GLA UNIVERSITY

COMPUTER NETWORK

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Outline

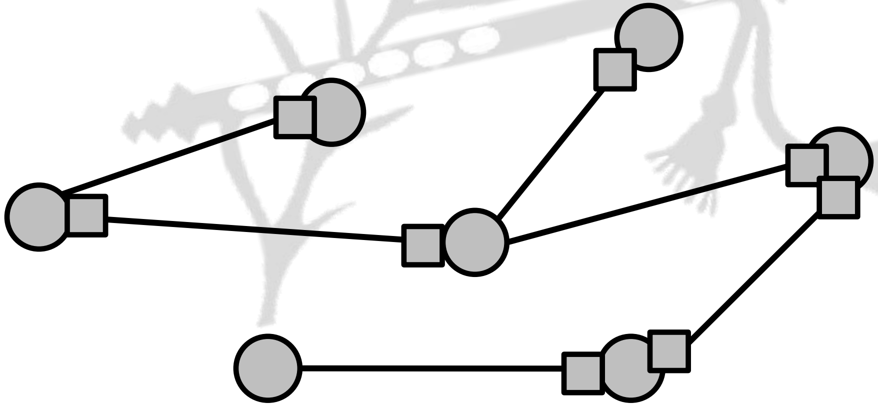
- **Introduction Concepts:**
  - Goals and Applications of networks
  - Network structure and architecture
  - The OSI reference model and services
  - Network topology design
  - Physical Layer Transmission Media
  - Line coding scheme
  - Switching methods (circuit switching, Packet switching)
  -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

INTRODUCTION CONCEPTS

Introduction

Network

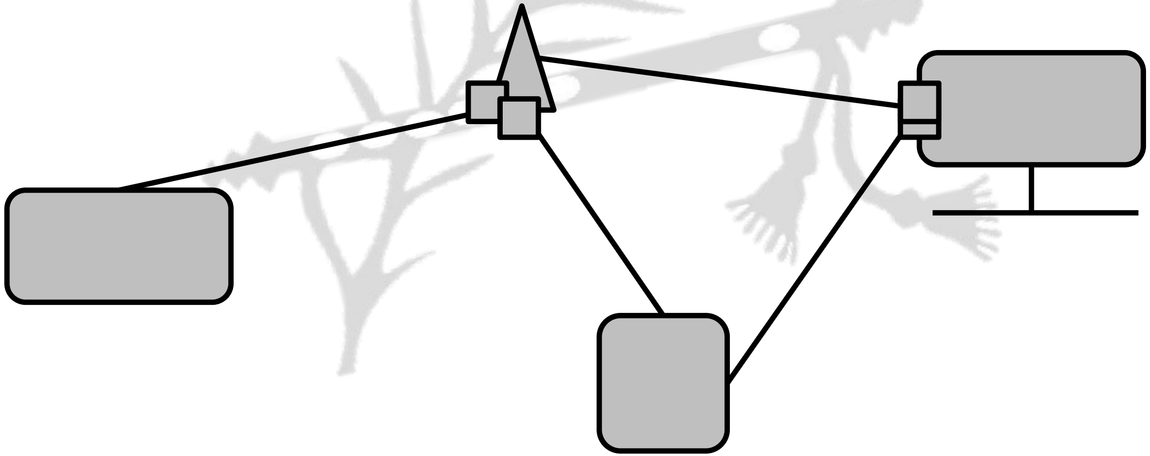
- It is defined as a medium which is responsible for carrying the data from one node to another
- Eg: intranet, internet, PAN, etc



