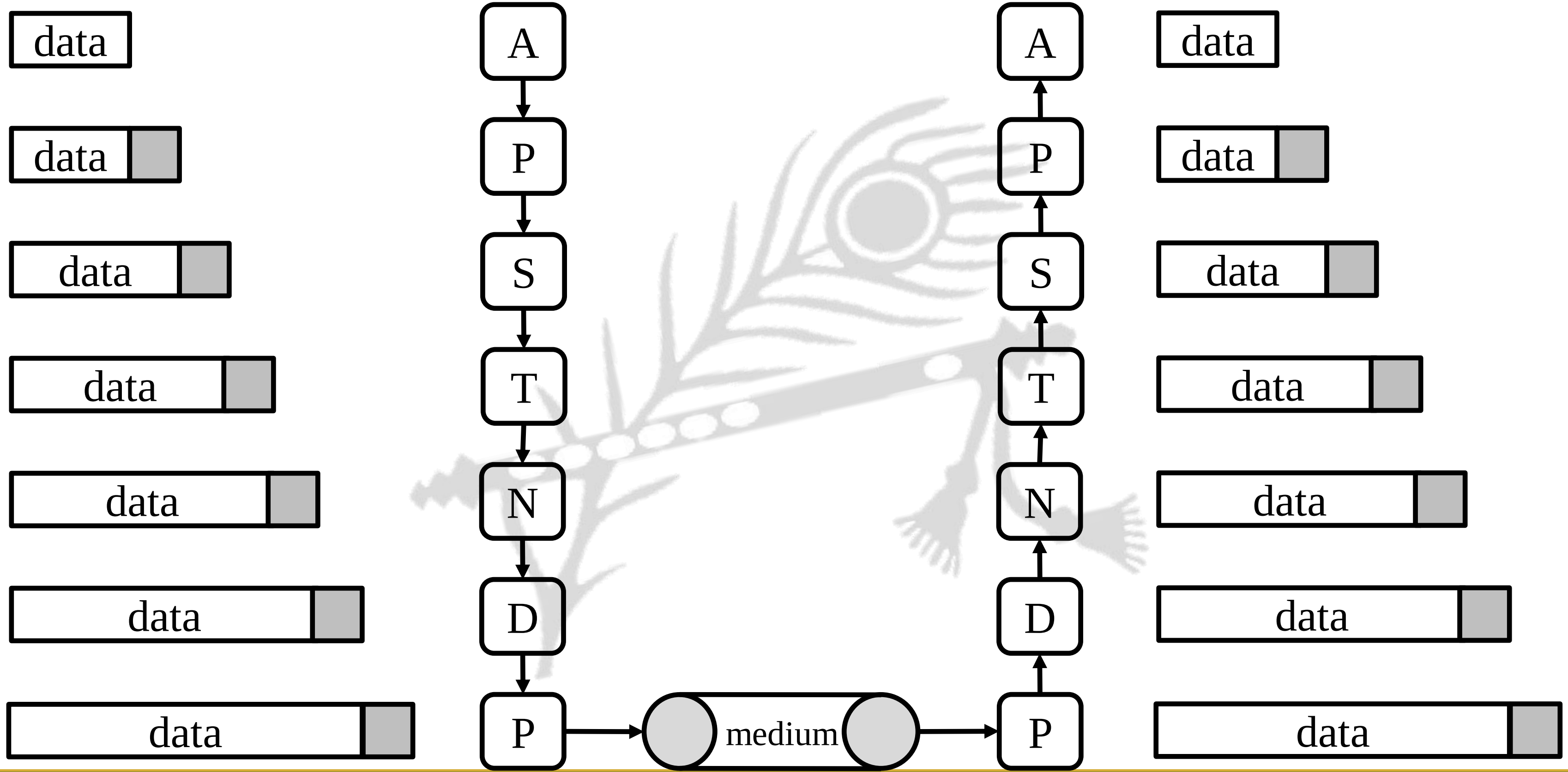


OSI reference model and its services (review)

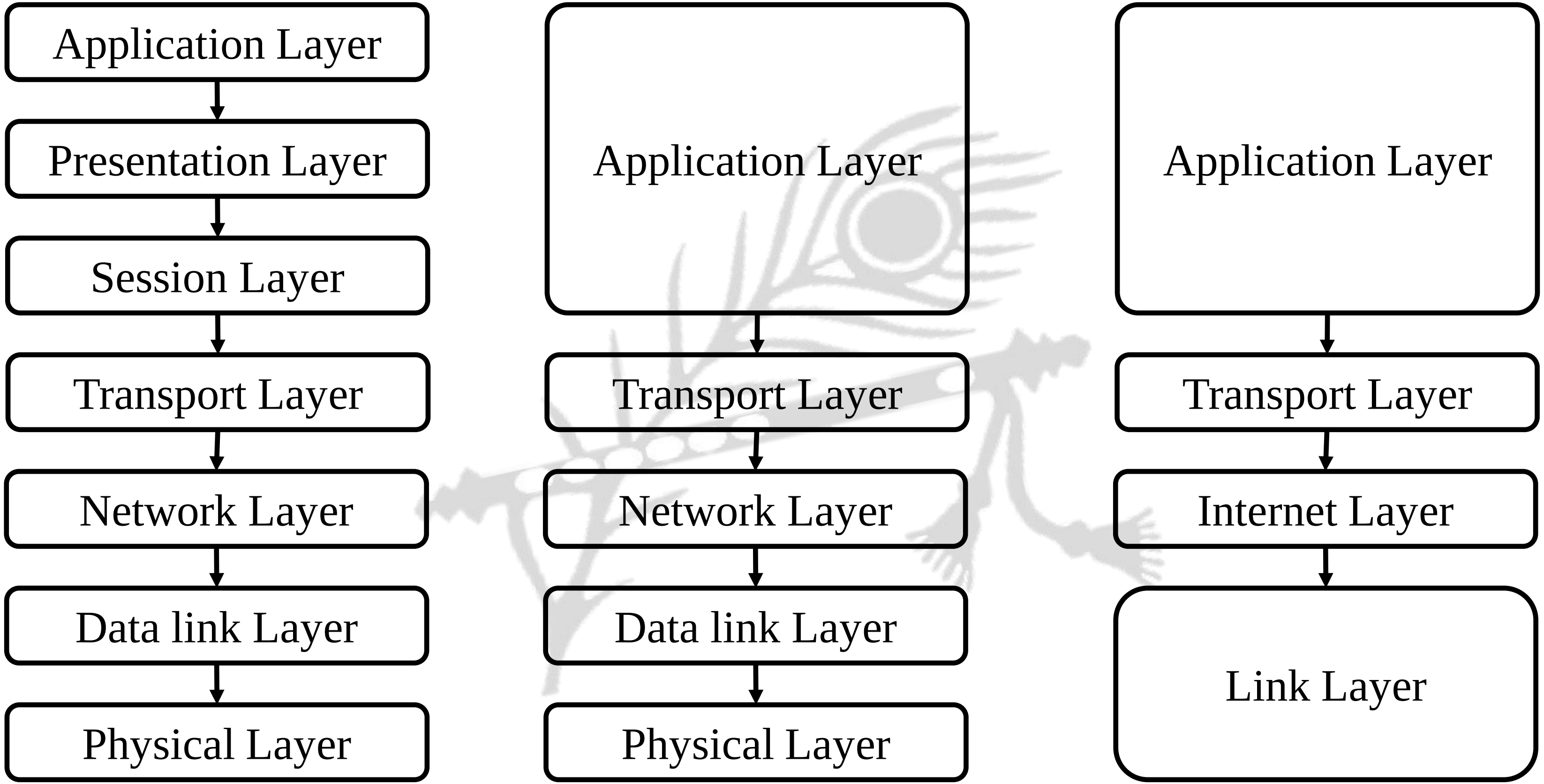


- Purpose
  - Transmits raw bits across a medium
- Functional
  - Flow of data (simplex, half duplex, full duplex)
  - Topology
  - Encoding

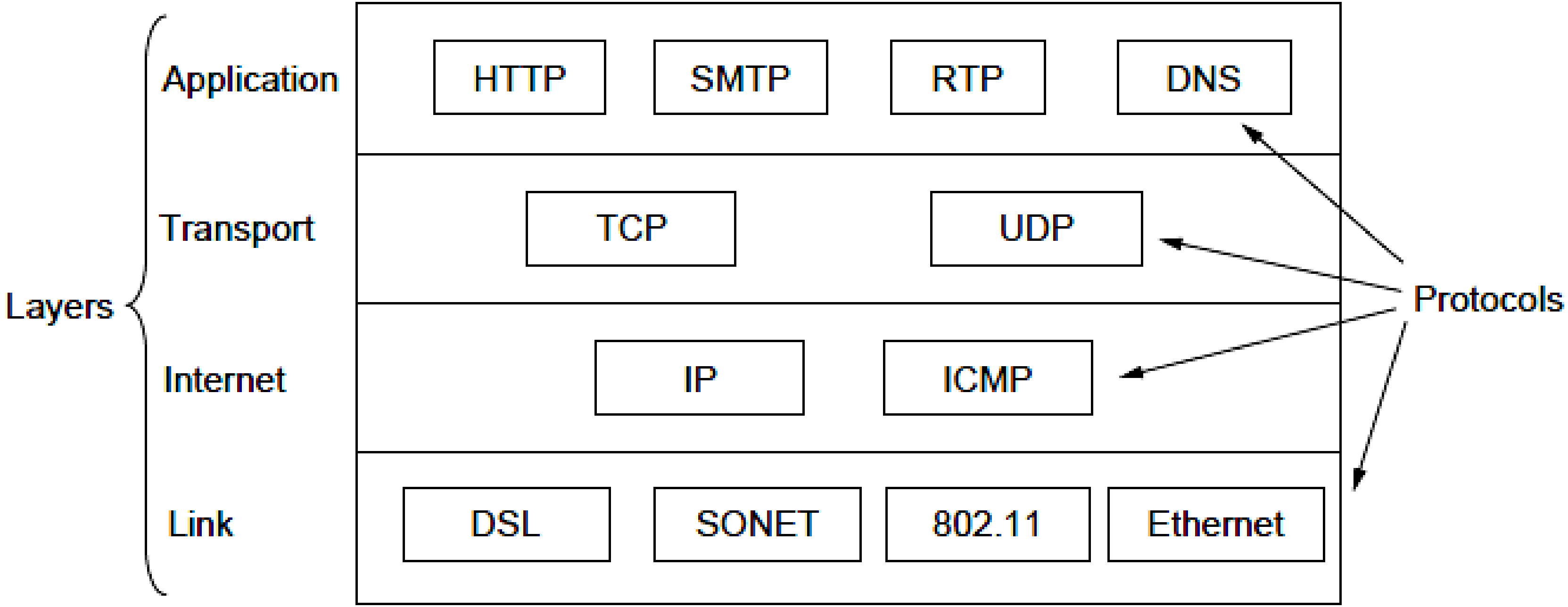
An exchange using OSI reference model



TCP/IP reference model



TCP/IP reference model



TCP/IP reference model

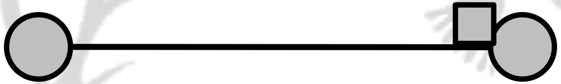
- Concepts central to the OSI model
  - Services
  - Interfaces
  - Protocols
- OSI has good definition of service, interface, and protocol. Fits well with object oriented programming concepts.
- Protocols are better hidden
- TCP/IP model did not distinguish between service, interface, and protocol
-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

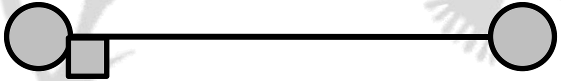
Transmission Mode

- 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

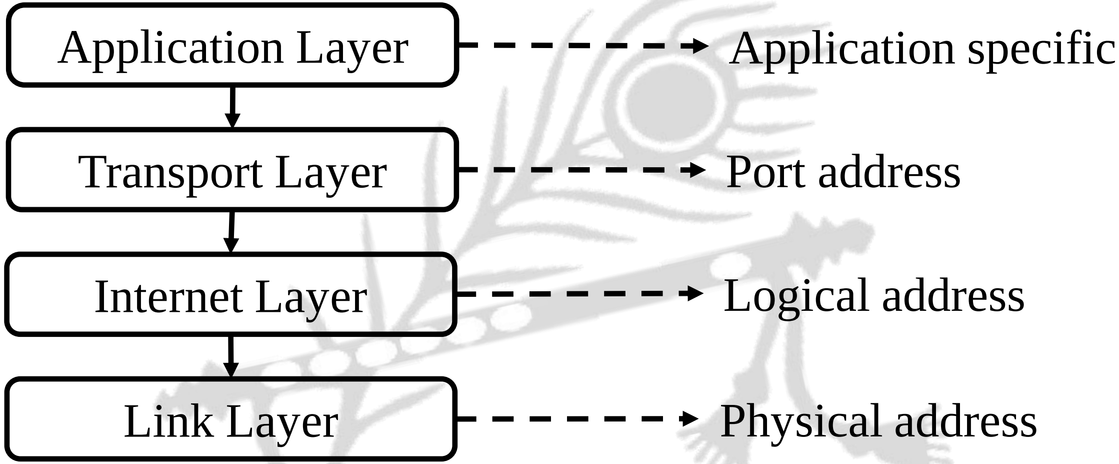
- Network layer
- packets
- Intelligent device
- LAN, MAN, WAN
- Full duplex
- IP address

ADDRESSING

Addressing

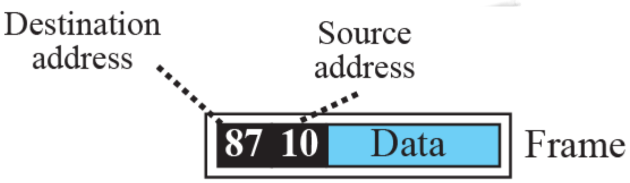
- Four levels of addresses are used in an internet employing the TCP/IP protocols:
  - physical address,
  - logical address,
  - port address, and
  - application-specific address.
- Each address is related to a one layer in the TCP/IP architecture

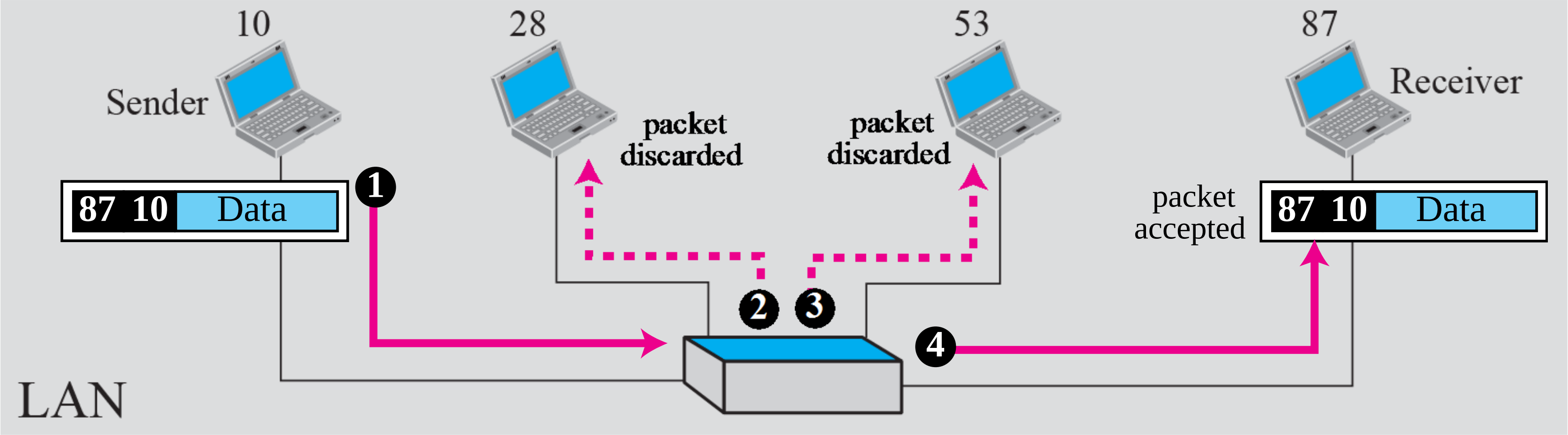
Addressing


Application Layer
Transport Layer
Internet Layer
Link Layer
Application specific
Port address
Logical address
Physical address

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

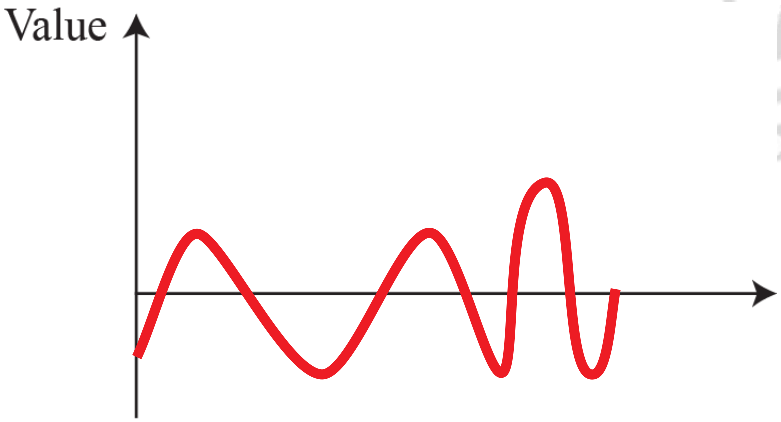
Analog and Digital data

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

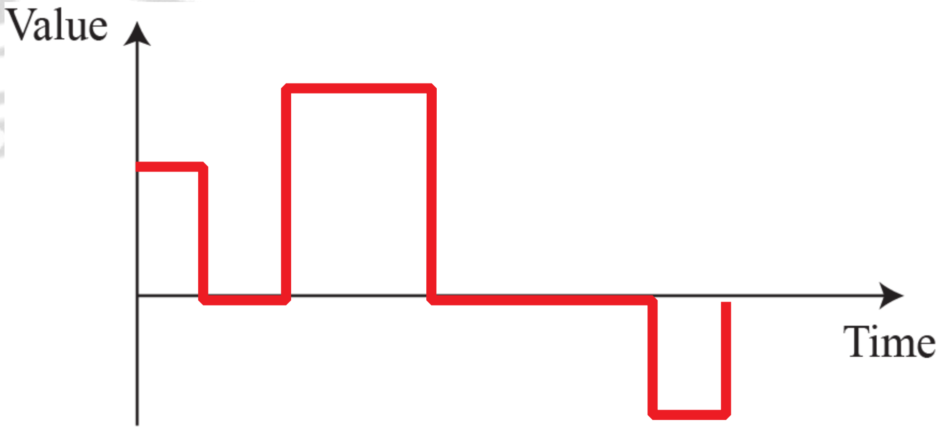
DATA AND SIGNALS

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

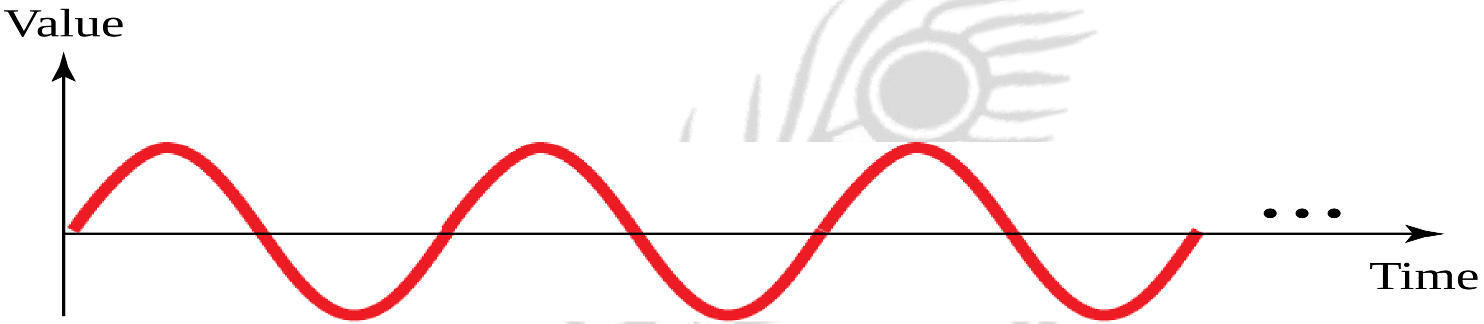
- A periodic signal completes a pattern within a measurable time frame, called a period, and repeats that pattern. The completion of one full pattern is called a cycle.
- A non periodic signal changes without exhibiting a pattern or cycle that repeats over time