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

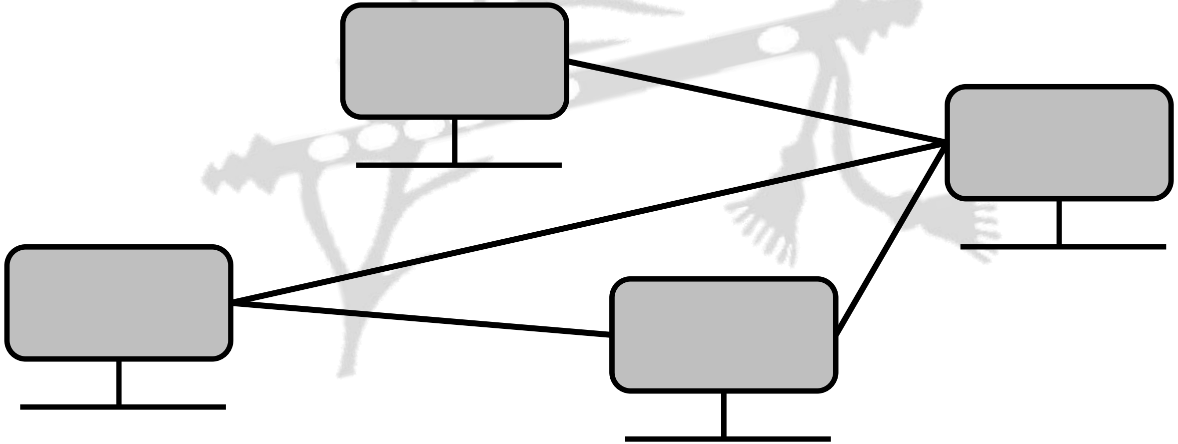
Network architecture

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

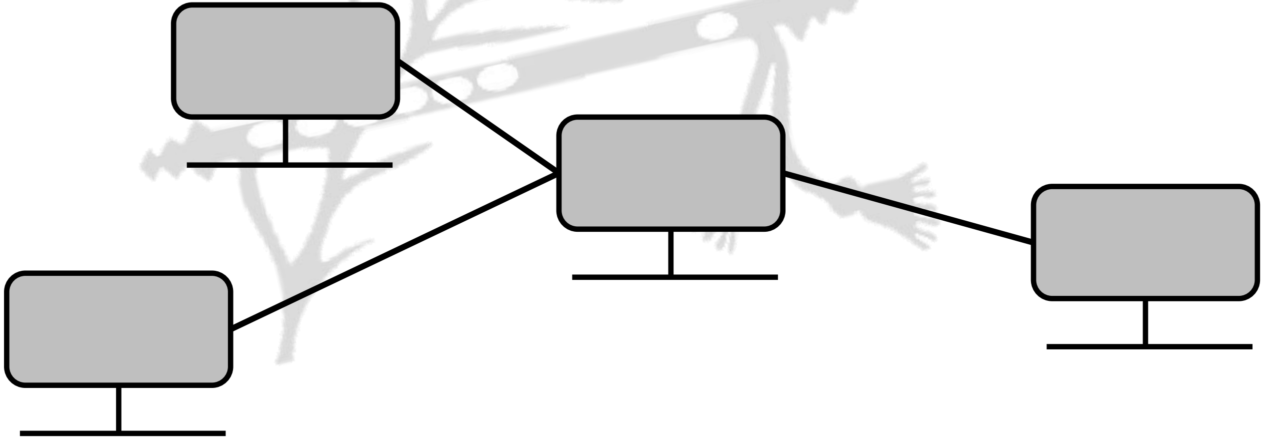
- Less costly as there is no central server
- In case of a node failure, other nodes in the network are not affected
- Installation is quite easy

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

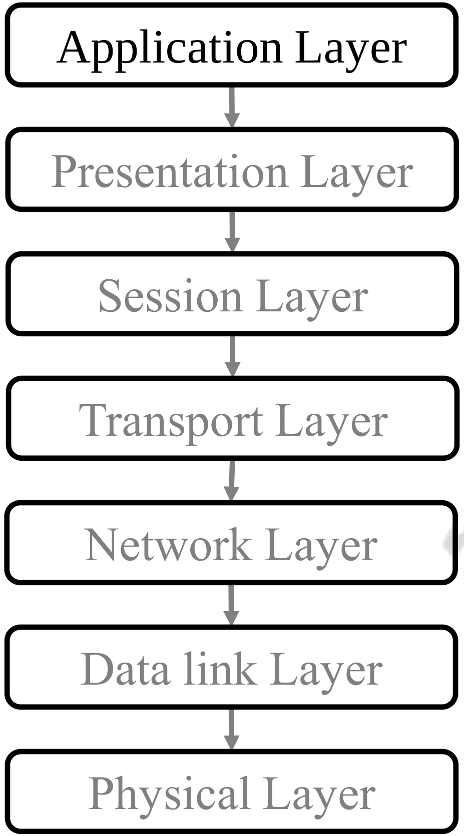
Transport Layer

Network Layer

Data link Layer

Physical Layer

OSI reference model and its services



- 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

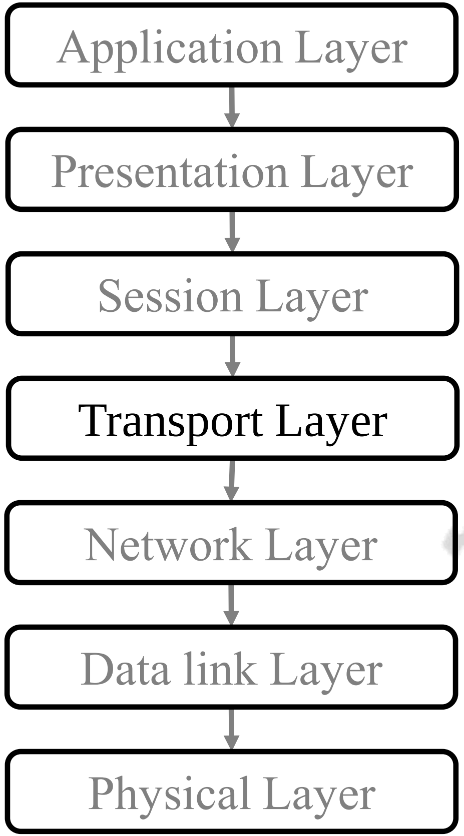
- The data from the application layer is extracted here and converted as per the required format to transmit over the network
- The functions of the presentation layer are :
  - Translation
  - Encryption/ Decryption
  - Compression

OSI reference model and its services

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

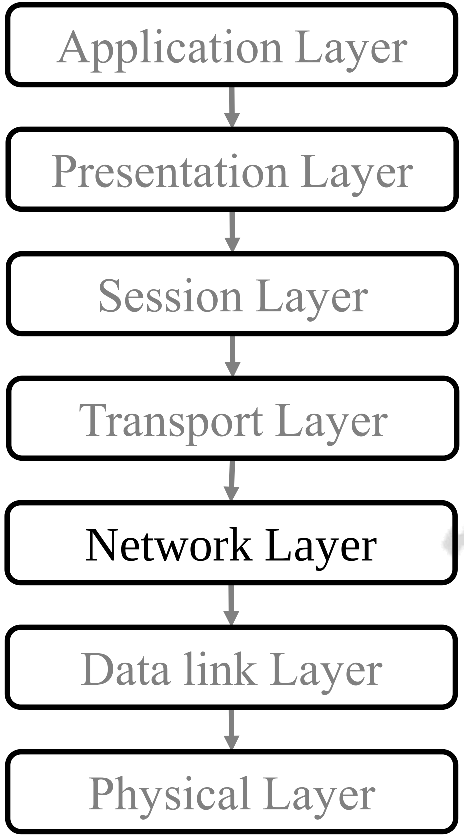
- This layer is responsible for establishment of connection, maintenance of sessions, authentication and security

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



- 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

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

- 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

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

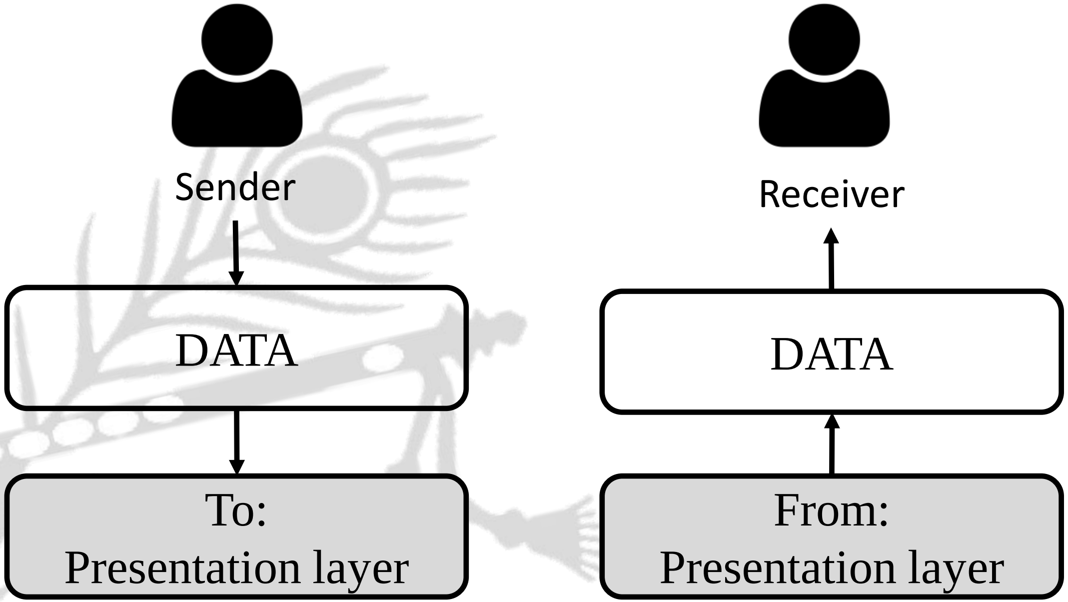
- It is responsible for the actual physical connection between the devices
- The physical layer contains information in the form of bits
- It is responsible for transmitting individual bits
- When receiving data, this layer will get the signal and convert it into 0s and 1s and send them to the Data Link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

OSI reference model and its services (in brief)

- **Application Layer** – Provides service to the user
- **Presentation Layer** – Performs translation, compression and encryption
- **Session Layer** – Manage session
- **Transport Layer** – Responsible for end-to-end transmission of data
- **Network Layer** – Data into packets and putting network header
- **Data link Layer** – Packets into frames, error free transfer and mapping
- **Physical Layer** – Frames into bits and a medium of transfer

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	Receiver
From: Application layer	To: Application layer
↓	↑
Encode, Encrypt, Compress	Decode, Decrypt, Decompress
↓	↑
To: Session layer	From: Session 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

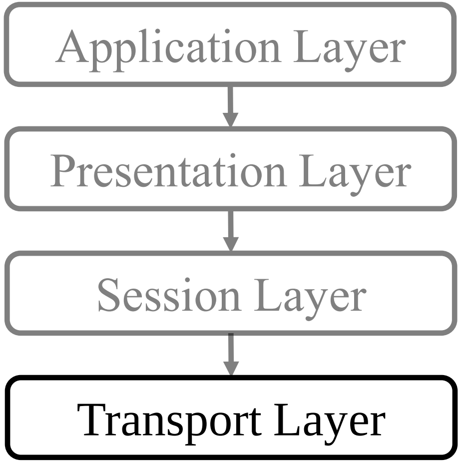
↓

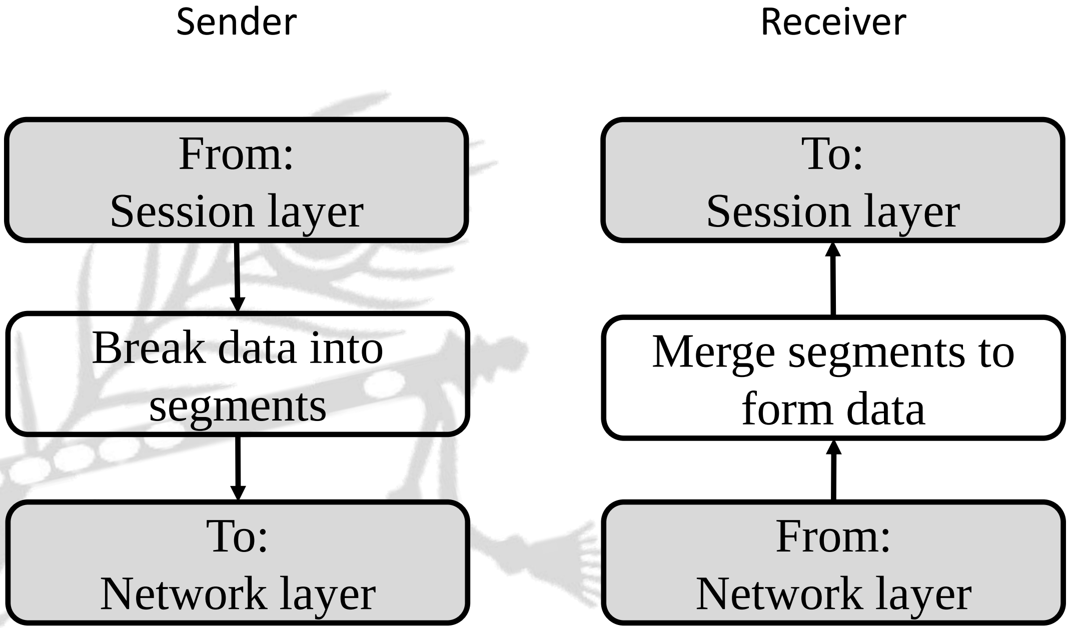
Transport Layer

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

DATA				
DS1	DS2	DS3	…	DSn

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)

Application Layer

Presentation Layer

Session Layer

Transport Layer

Function of this layer:

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

Sender

From: Session layer

Break data into segments

To: Network layer

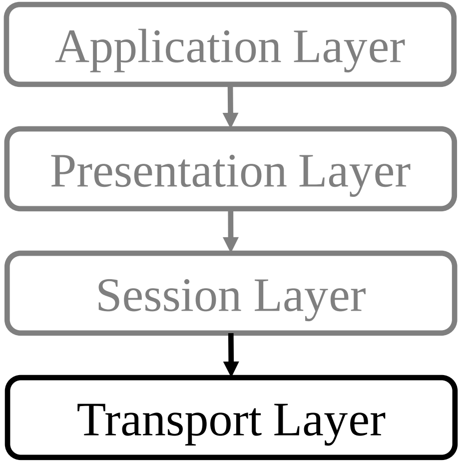
Receiver

To: Session layer

Merge segments to form data

From: Network layer

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)

Application Layer

Presentation Layer

Session Layer

Transport Layer

Network Layer

Sender

From:
Transport layer

Break segments into packets

To:
DLL

Receiver

To:
Transport layer

Merge packets to form segments

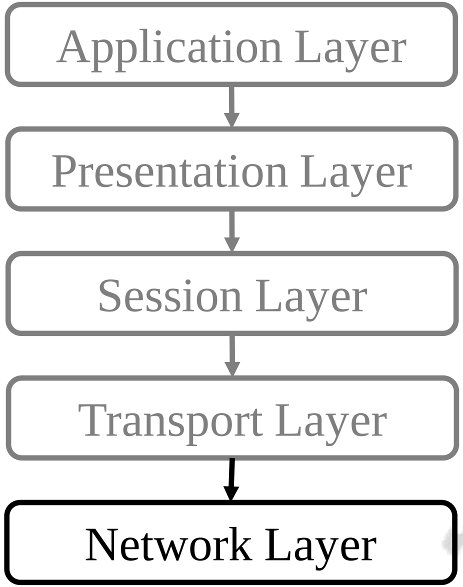
From:
DLL

Protocol used:

- IP

DS1				
DSP1	DSP2	DSP3	…	DSPn

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 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

From: Network layer
↓
Break packets into frames
↓
To: Physical layer

Receiver

From: Physical layer
↑
Merge frames to form packets
↑
To: Network layer

DSP1				
DSPF1	DSPF2	DSPF3	…	DSPFn

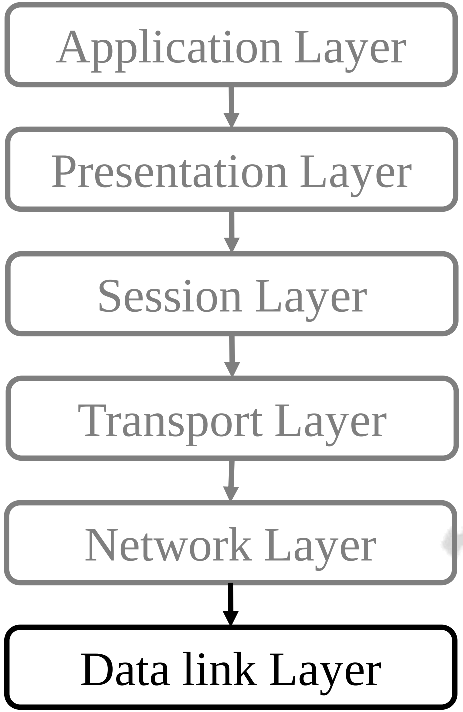
OSI reference model and its services (review)

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

It contains two sub-layers:

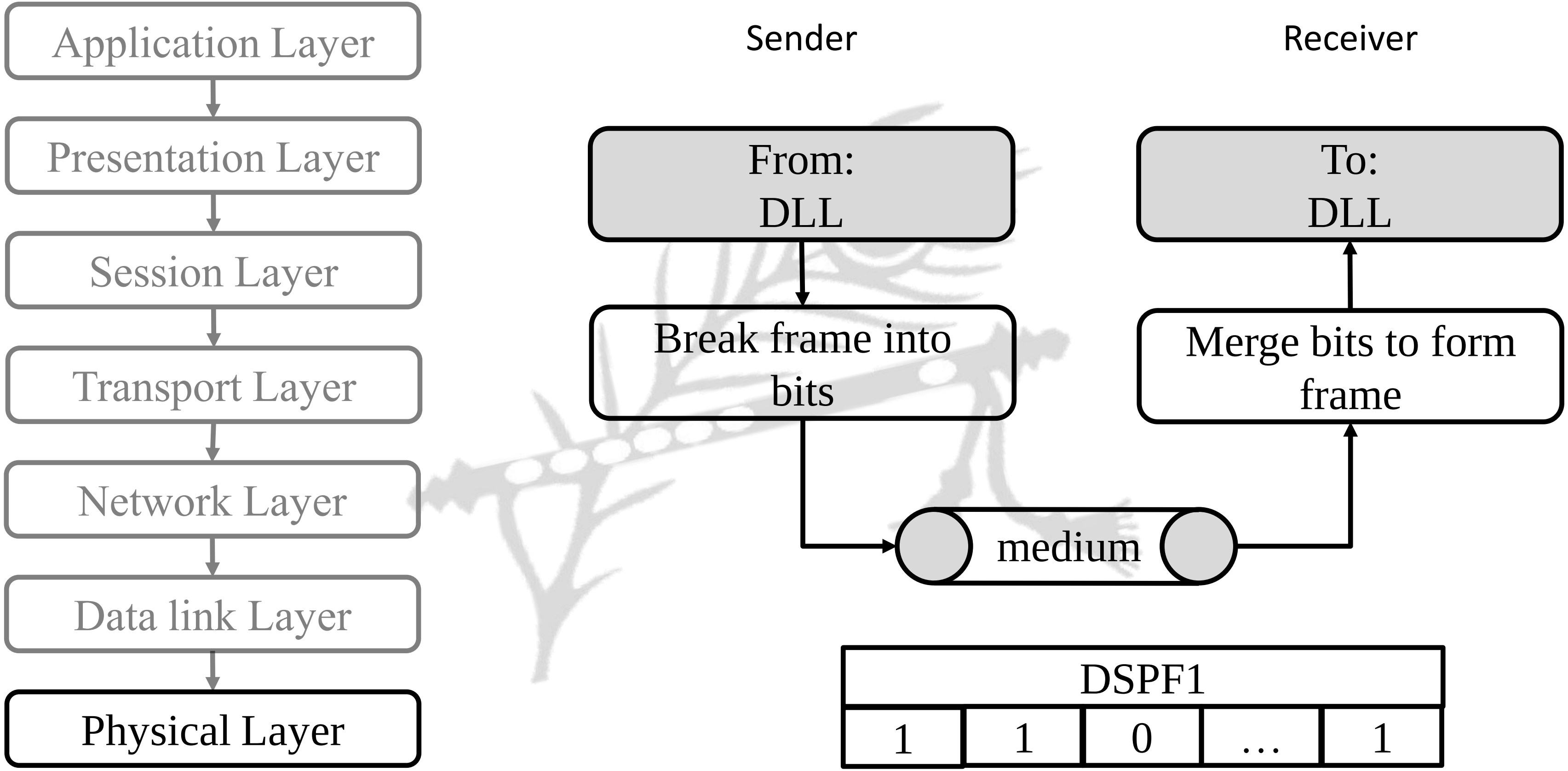
- Logical Link Control Layer
  - It identifies the address of the network layer protocol from the header
  - It also provides flow control
- Media Access Control Layer
  - A Media access control layer is a link between the Logical Link Control layer and the network's physical layer