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

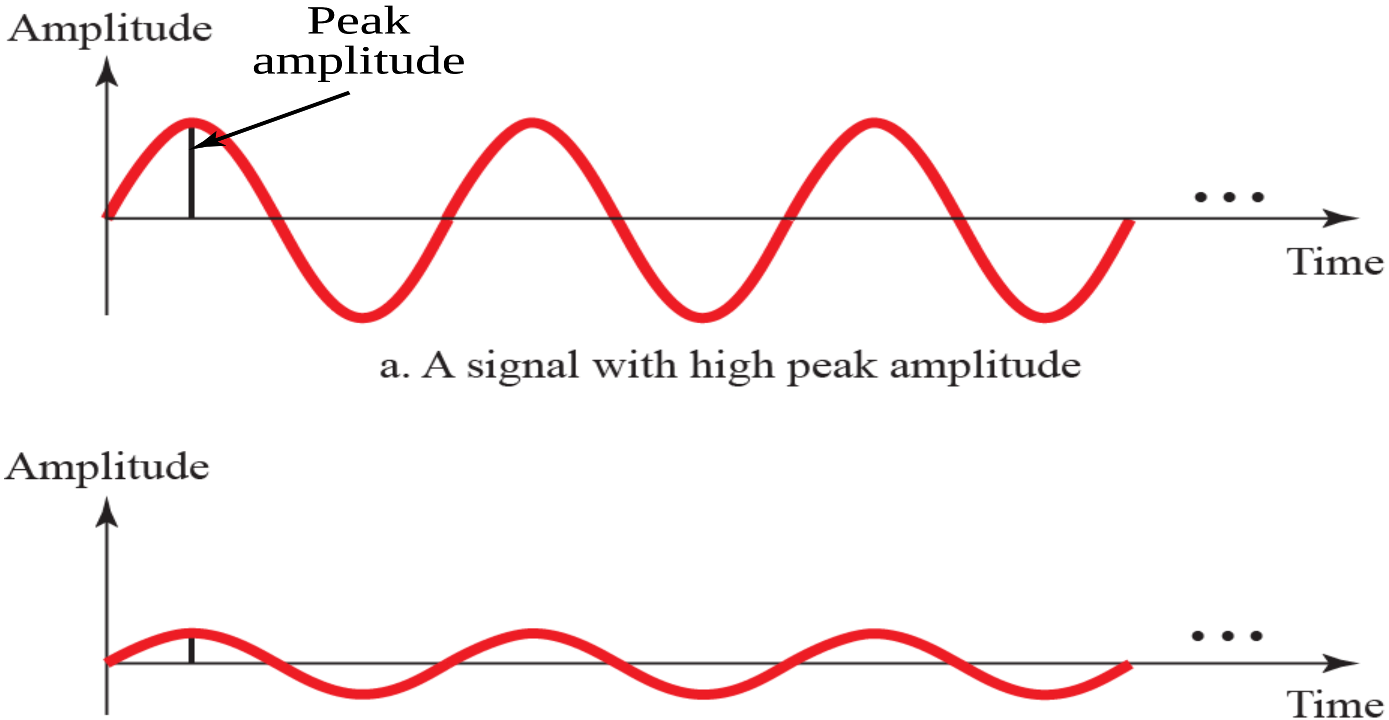
$$f = \frac{1}{T} \qquad \text{and} \qquad T = \frac{1}{f}$$

Periodic and Non-periodic



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

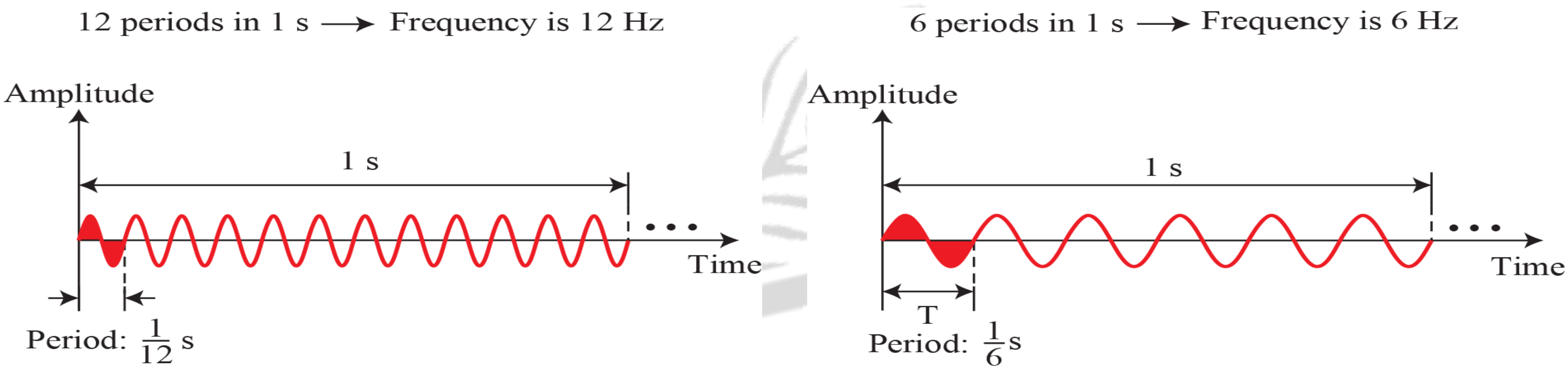
Periodic and Non-periodic



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 (μs)	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} μs)

By substituting:

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

Eg

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

Solution

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

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 Hz = 10^{-3} kHz).

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

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

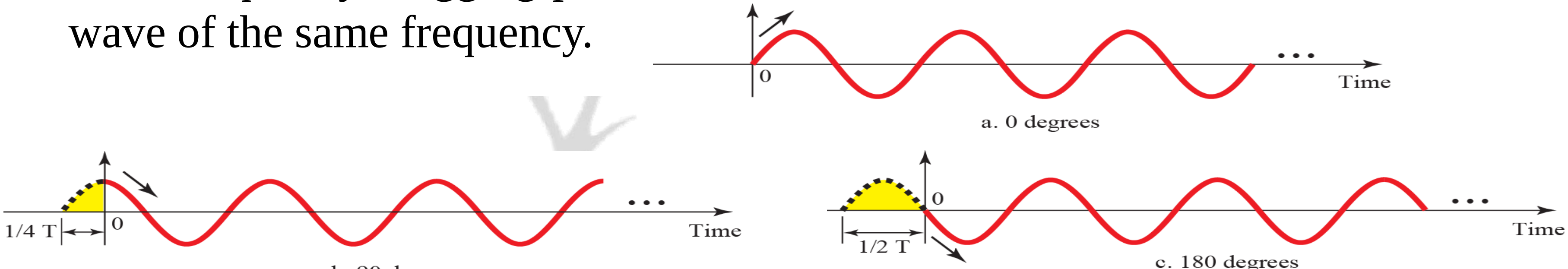
Frequency

- 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.



a. 0 degrees
b. 90 degrees
c. 180 degrees

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

$$\frac{1}{6} * 360$$
$$= 60°$$
$$= 60 * 2\Pi/360 \text{ rad}$$
$$= \Pi/3 \text{ rad}$$

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

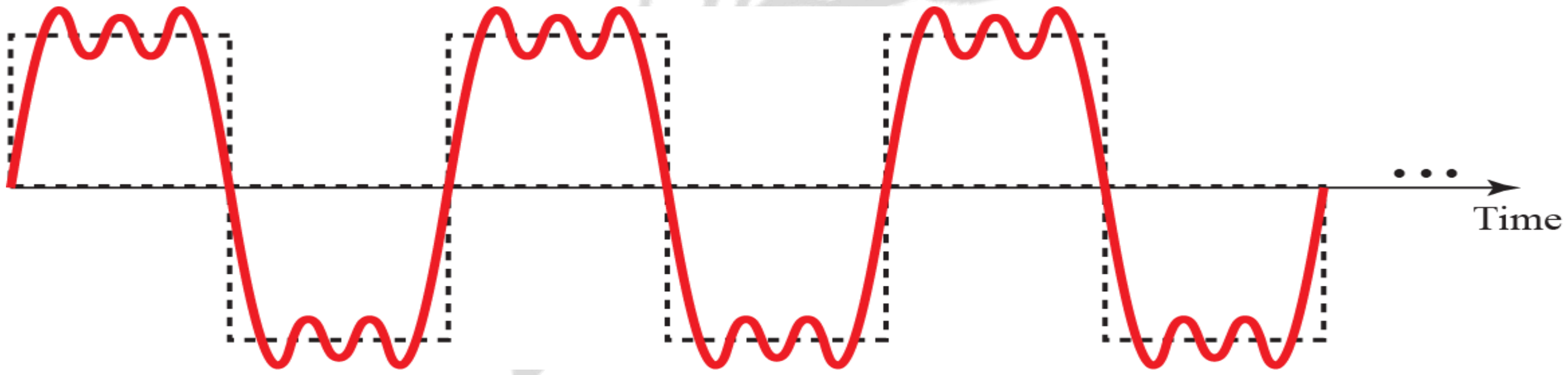
- A single-frequency sine wave is not useful in data communications
- We need to send a composite signal, a signal made of many simple sine waves
- According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases

Composite Signals and Periodicity

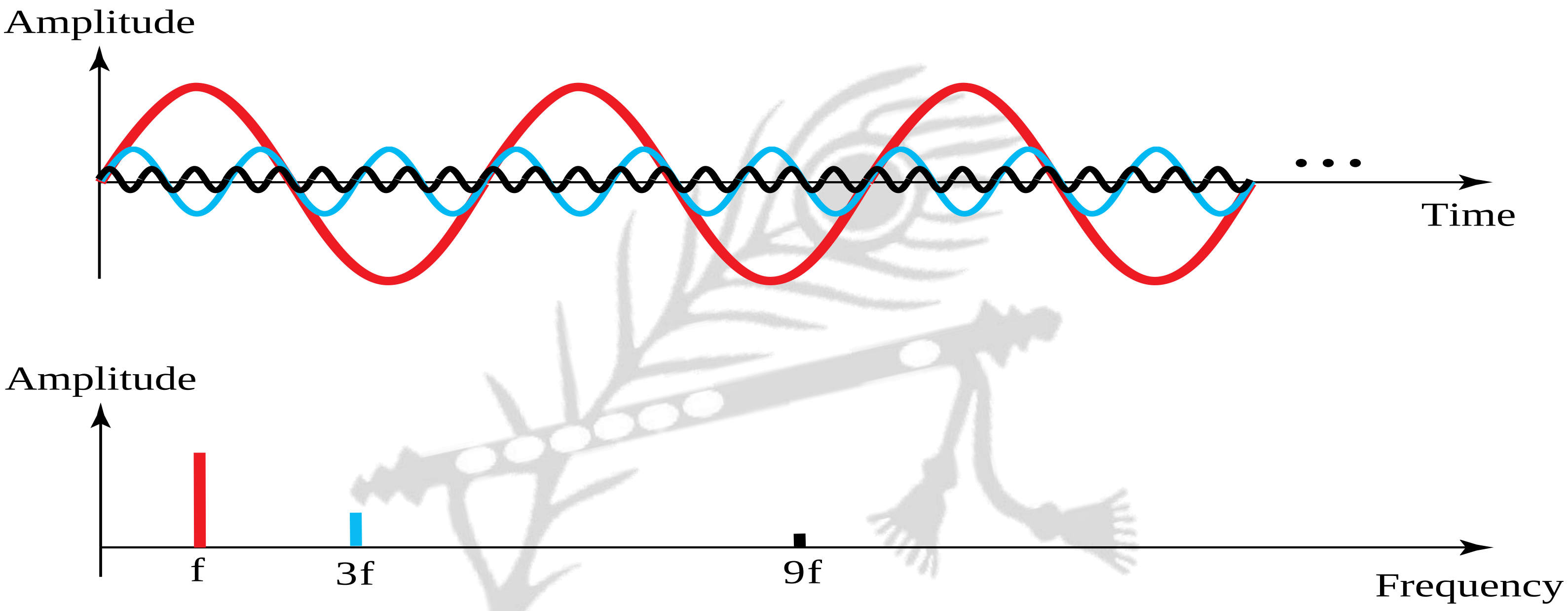
- If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies
- If the composite signal is non-periodic, the decomposition gives a combination of sine waves with continuous frequencies

Composite Period Signal

- A Composite Signal is collection of multiple single simple signals

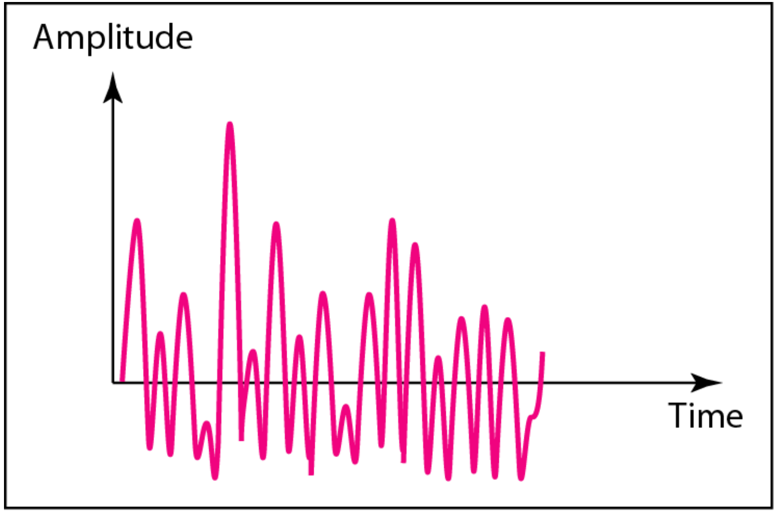


Decomposition of a composite periodic signal

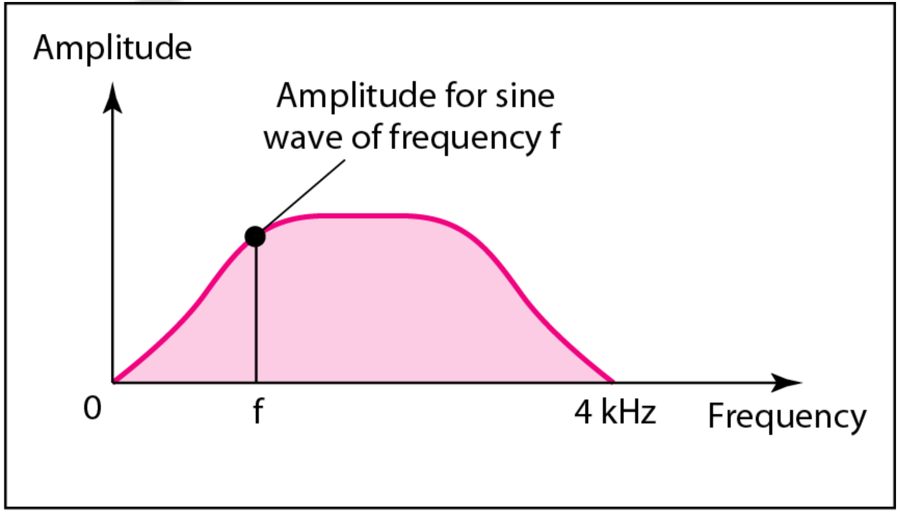


b. Frequency-domain decomposition of the composite signal

Decomposition of a composite non-periodic signal



a. Time domain

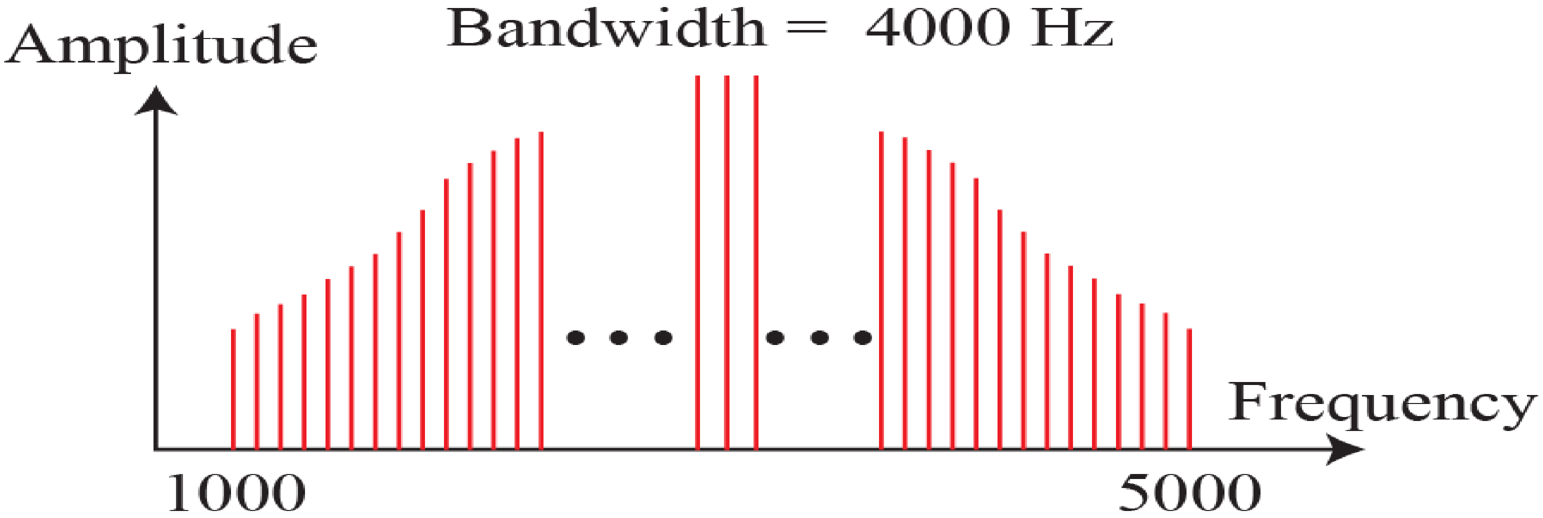


b. Frequency domain

Bandwidth

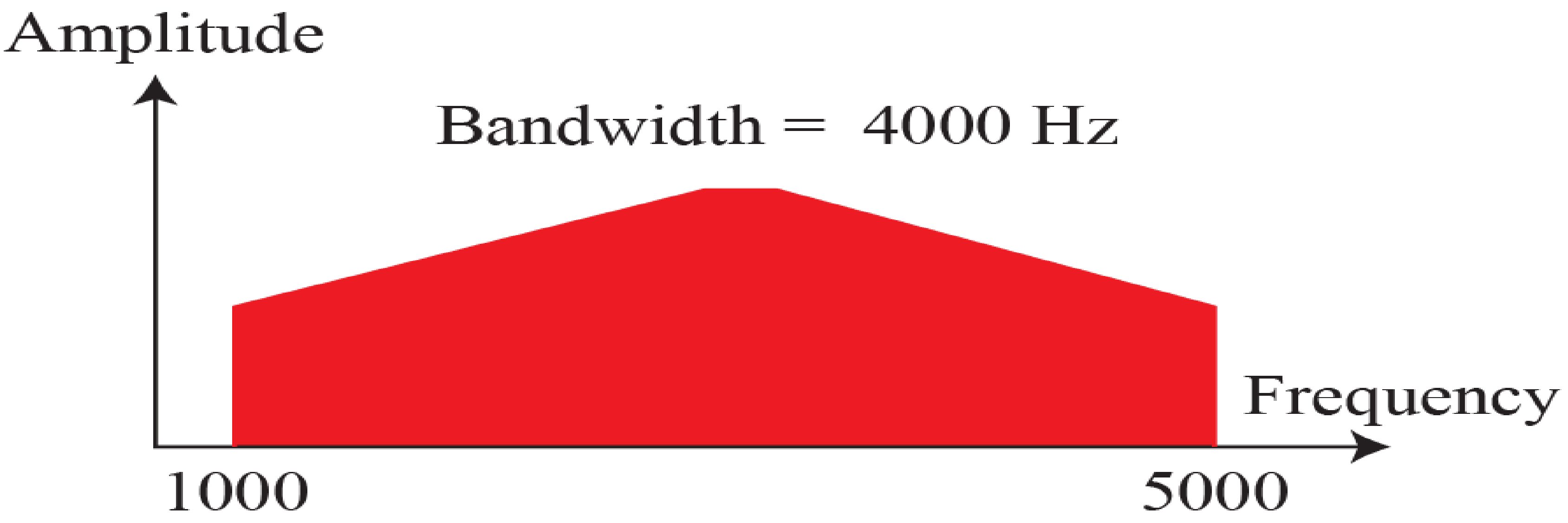
- The range of frequencies contained in a composite signal is its bandwidth
- The bandwidth is normally a difference between two numbers
- Eg:
  - if a composite signal contains frequencies between 1000 and 5000, its bandwidth is 5000 − 1000, or 4000