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)

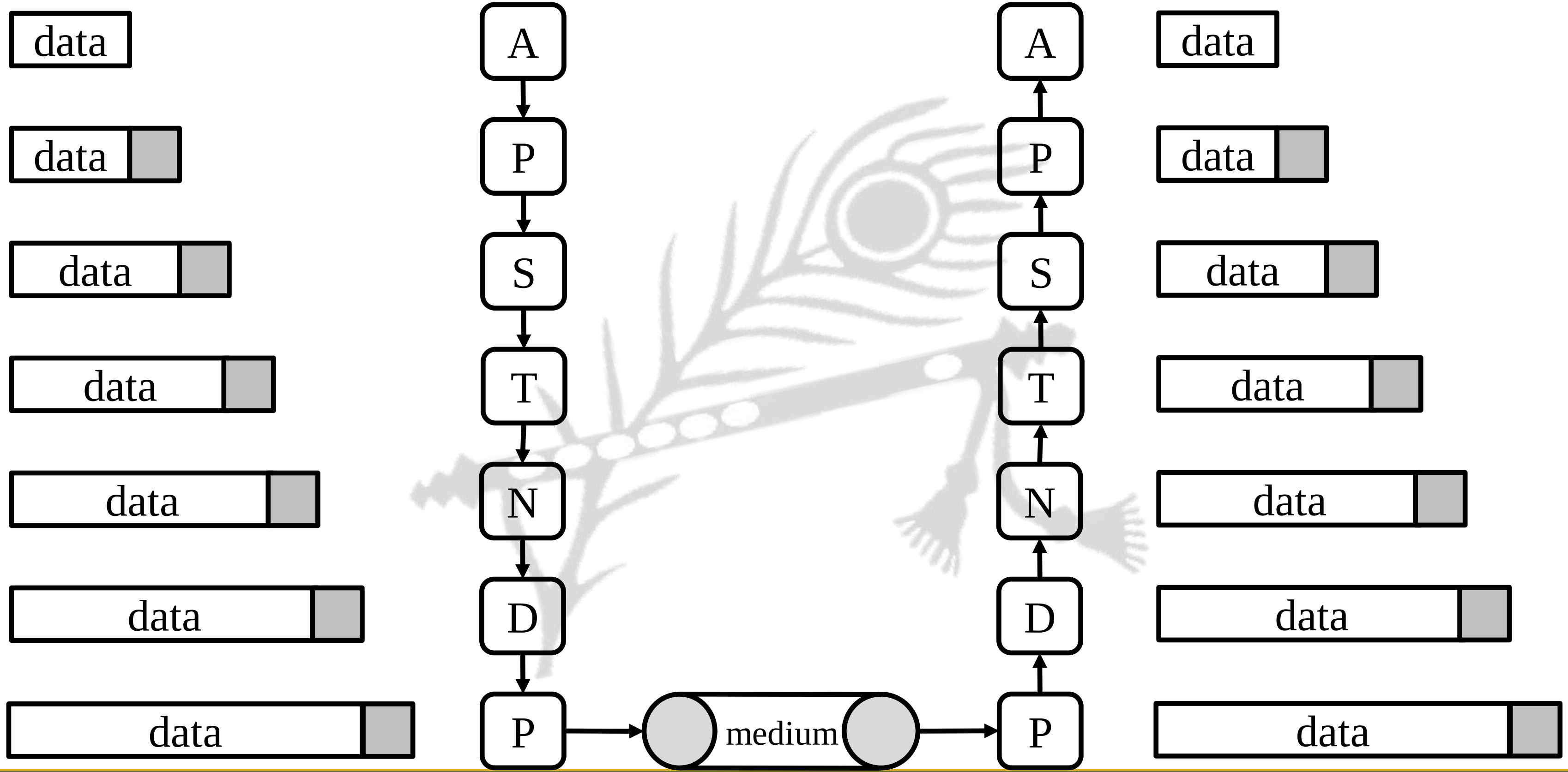


OSI reference model and its services (review)

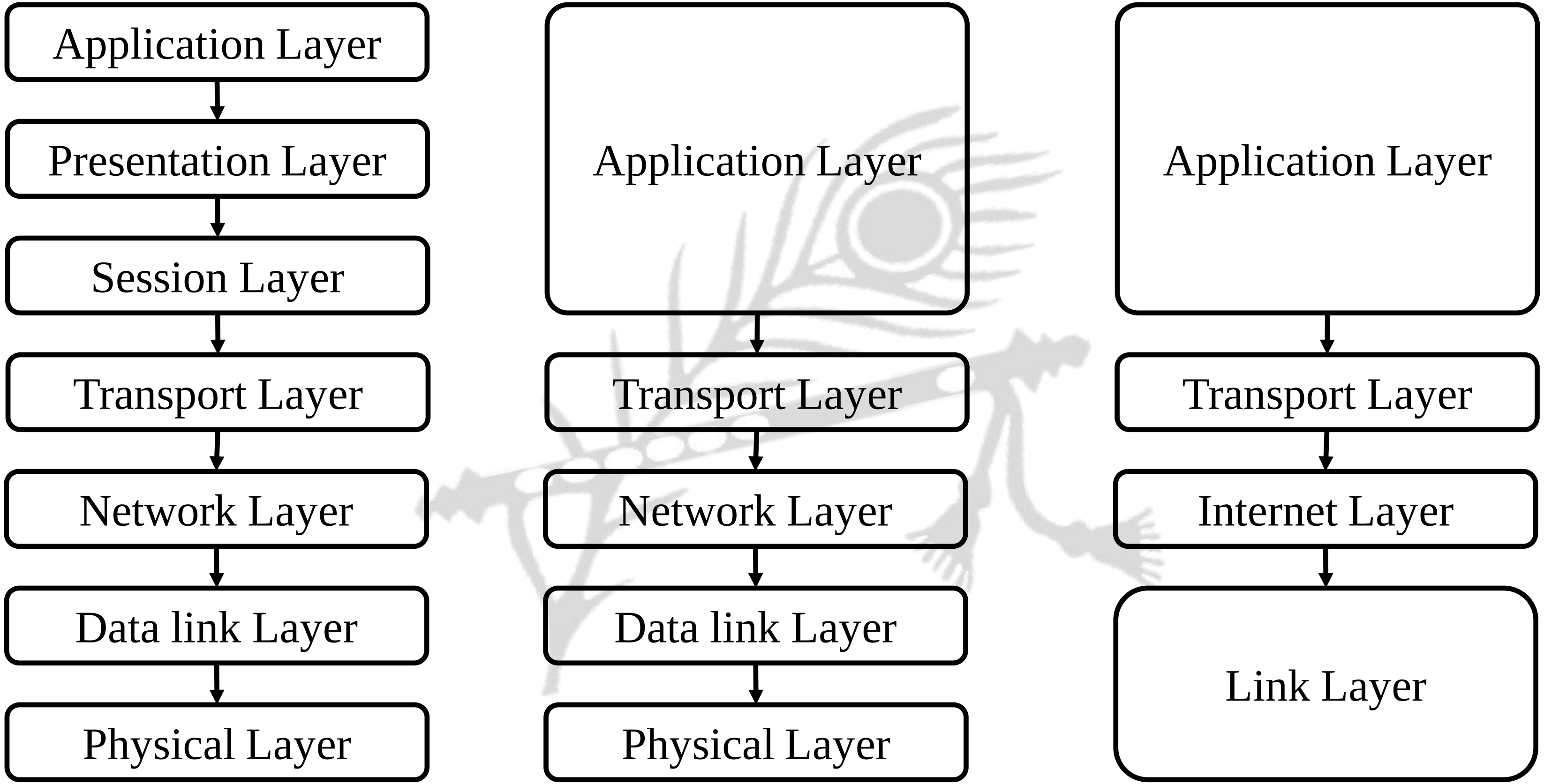
Application Layer
↓
Presentation Layer
↓
Session Layer
↓
Transport Layer
↓
Network Layer
↓
Data link Layer
↓
Physical Layer