Bandwidth



a. Bandwidth of a periodic signal

Bandwidth



b. Bandwidth of a nonperiodic signal

- 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,

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

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,

$$B = f_h - f_l$$

$$20 = 60 - f_l$$

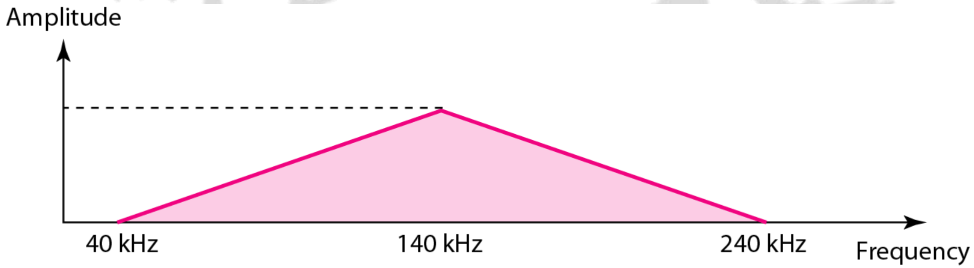
$$f_l = 40 \text{ Hz}$$

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



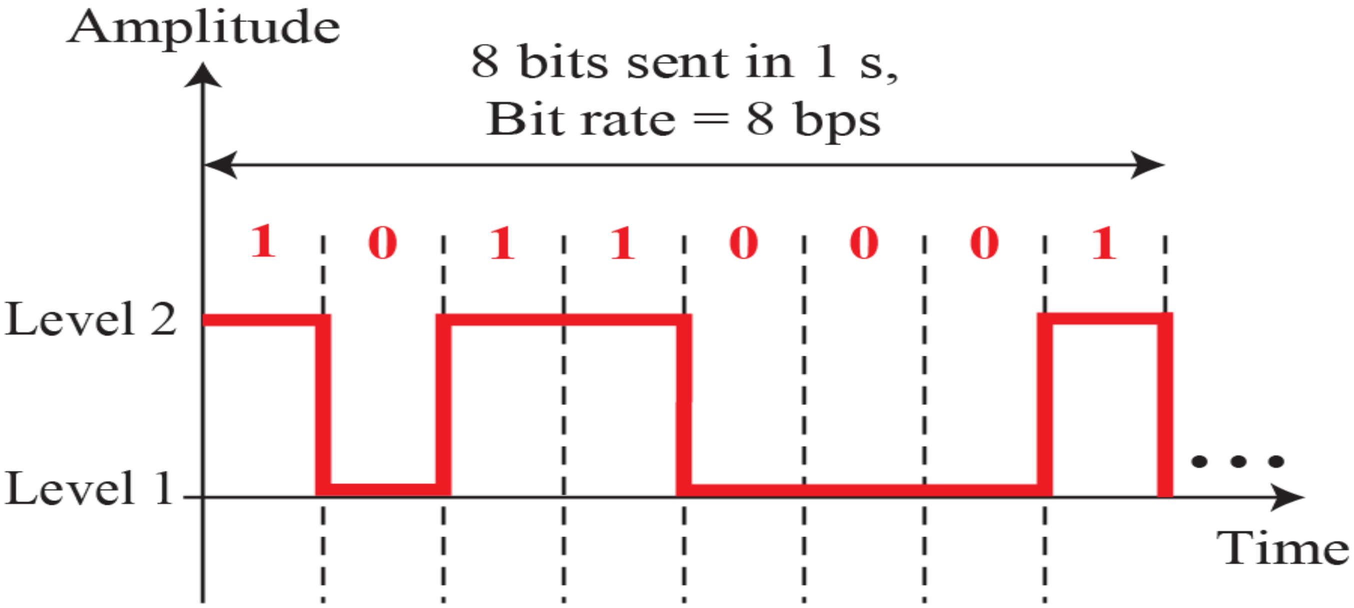
Fourier Analysis

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

Digital Signals

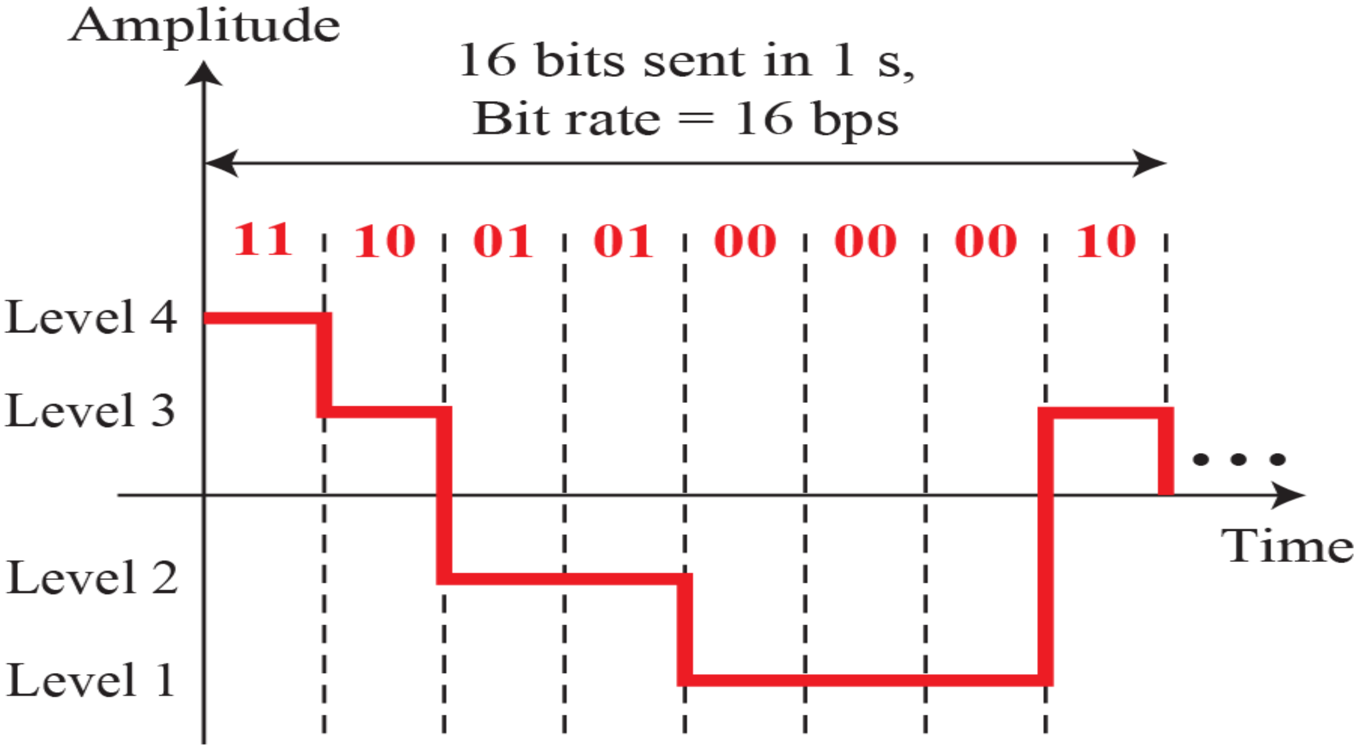
- In addition to being represented by an analog signal, information can also be represented by a digital signal
- Eg:
  - 1 can be encoded as a positive voltage and a 0 as zero voltage
- A digital signal can have more than two levels

Digital Signal



a. A digital signal with two levels

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

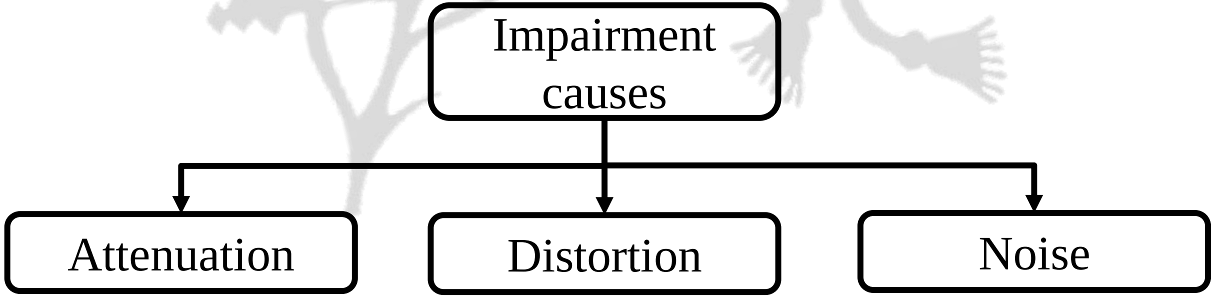
- Eg:
  - A digital signal has nine levels. How many bits are needed per level?

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

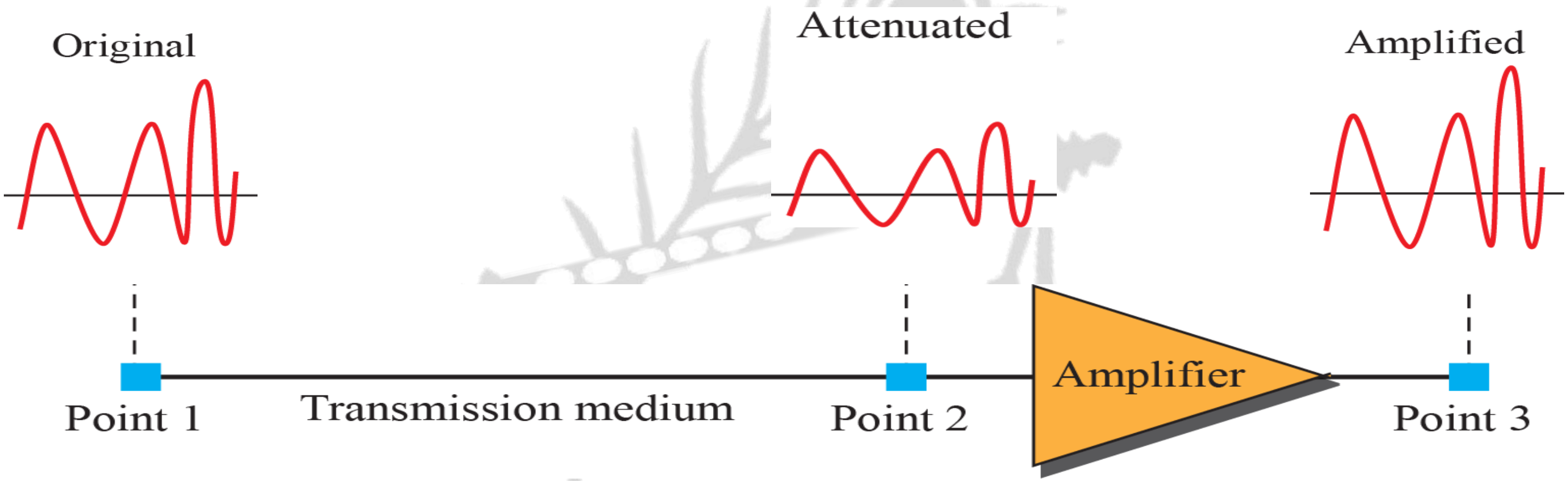
Attenuation

- 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



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

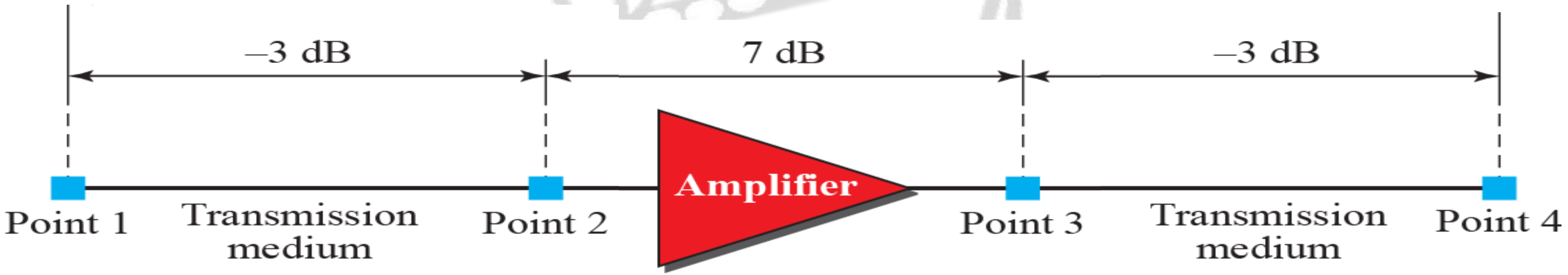
$$
\begin{aligned}
& 10 \log_{10} P_2/P_1 \\
&= 10 \log_{10} (10\, P_1/P_1) \\
&= 10 \log_{10} (10) \\
&= 10\ (1) \\
&= 10 \text{ dB}
\end{aligned}
$$

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 $dB_m = 10 \log10 P_m$, where P_m is the power in milliwatts. Calculate the power of a signal if its $dB_m = -30$

Solution

$$10 \log_{10} P_m = dB_m$$
$$10 \log_{10} P_m = -30$$
$$\log_{10} P_m = -3$$
$$P_m = 10^{-3}\, mW$$

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

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

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

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

$$P_2 = 0.7P_1$$

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

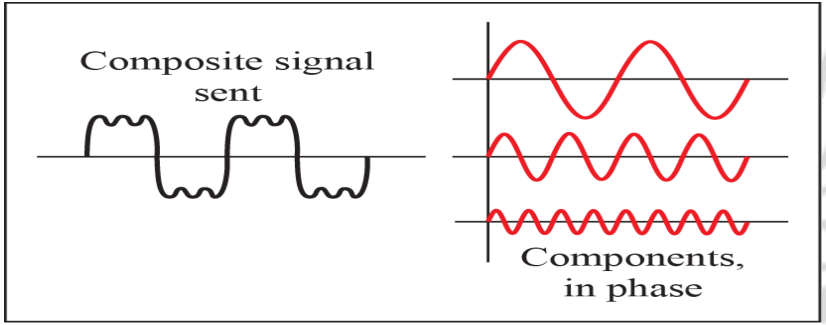
Impairment

Distortion

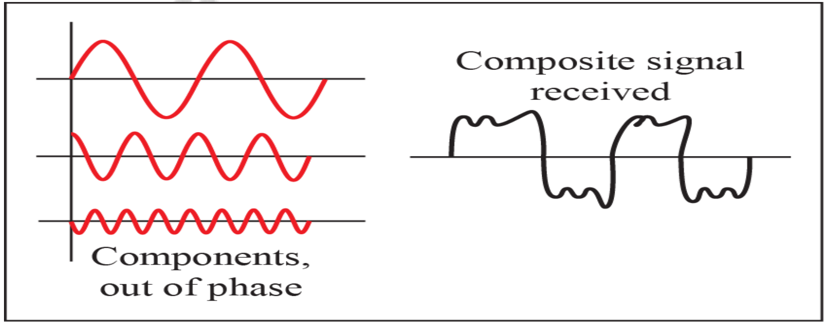
- Distortion means that the signal changes its form or shape
- Distortion can occur in a composite signal made of different frequencies
- Each signal component has its own propagation speed through a medium and, therefore, its own delay in arriving at the final destination
- Differences in delay may 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

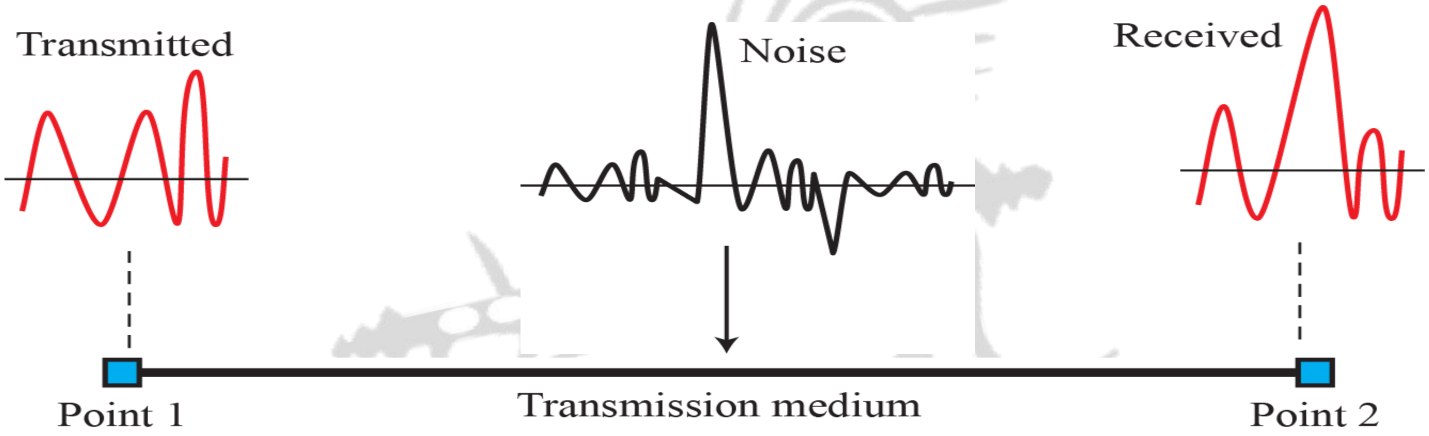
Impairment

Noise

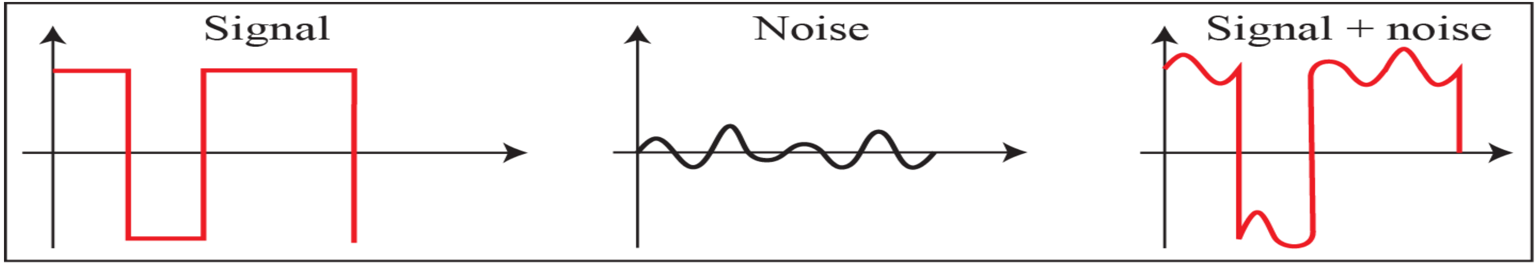
- Noise is another cause of impairment
- Several types of noise, such as thermal noise, induced noise, crosstalk, etc may corrupt the signal
  - Thermal noise is the random motion of electrons in a wire, which creates an extra signal not originally sent by the transmitter
  - Induced noise comes from 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

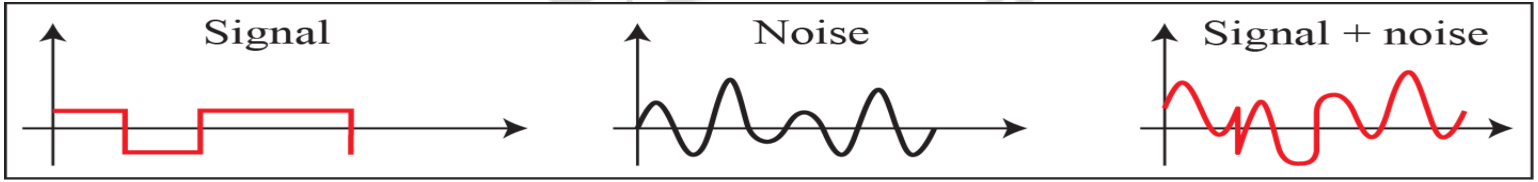
Noise



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



a. High SNR



b. Low SNR

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:

$$SNR = 10 * 10^{-3}/10^{-6}$$
$$= 10 * 10^{3}$$
$$= 10000 \text{ dB}$$
$$SNR_{dB} = 10 \log_{10}10000$$
$$= 10 \log_{10}10^{4}$$
$$= 40 \text{ dB}$$

SNR

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

Solution

$$SNR = (\text{signal power})/0$$
$$= \infty$$

$$SNR_{dB} = 10 \log_{10} \infty$$
$$= \infty$$

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

$$Bit\ rate = 2 * BW * log_2 L$$

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

$$\text{Bit rate} = 2 * 3000 * \log_2 2$$
$$= 6000 \text{ bps}$$

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

$$\text{Bit rate} = 2 * 3000 * \log_2 4$$
$$= 12000 \text{ bps}$$

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

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

- 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 $SNR_{dB} = 36$ and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as

Solution

$$SNR_{dB} = 10 \log_{10} SNR$$
$$36 = 10 \log_{10} SNR$$
$$SNR = 10^{3.6}$$
$$SNR = 3981$$

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

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

$$Latency = P_d + T_t + Q_t + P_t$$

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

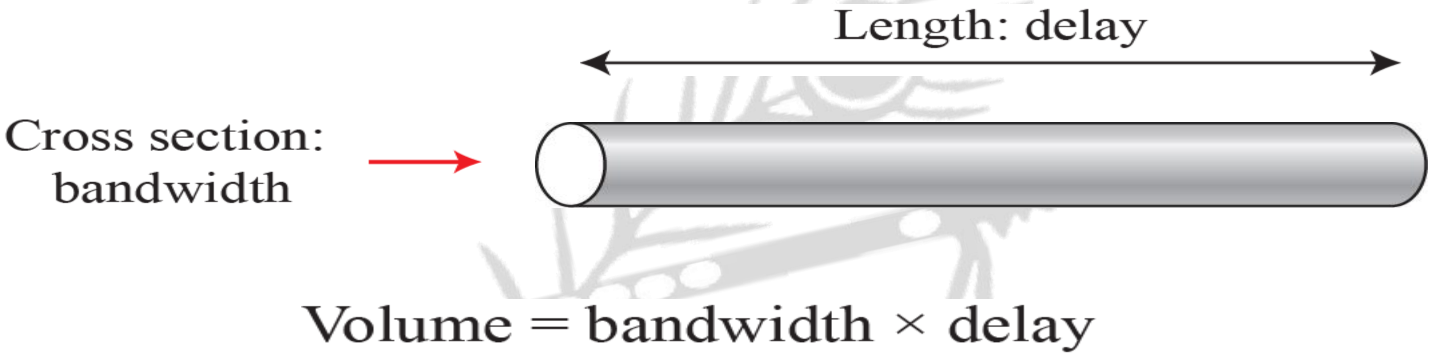
- The throughput is a measure of how fast we can actually send data through a network

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

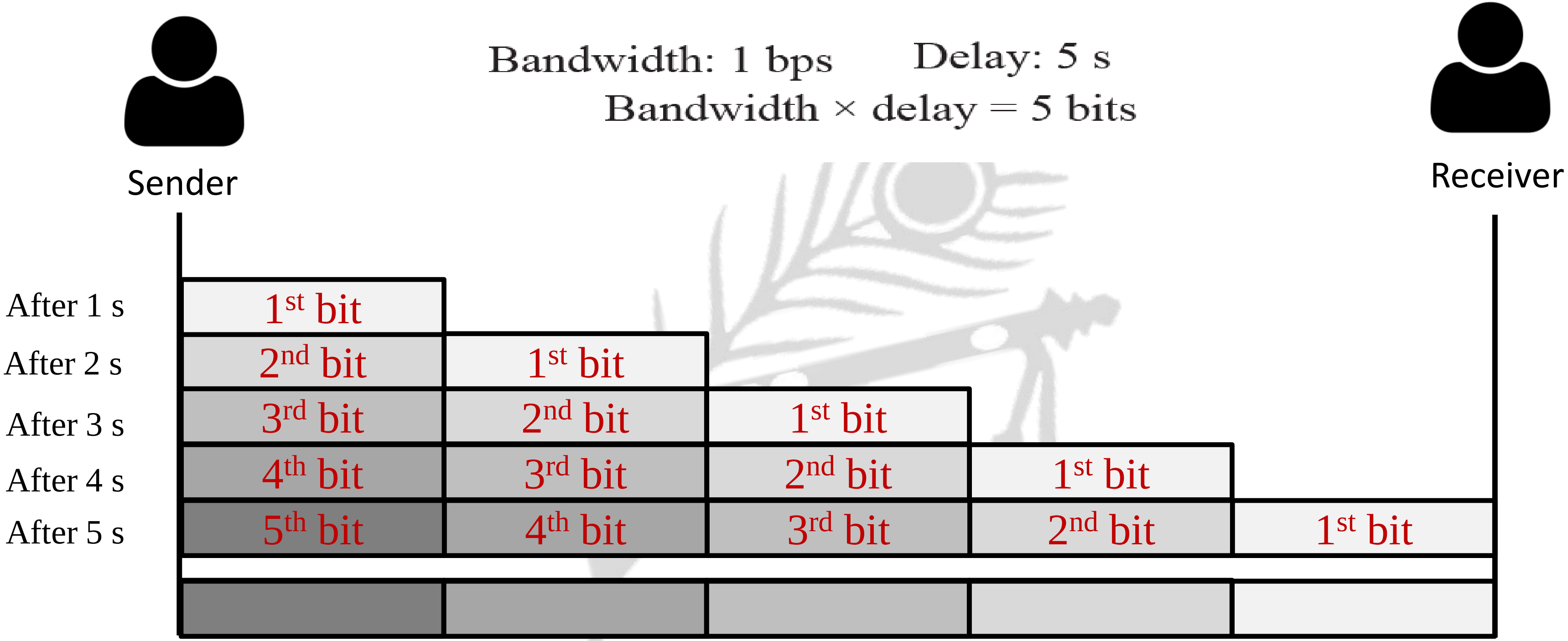
- Bandwidth and delay are two performance metrics of a link



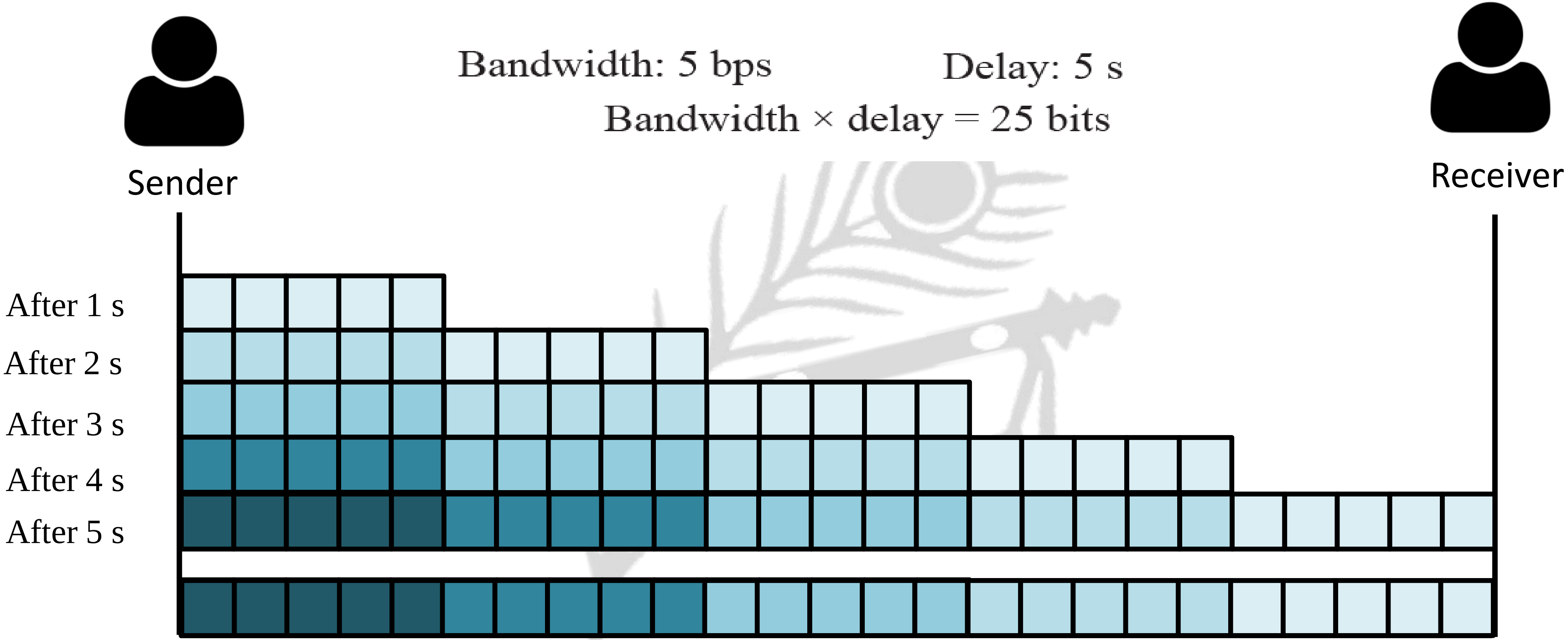
Bandwidth-Delay

Bandwidth: 1 bps Delay: 5 s

$$\text{Bandwidth} \times \text{delay} = 5 \text{ bits}$$



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

$$\text{Propagation Time} = (12000 * 1000)/(2.4 * 10^8)$$
$$= 0.05 \text{ s}$$
$$= 50 \text{ ms}$$
$$\text{Transmission Time} = (2.5 * 10^3 * 8)/(10^9)$$
$$= 20000/10^9$$
$$= 0.00002 \text{ s} = 0.02 \text{ ms}$$

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

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

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

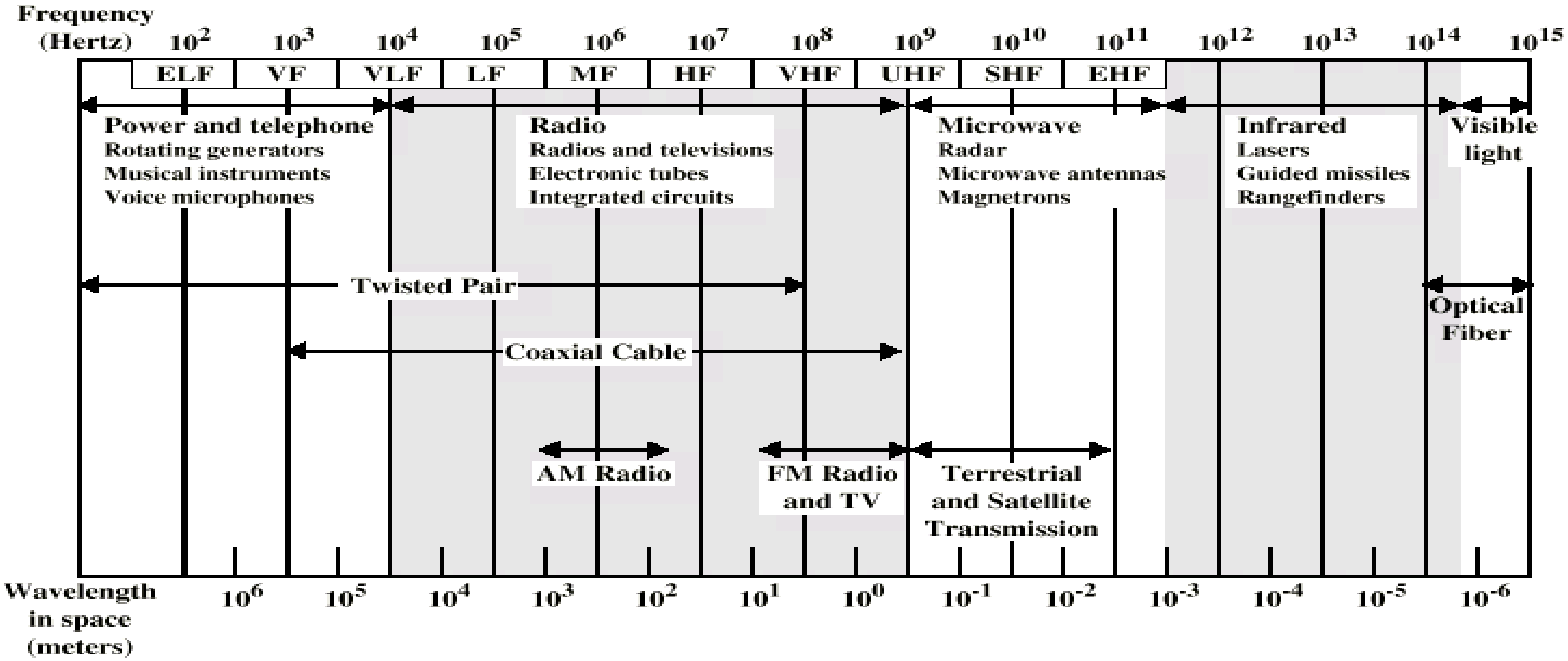
Media

- 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

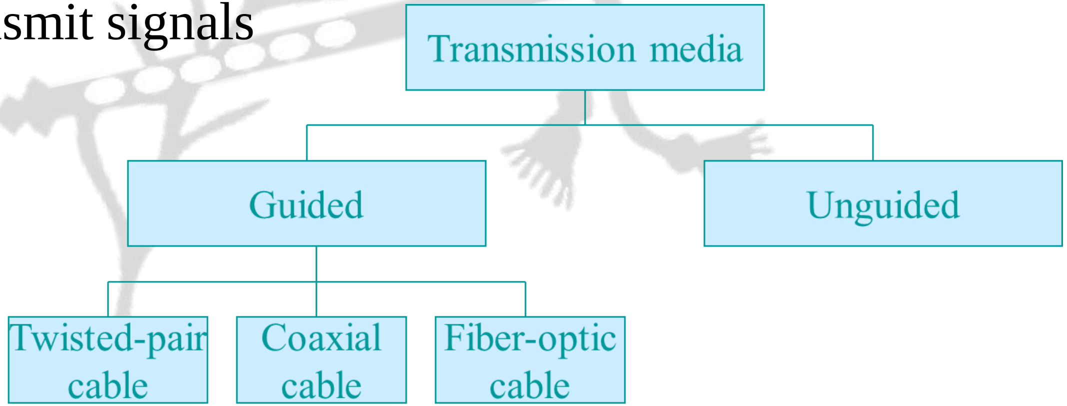
- Attenuation
- Delay Distortion
- Noise
  - Thermal/White Noise
  - Intermodulation Noise
  - Crosstalk
  - Echo
  - Impulse Noise

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

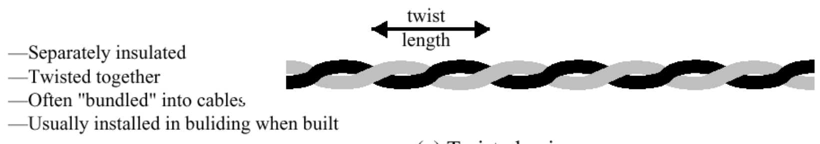
- Wire types: *single conductor*, *twisted pair*, & *shielded multiconductor bundles*
- Large installed base
- Reasonable cost
- Relatively low bandwidth, however, recent LAN speeds in the 100 Mbps range have been achieved
- Susceptible to external interference
- Shielding can reduce external interference
- 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



(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

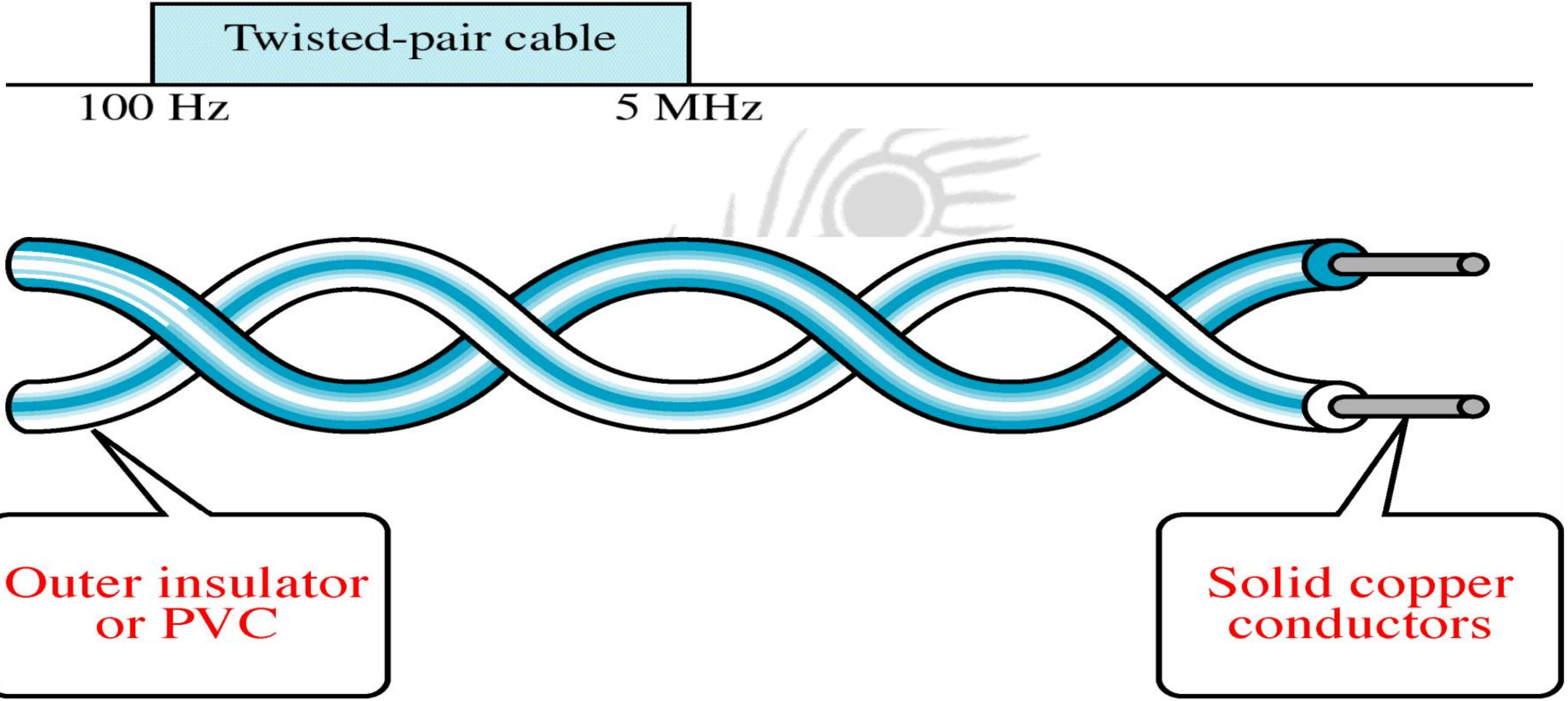
Ratings of Twisted Pair

- 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

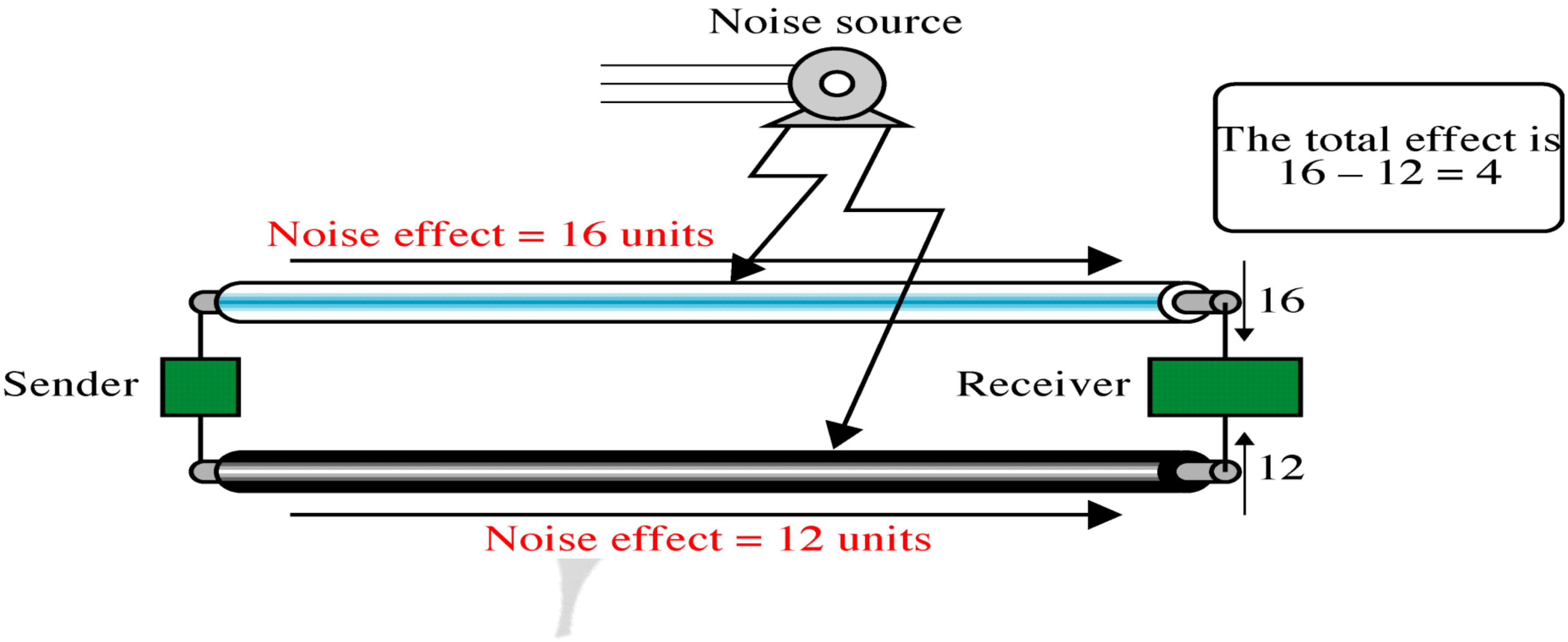
Twisted Pair Advantages

- 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)