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

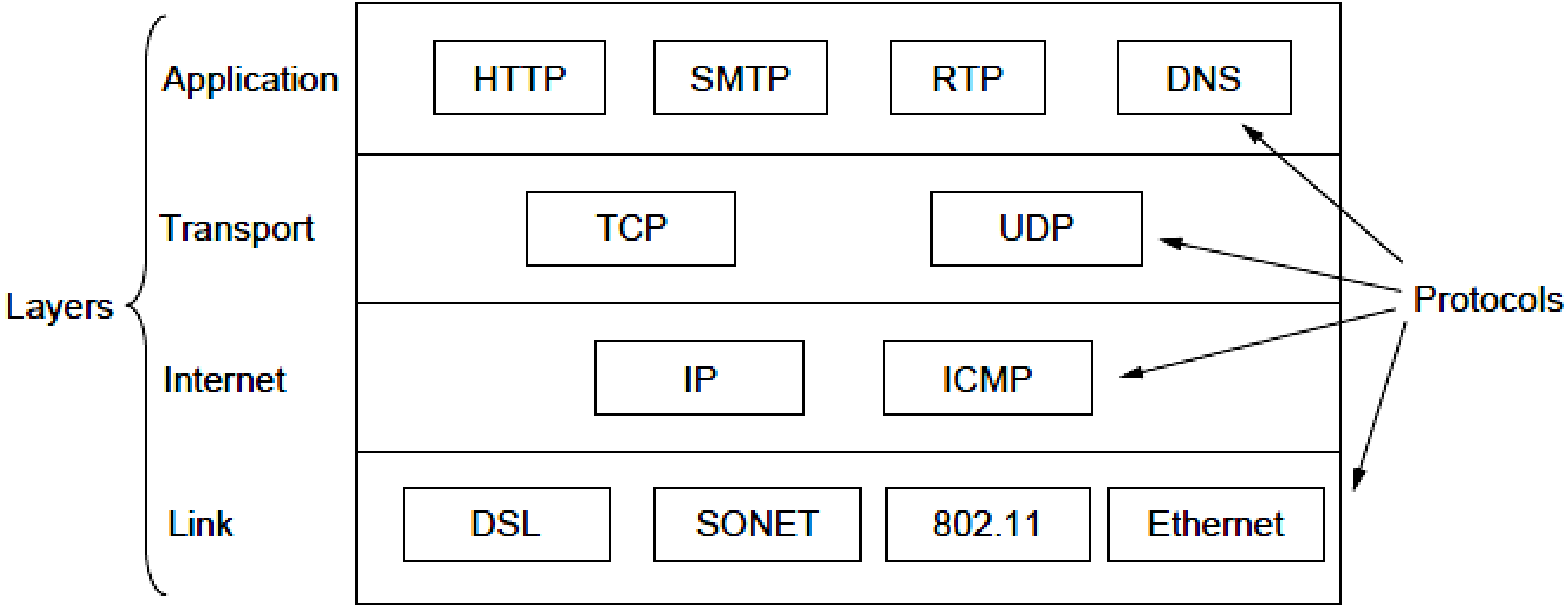
An exchange using OSI reference model



TCP/IP reference model



TCP/IP reference model



TCP/IP reference model

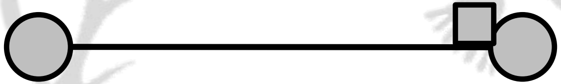
- Concepts central to the OSI model
  - Services
  - Interfaces
  - Protocols
- OSI has good definition of service, interface, and protocol. Fits well with object oriented programming concepts.
- Protocols are better hidden
- TCP/IP model did not distinguish between service, interface, and protocol
-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

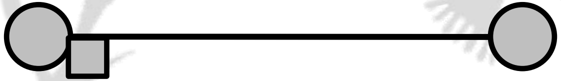
Transmission Mode

- 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

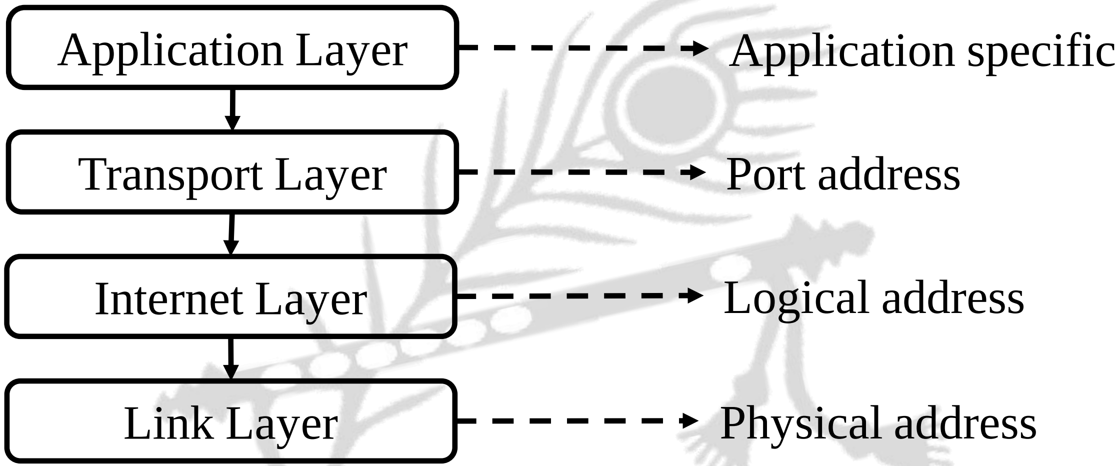
- Network layer
- packets
- Intelligent device
- LAN, MAN, WAN
- Full duplex
- IP address

ADDRESSING

Addressing

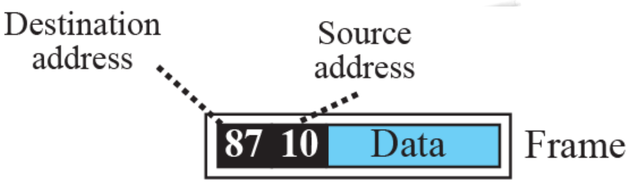
- Four levels of addresses are used in an internet employing the TCP/IP protocols:
  - physical address,
  - logical address,
  - port address, and
  - application-specific address.
- Each address is related to a one layer in the TCP/IP architecture