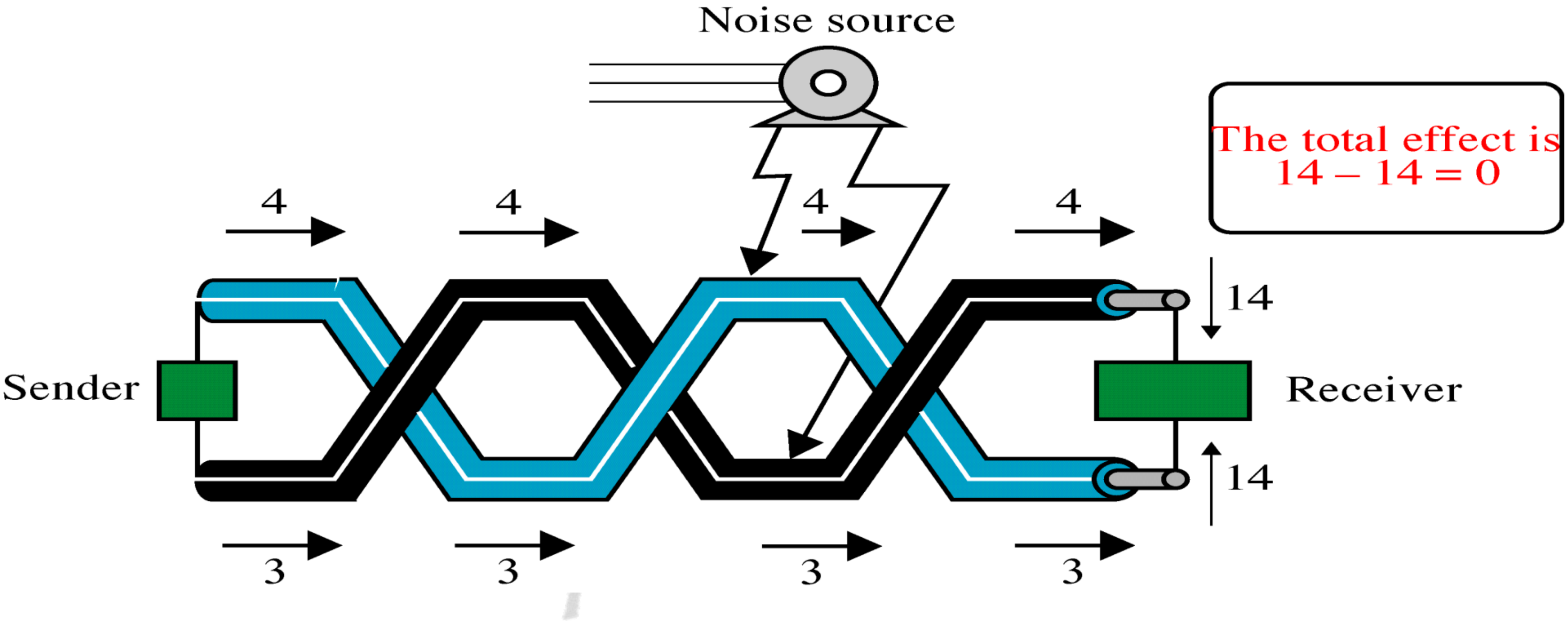
Twisted-Pair Cable



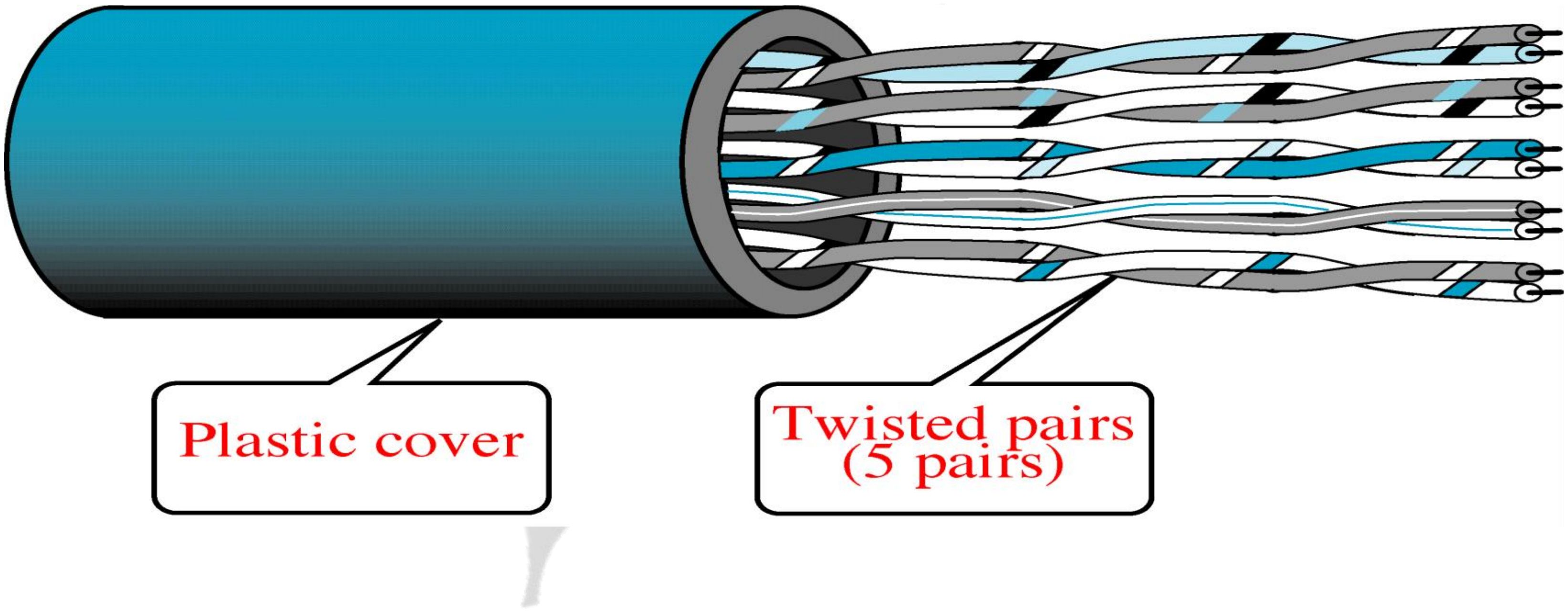
Effect of Noise on Parallel Lines



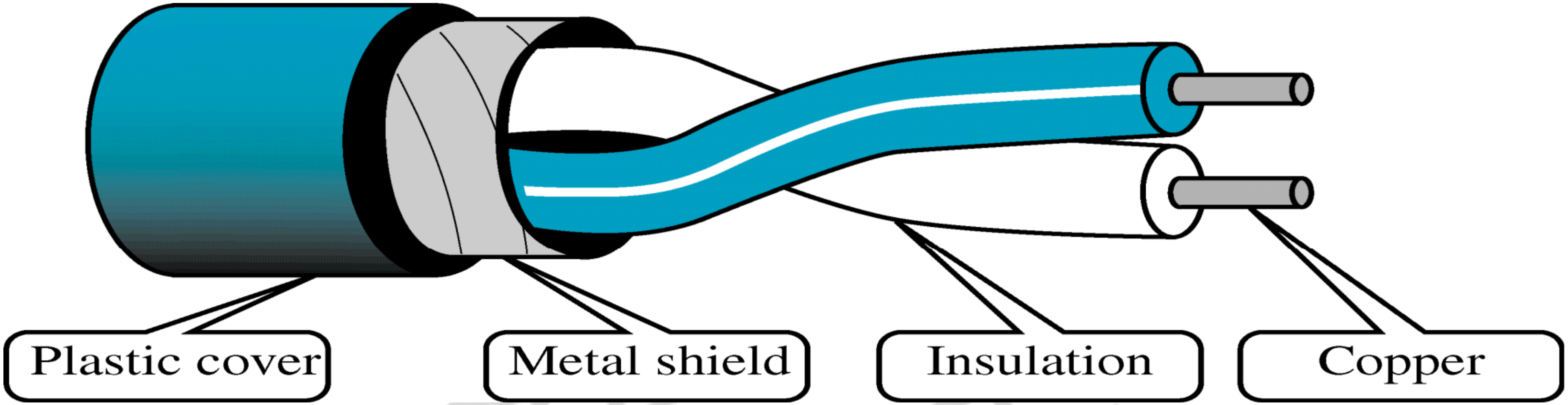
Noise on Twisted-Pair Lines



Unshielded Twisted-Pair Cable



Shielded Twisted-Pair Cable

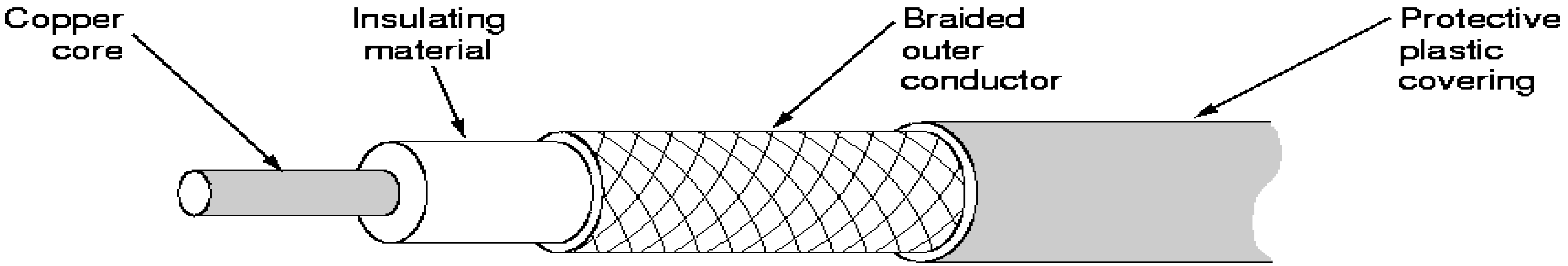


Wired Transmission Media

- 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

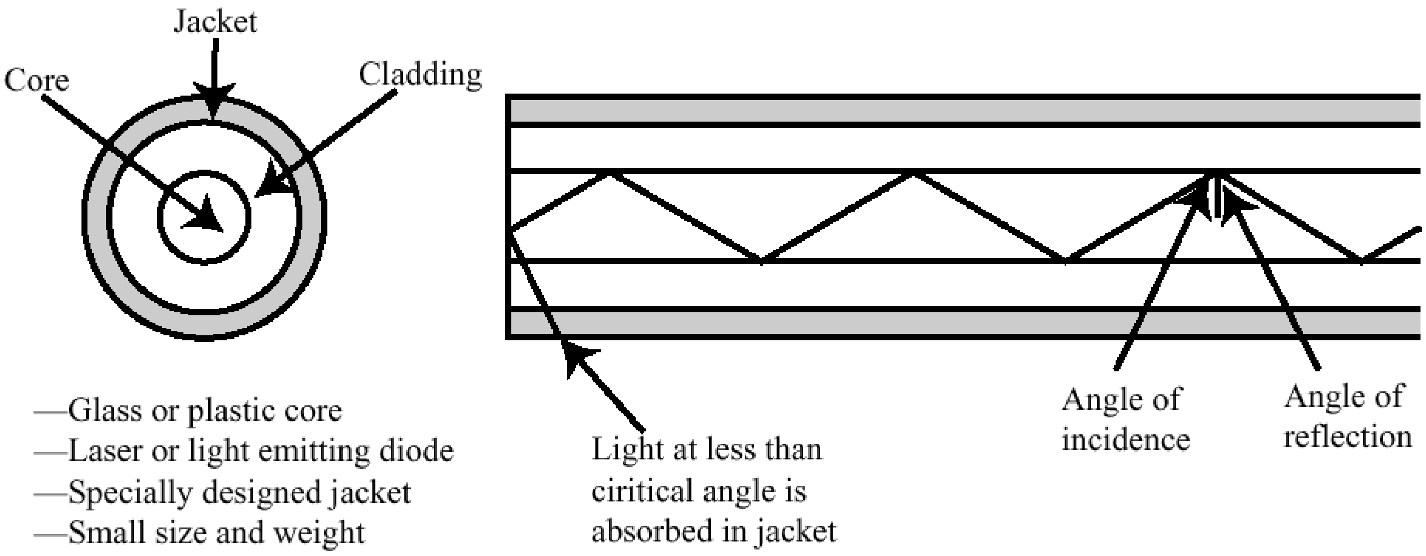
- Better shielding allows for longer cables and higher transfer rates.
- 100 m cables
  - 1 to 2 Gbps feasible (modulation used)
  - 10 Mbps typical
- Higher bandwidth
  - 400 to 600Mhz
  - up to 10,800 voice conversations
- Can be tapped easily: stations easily added (pros and cons)
- Much less susceptible 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 ≥ 2 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

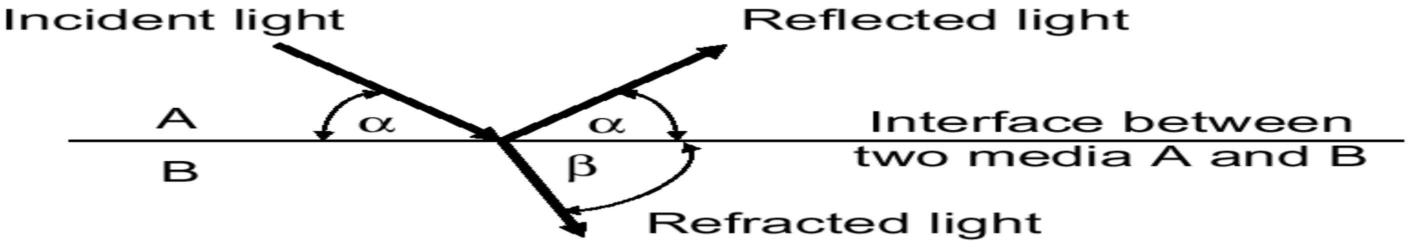
- Need optical-electrical interface (more expensive than electrical interface)



(c) Optical Fiber

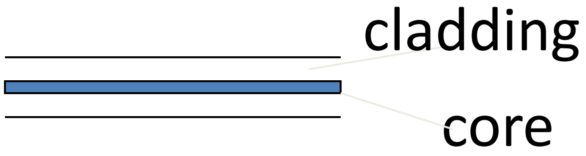
Wired Transmission Media

- Principle of optical fiber transmission: Based on the principle of total internal reflection
- If β>α, medium B (water) has a higher optical density than medium A (air)
- In case the index of refraction<1 (α>β), 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



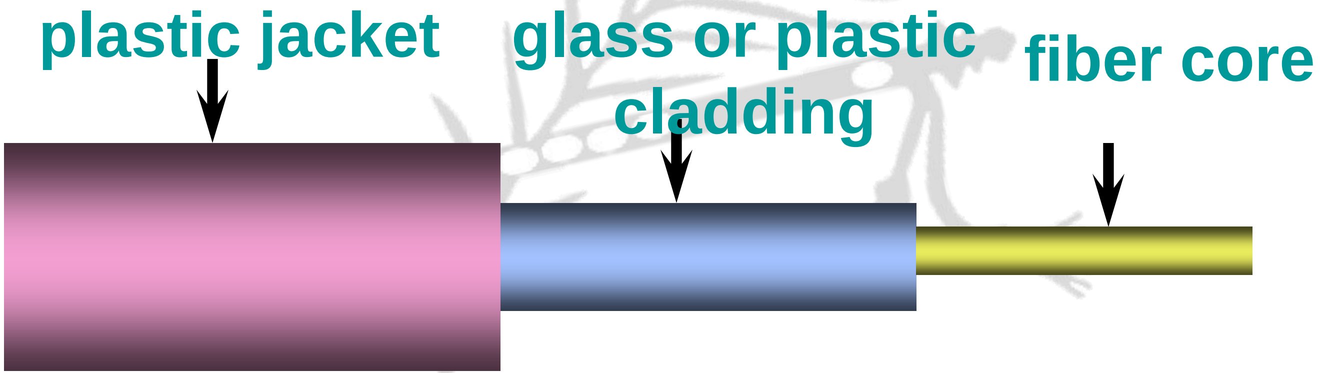
Fiber optics & Physics 101

- 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 wavelenth.

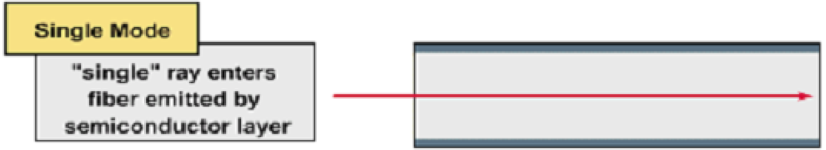
- Mode
  - Multimode
    - Step index
    - Graded-index
  - Single mode

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

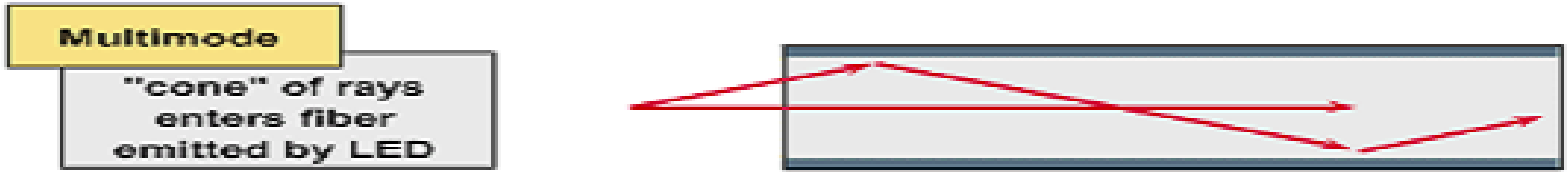
Types of optical fiber

- 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

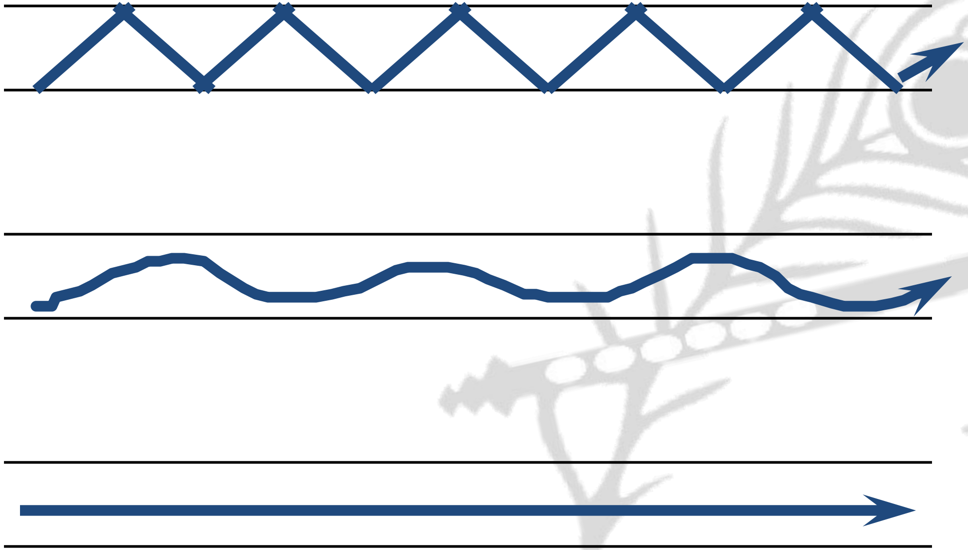


Types of optical fiber

- 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



Fiber Optic Signals

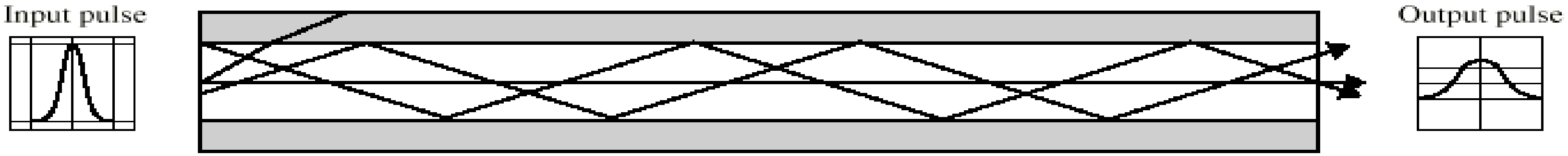


fiber optic multimode
step-index

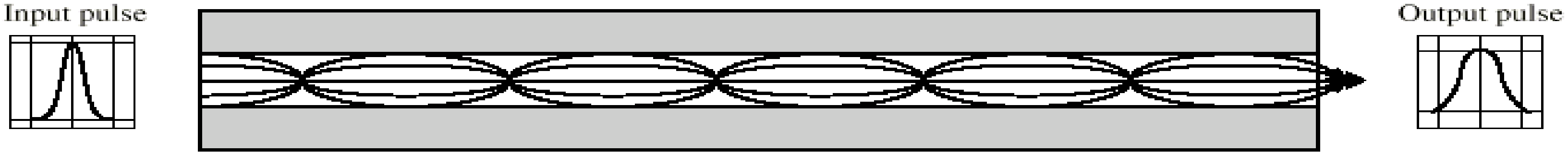
fiber optic multimode
graded-index

fiber optic single mode

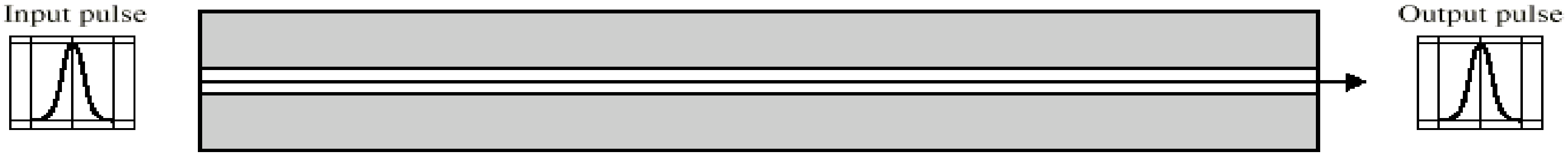
Optical Fiber Transmission Mode



(a) Step-index multimode



(b) Graded-index multimode



(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

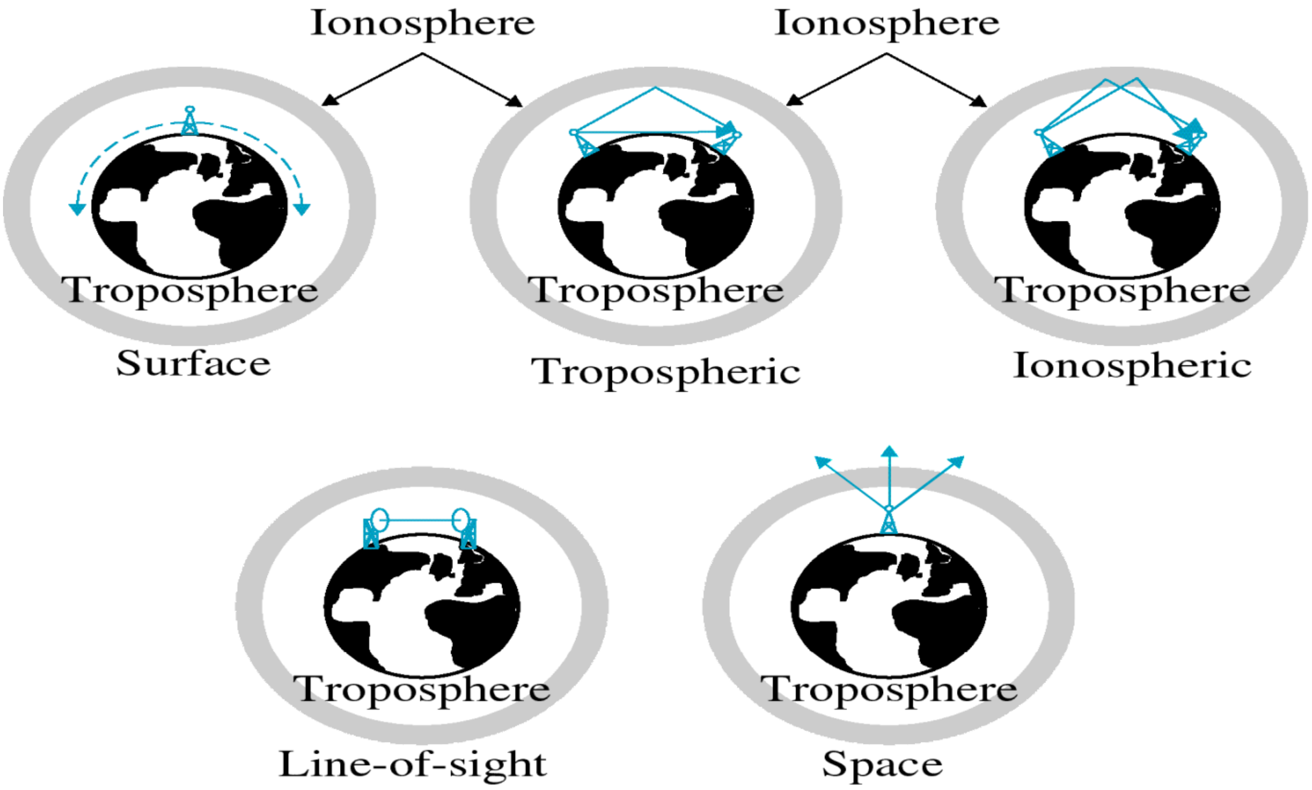
Infrared

- 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/r3 in air).
  - High frequencies
    - Travel in straight lines and bounce off obstacles.
    - Absorbed by rain.
  - Subject to electrical interference

Propagation Types



LINE CODING

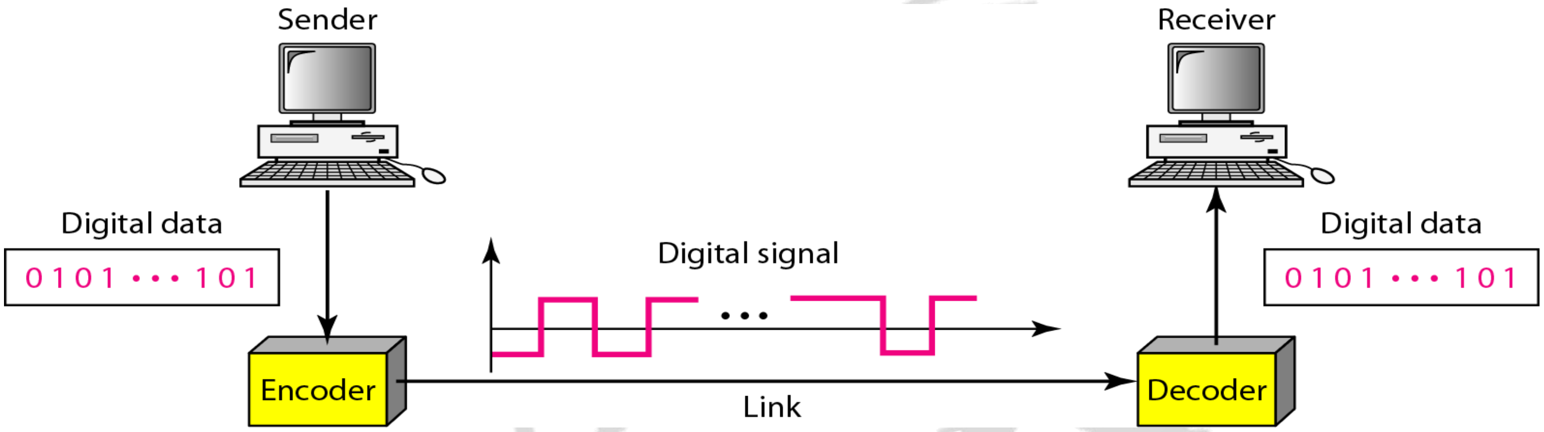
Digital-to-digital conversion

- 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

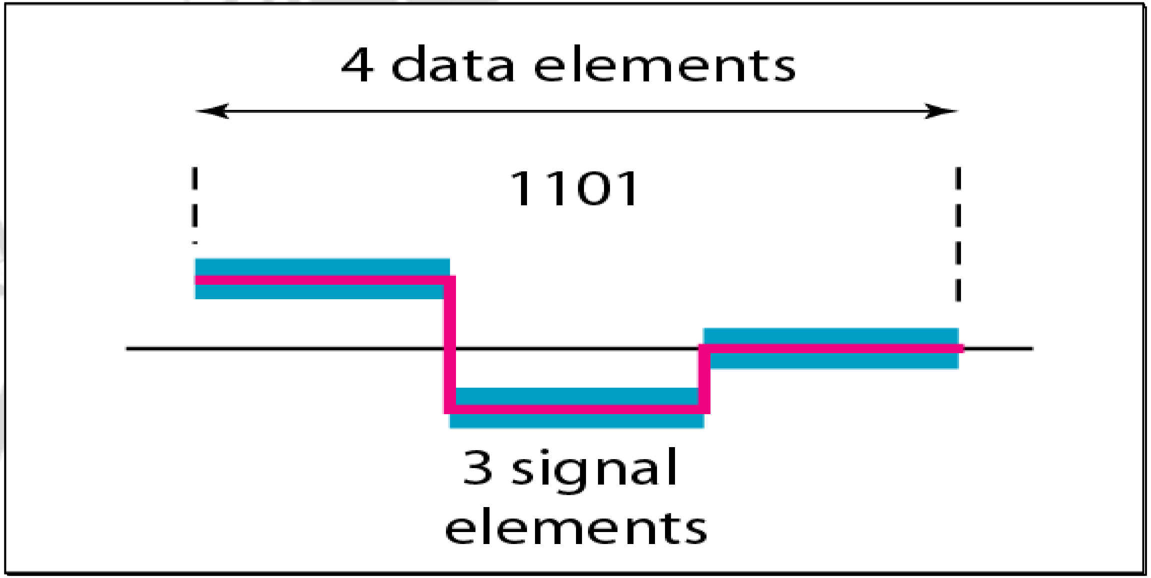
Data

- 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

$$S = c * N * 1/r$$
$$= \tfrac{1}{2} * 100000 * 1$$
$$= 50000$$
$$= 50k \text{ baud}$$

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

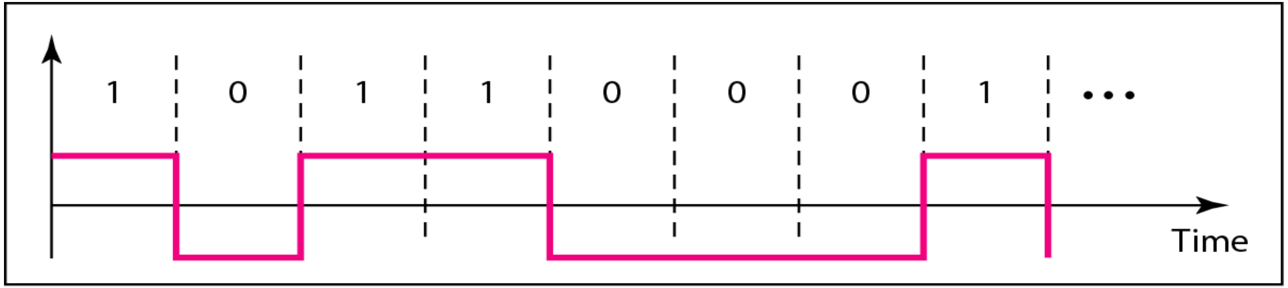
Line Coding

- 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

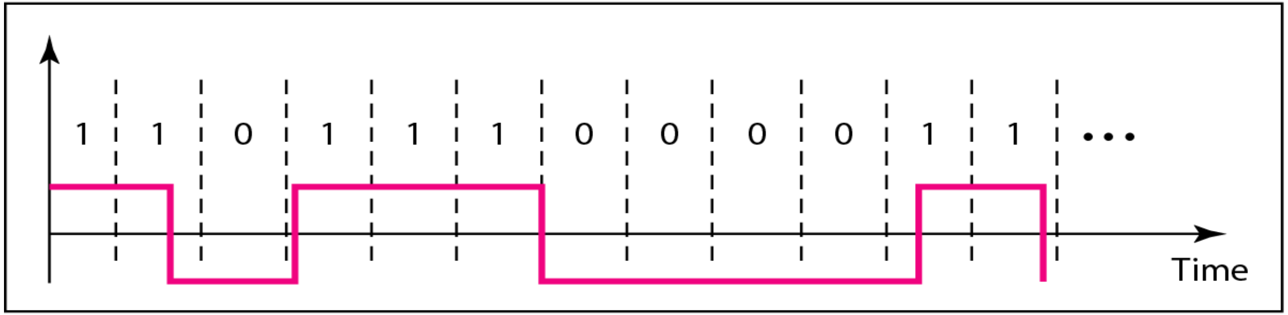
Characteristics of Line Coding techniques

- 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

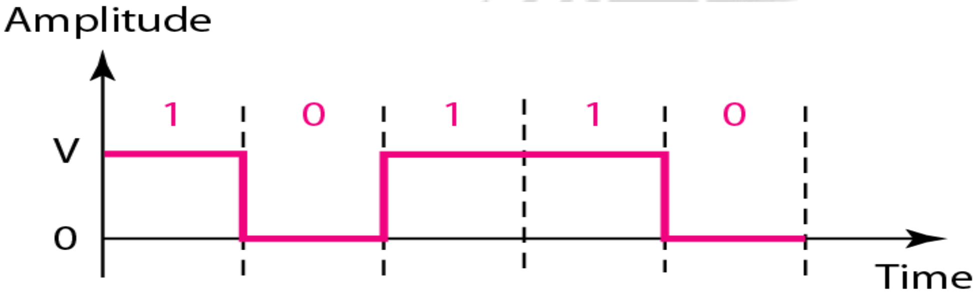
- At 1 kbps, the receiver receives 1001 bps instead of 1000 bps
- At 1 Mbps, the receiver receives 1,001,000 bps instead of 1,000,000 bps

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

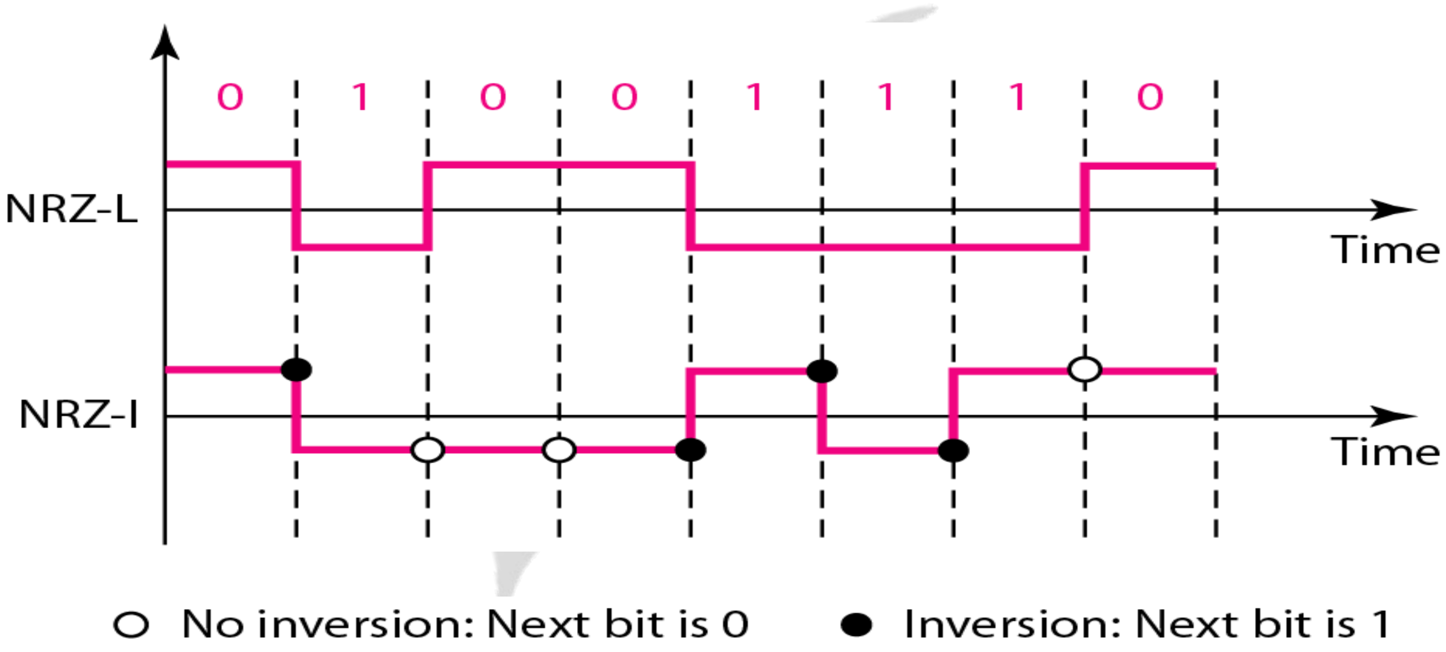


- NOTE: data element ‘1’ is on negative side of axis and data element ‘0’ is on the axis can also be assumed

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

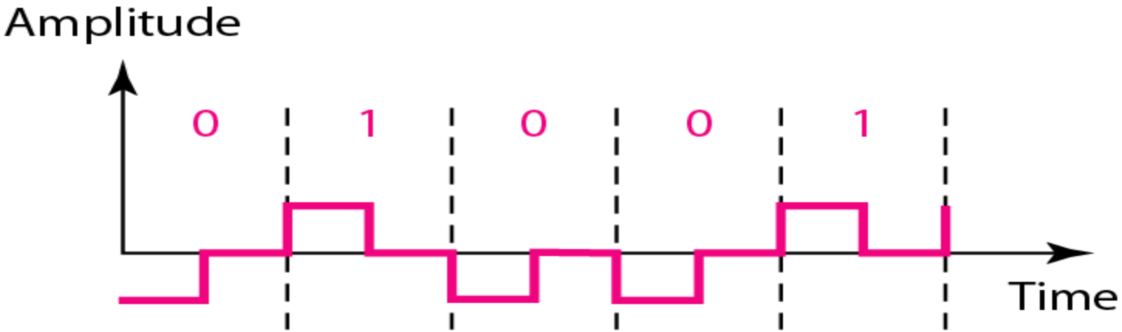
- In NRZ-L the level of the voltage determines the value of the bit
- In NRZ-I the inversion or the lack of inversion determines the value of the bit

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

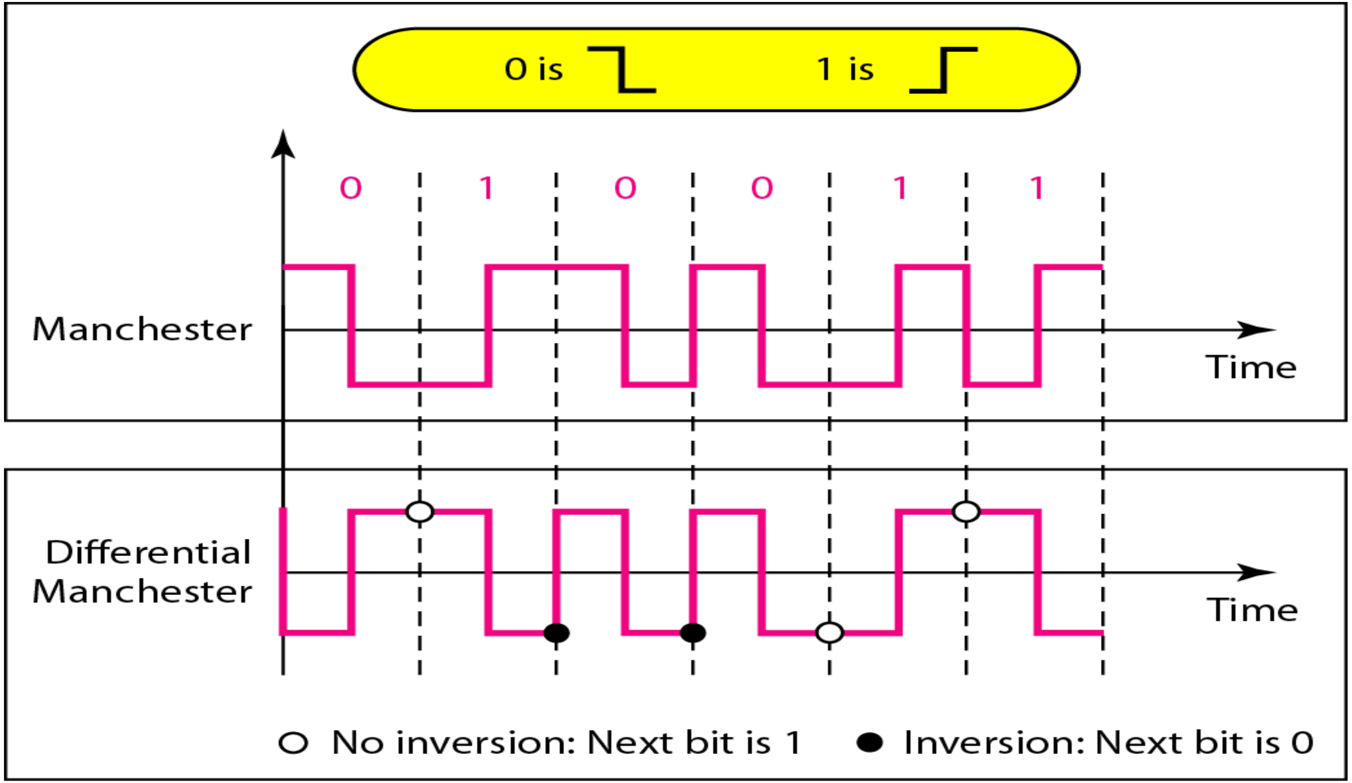
- One bit duration, signal is returning to zero axis during the bit i.e., at the middle of the signal element transmission and not at the edge of the interval



Polar Biphase

- 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 Biphase



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

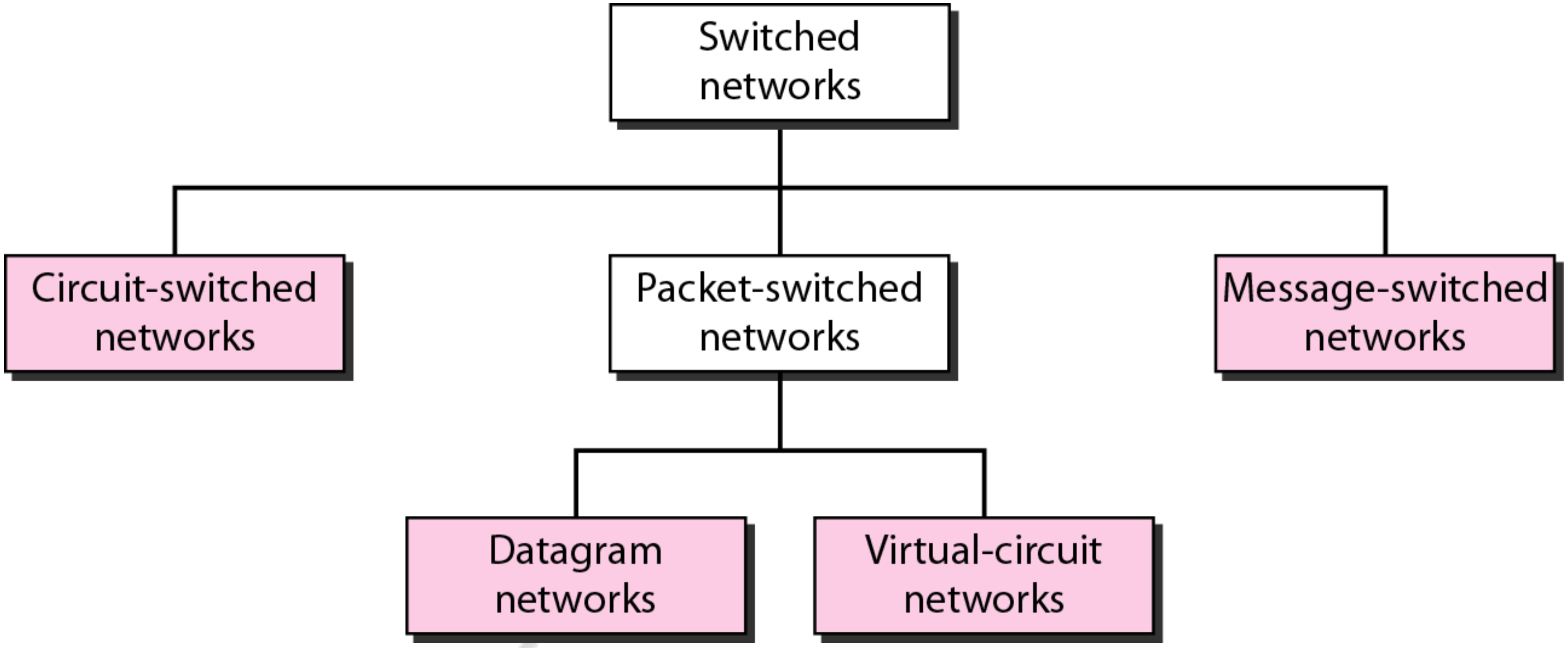
Switching Technique

- 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:

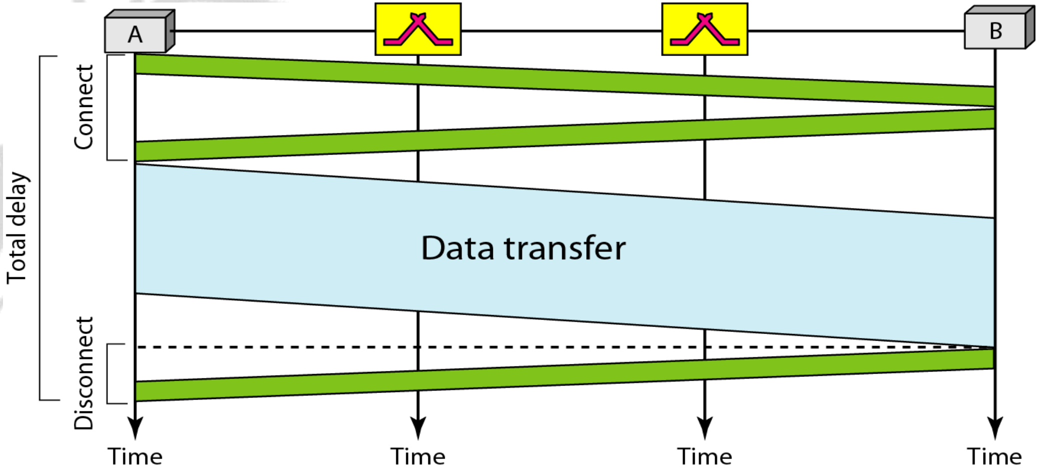
- The communication channel (once established) is dedicated

Disadvantages:

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

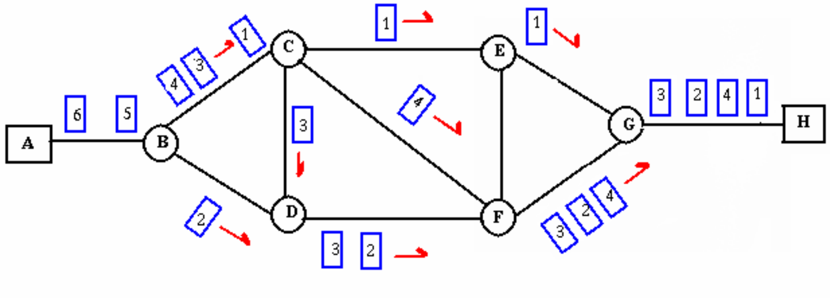
Delay in a circuit-switched network

- 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

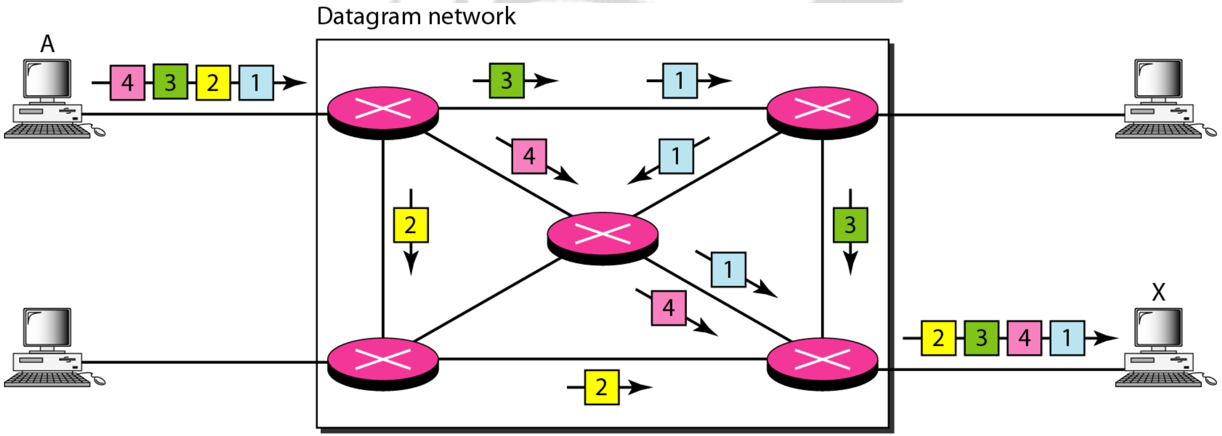
- Advantages
  - Delay in delivery of packets is less
  - Switching devices don’t require massive storage
  - Data delivery can continue even if some parts of the network fails
  - It allows simultaneous usage of the same channel by multiple users
  - It ensures better bandwidth usage

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

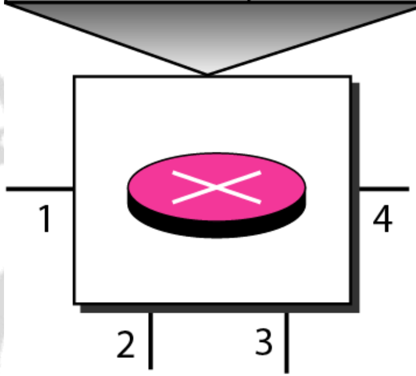


Packet Switching

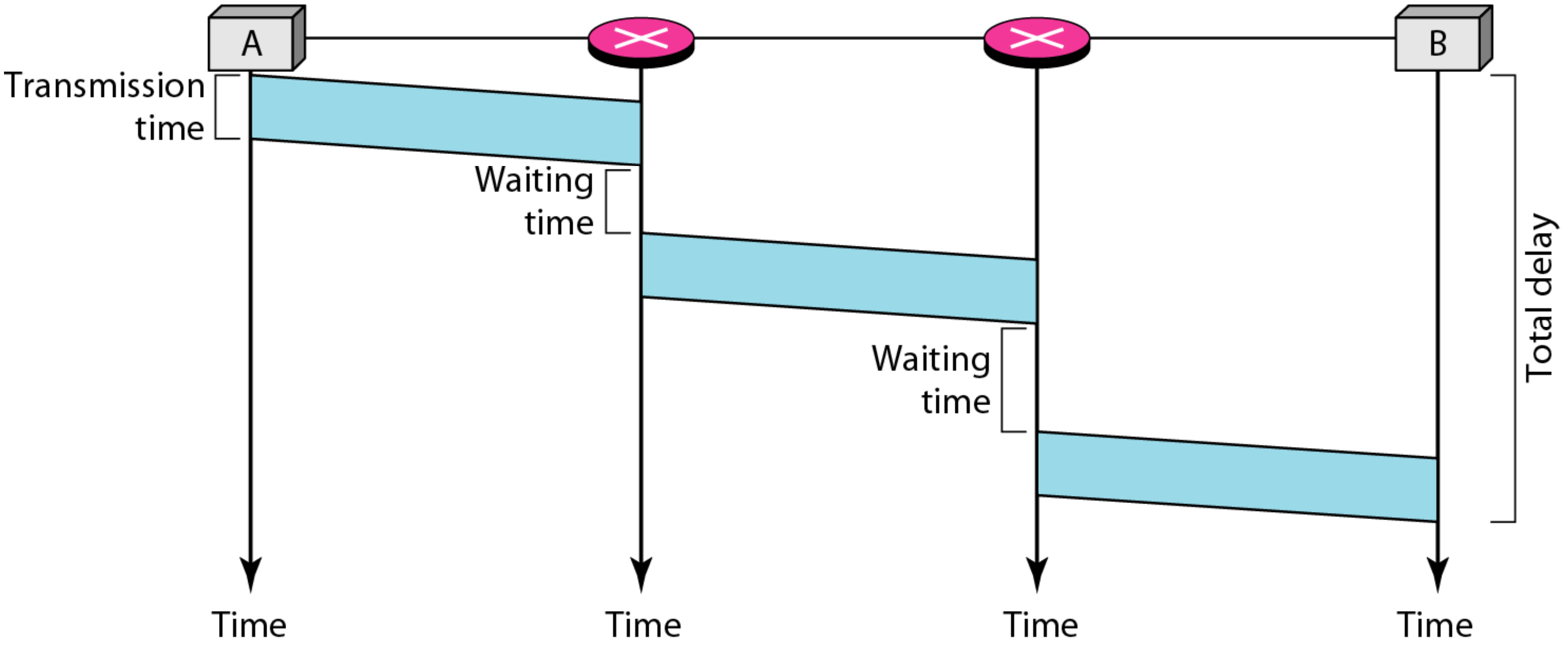
- In a packet-switched network, there is no resource reservation; resources are allocated on demand
- A switch in a datagram network uses a routing table that is based on the destination address
- The destination address in the header of a packet in a datagram network remains the same during the entire 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 x 10^8 m, find the order of arrival at the destination and the delay for each. Ignore any other delays in transmision.

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:

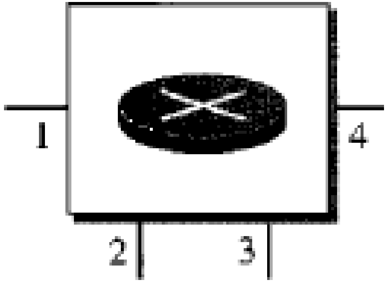
First:	$(3200\ \text{Km}) / (2 \times 10^8\ \text{m/s})$	$+ (3 + 20 + 20)$	$=$	**59.0 ms**
Second:	$(11700\ \text{Km}) / (2 \times 10^8\ \text{m/s})$	$+ (3 + 10 + 20)$	$=$	**91.5 ms**
Third:	$(12200\ \text{Km}) / (2 \times 10^8\ \text{m/s})$	$+ (3 + 10 + 20 + 20)$	$=$	**114.0 ms**
Fourth:	$(10200\ \text{Km}) / (2 \times 10^8\ \text{m/s})$	$+ (3 + 7 + 20)$	$=$	**81.0 ms**
Fifth:	$(10700\ \text{Km}) / (2 \times 10^8\ \text{m/s})$	$+ (3 + 7 + 20 + 20)$	$=$	**103.5 ms**

The order of arrival is: $\mathbf{3} \rightarrow \mathbf{5} \rightarrow \mathbf{2} \rightarrow \mathbf{4} \rightarrow \mathbf{1}$

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

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

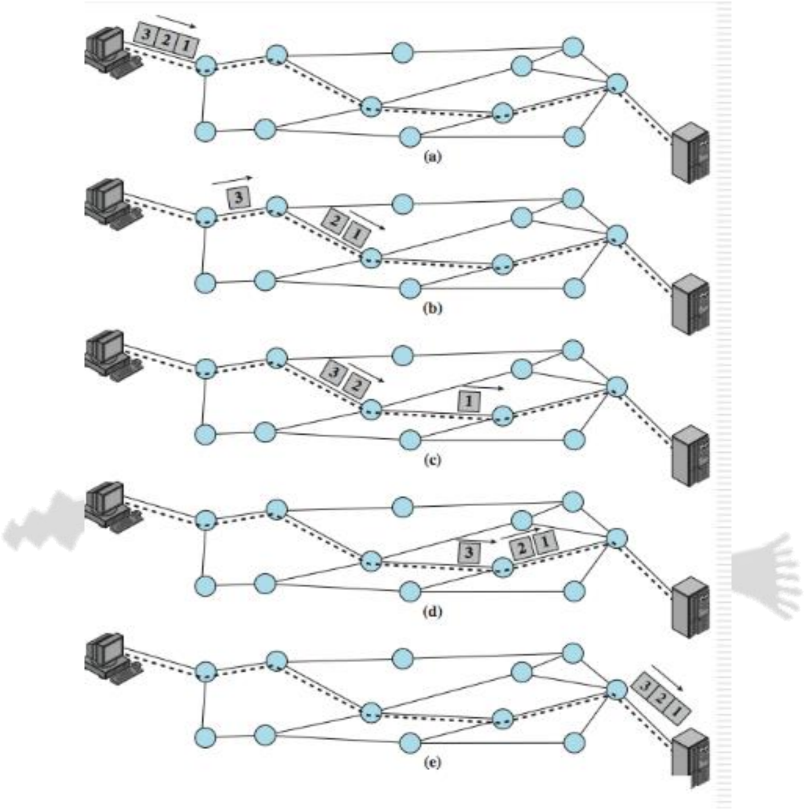


Packet 1: 2
Packet 2: 3
Packet 3: 3
Packet 4: 2

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

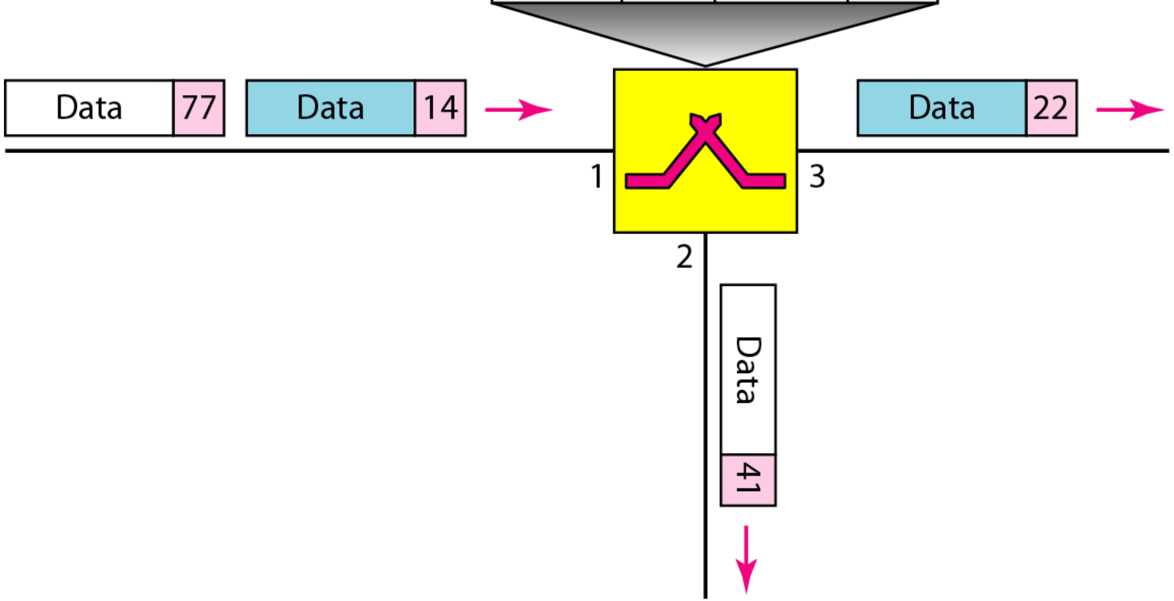


Virtual circuit switched networks

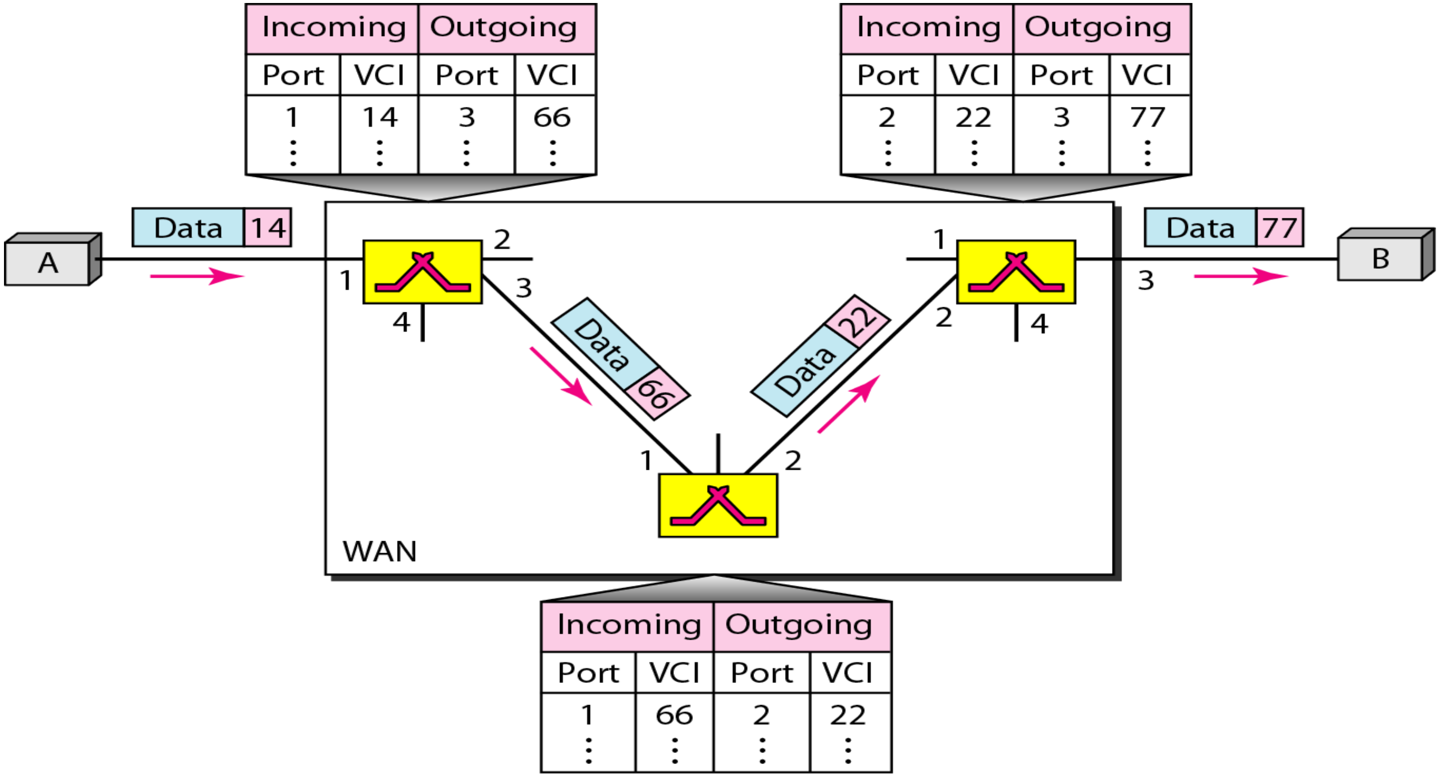
- How it is implemented ?
  - Addressing:
    - In a virtual-circuit network, two types of addressing are involved: global and local (virtual-circuit identifier)
  - Global Addressing:
    - A source or a destination IP address is considered to be global address
  - Virtual-Circuit Identifier:
    - 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

Incoming		Outgoing	
Port	VCI	Port	VCI
1	14	3	22
1	77	2	41



Data transfer in a virtual-circuit network



Virtual circuit switched networks

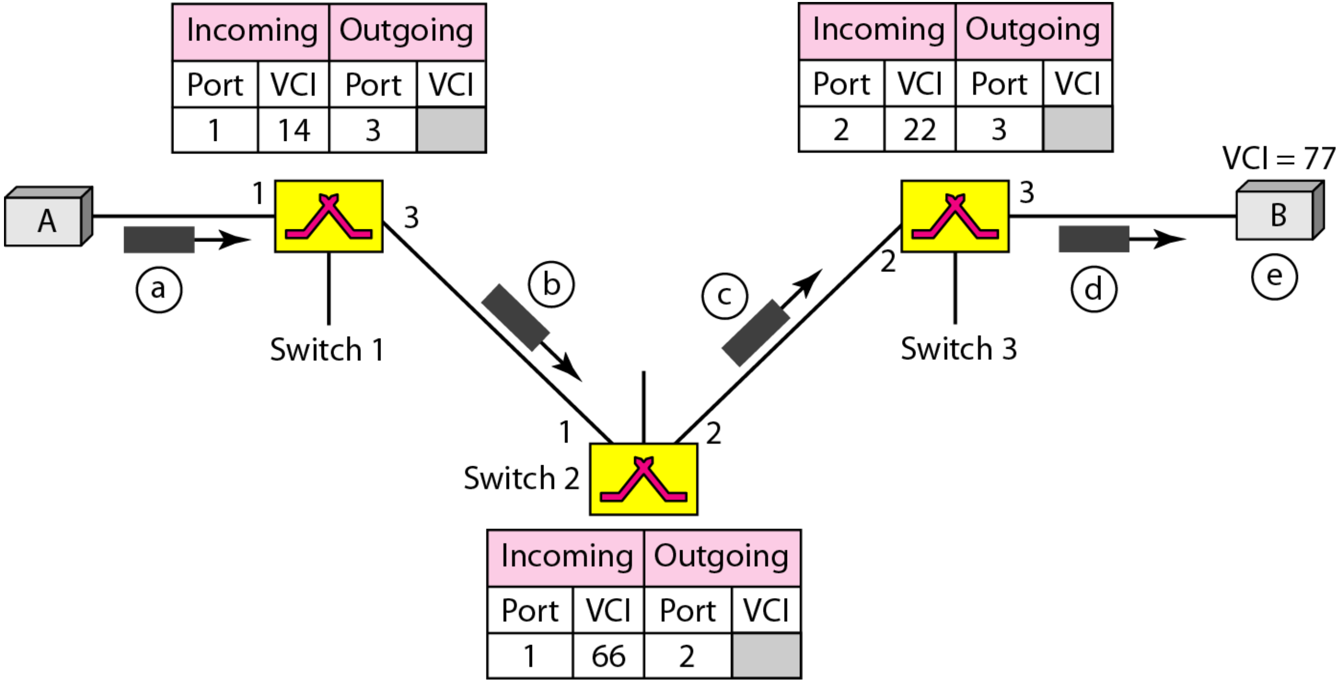
How Virtual Circuit is Established ?

- 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

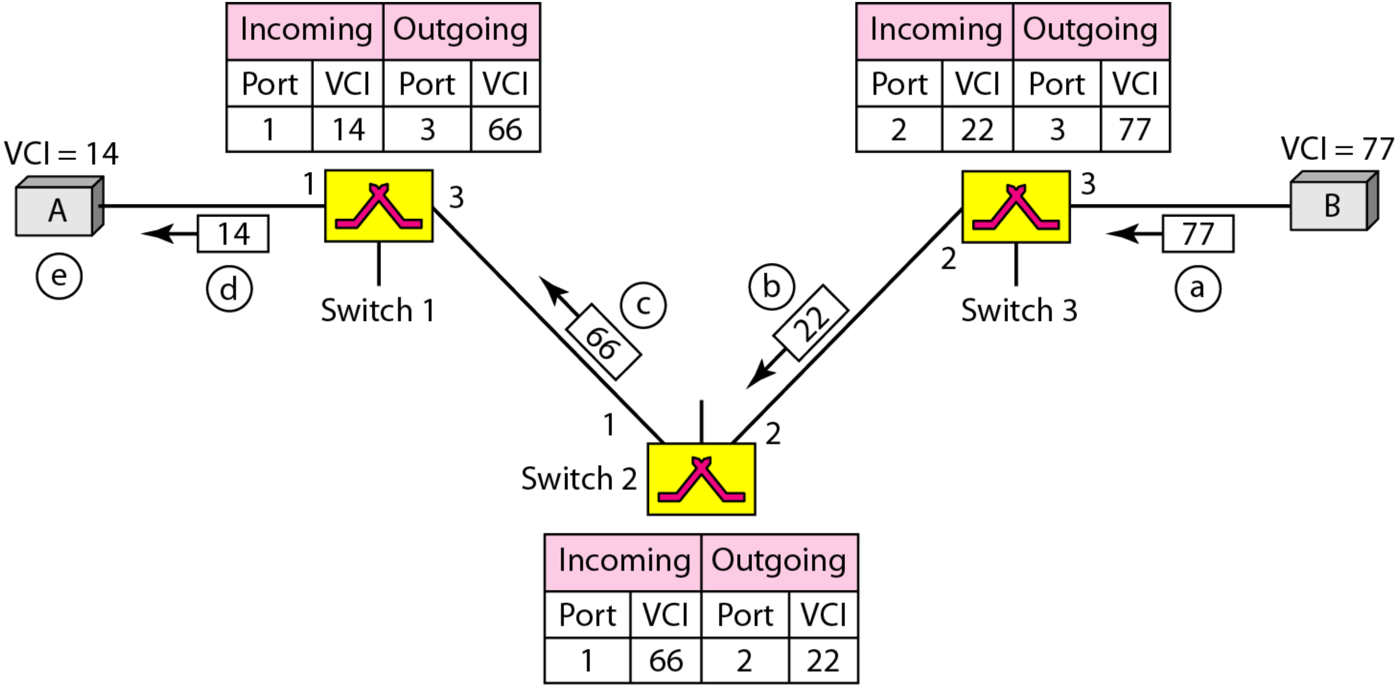
Virtual circuit switched networks

- 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



Switch 1:

Incoming		Outgoing	
Port	VCI	Port	VCI
1	14	3	66

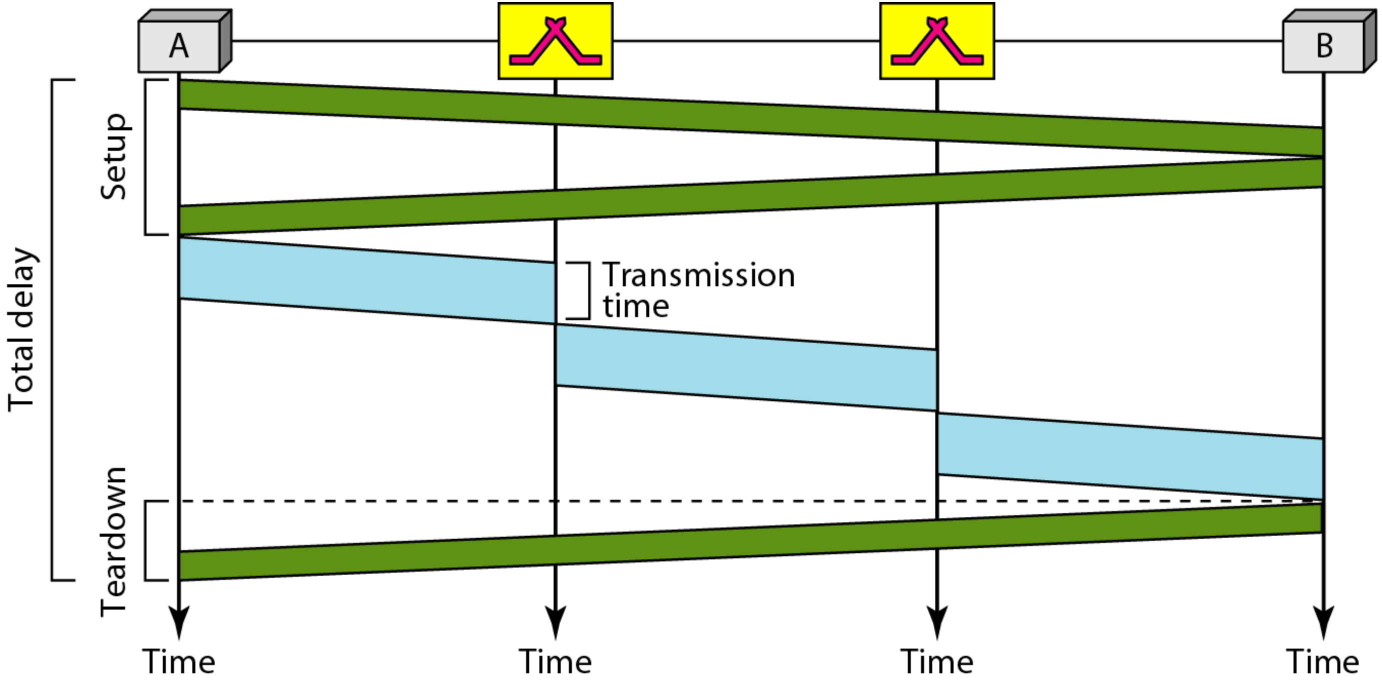
Switch 3:

Incoming		Outgoing	
Port	VCI	Port	VCI
2	22	3	77

Switch 2:

Incoming		Outgoing	
Port	VCI	Port	VCI
1	66	2	22

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

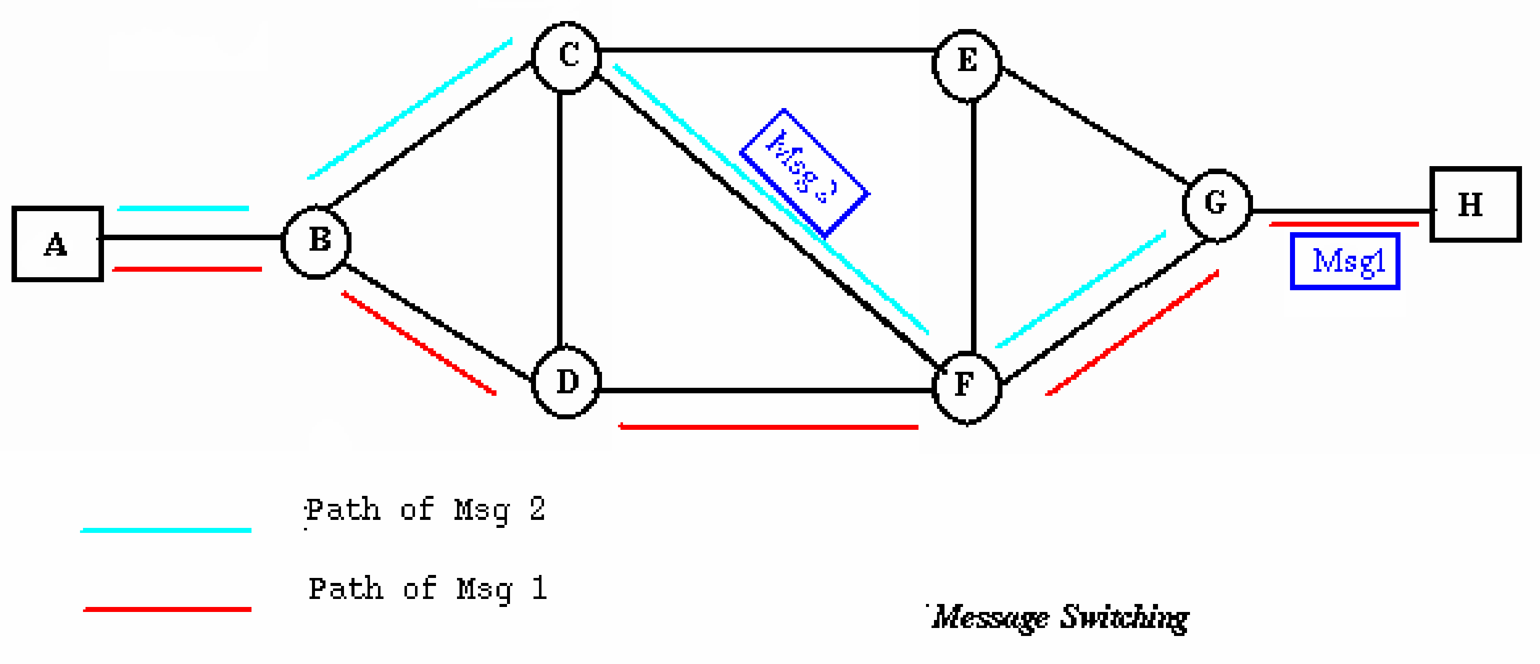
Disadvantages of packet switching

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

Message Switching

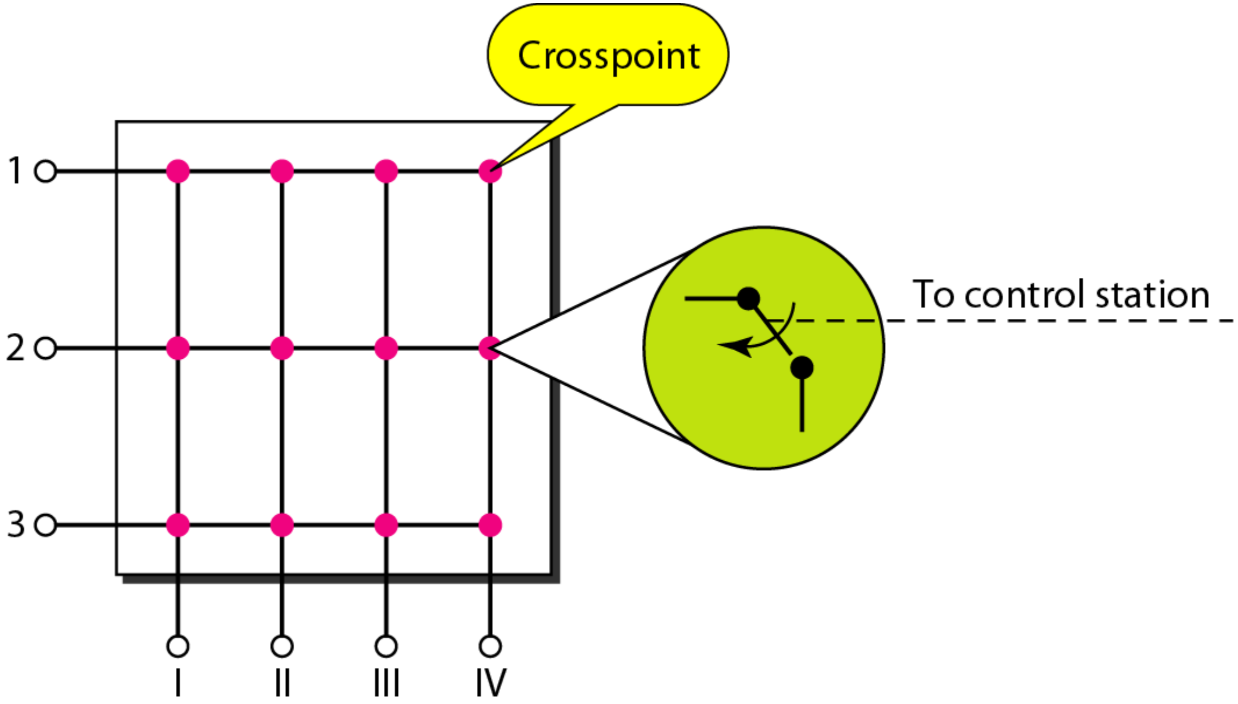
- With message switching there is no need to establish a dedicated path between source and destination
- When a station sends a message, the destination address is appended to the message
- Each node receives the entire message, stores it on disk, and then transmits the message to the next node
- This 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

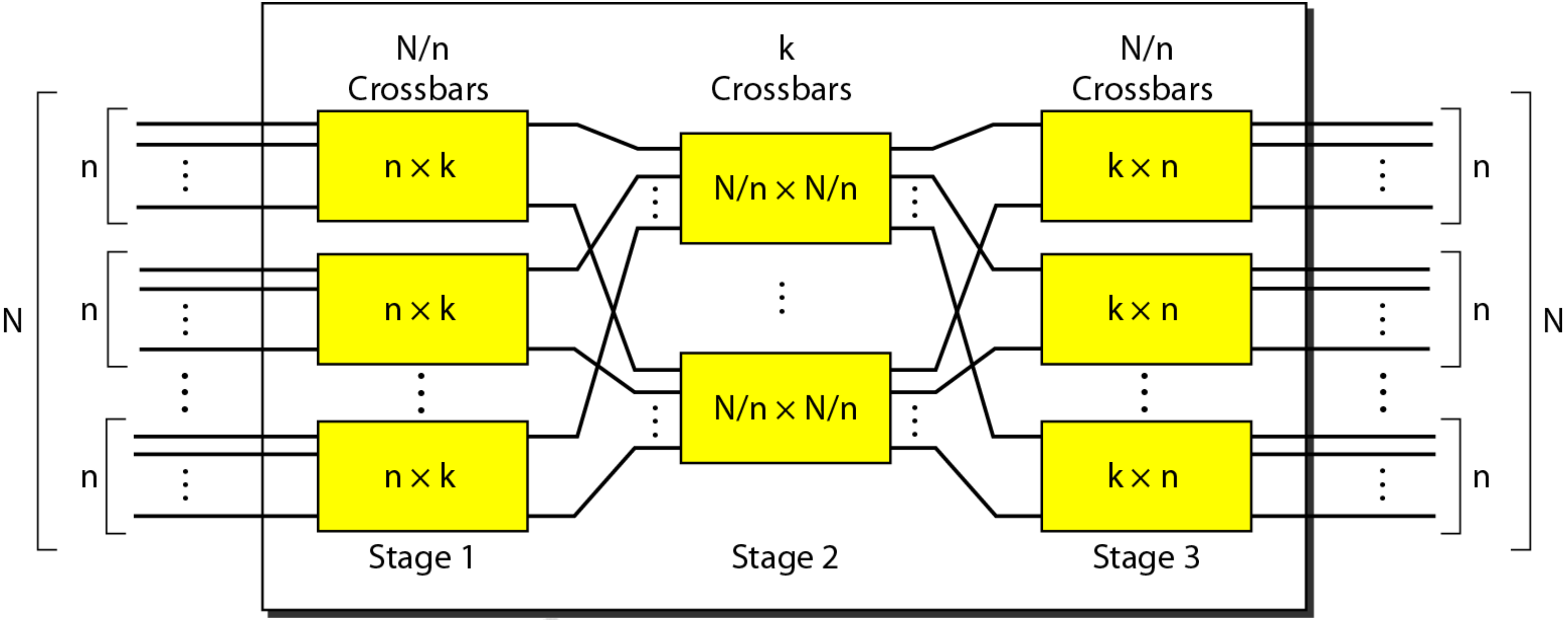


Message Switching

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 × 200 = 40,000)