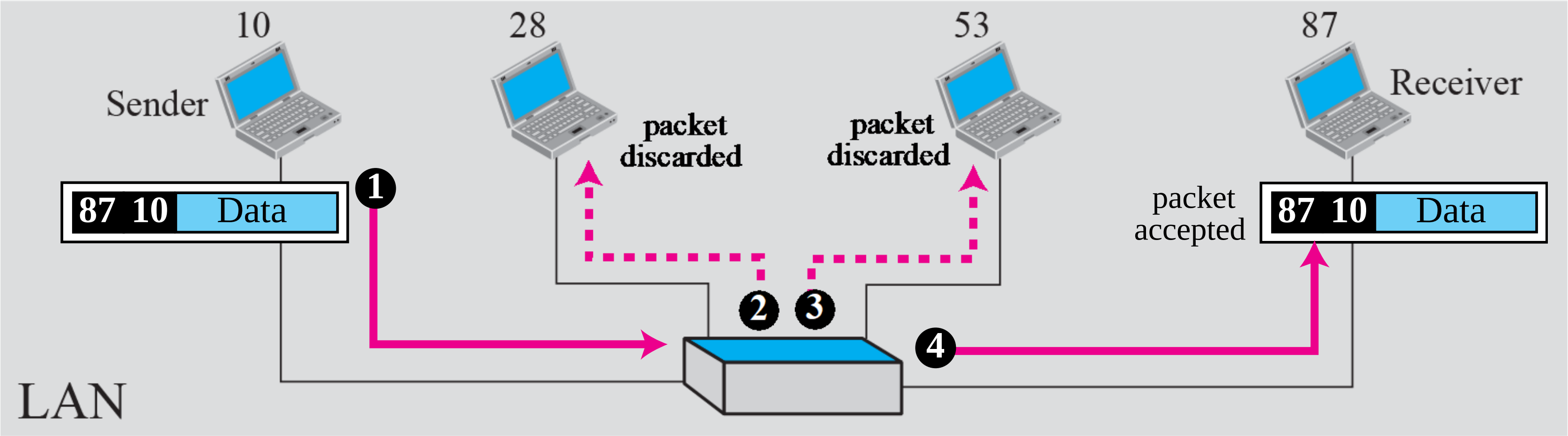
Addressing


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

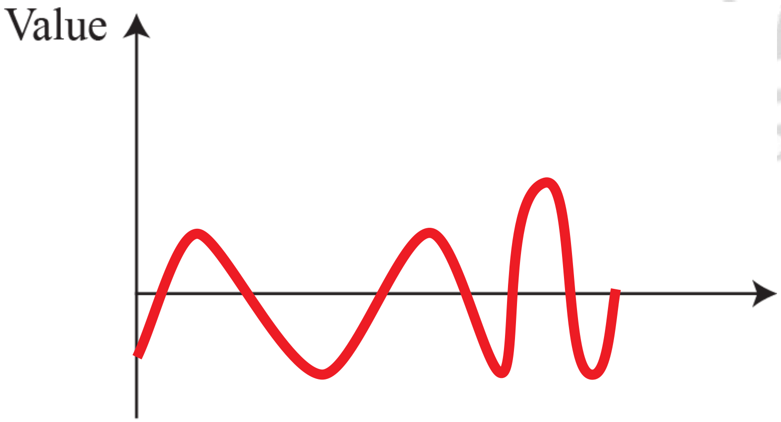
Analog and Digital data

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

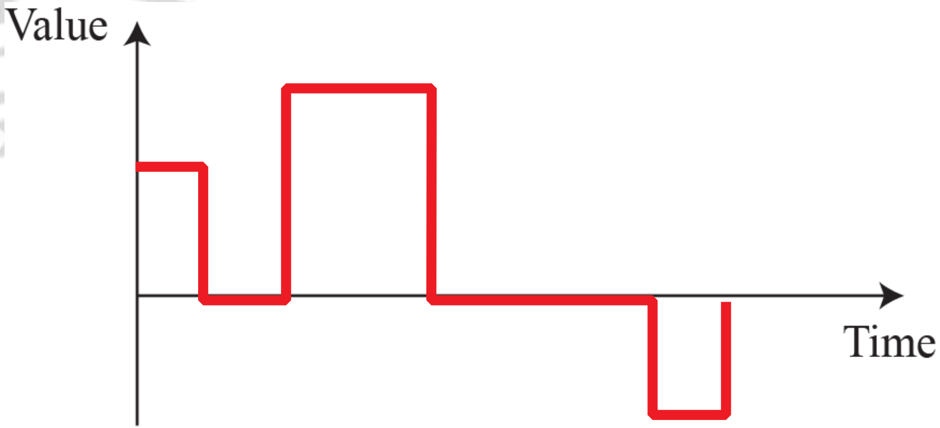
Data and Signals

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

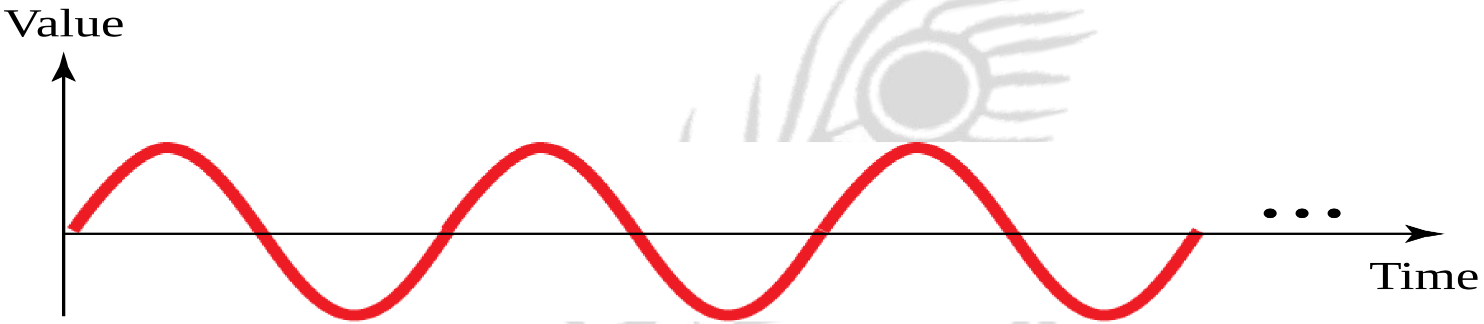
- A periodic signal completes a pattern within a measurable time frame, called a period, and repeats that pattern. The completion of one full pattern is called a cycle.
- A non periodic signal changes without exhibiting a pattern or cycle that repeats over time

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

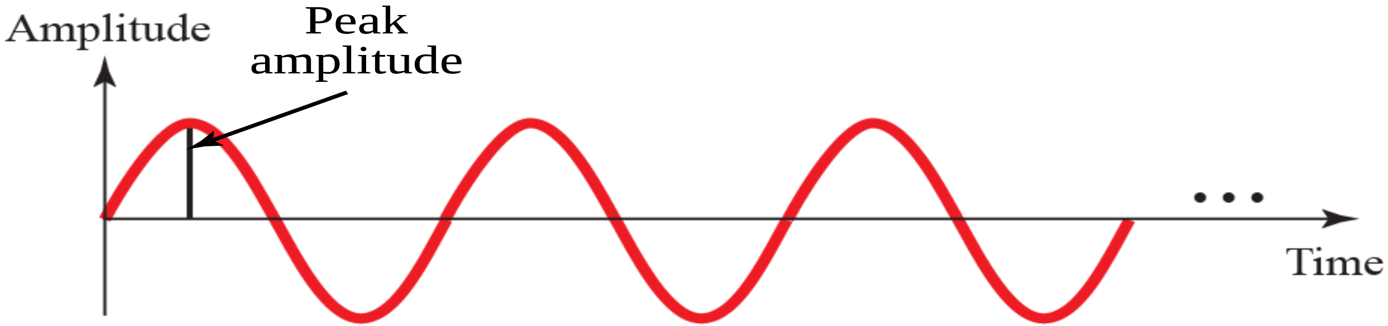
$$\boxed{f = \frac{1}{T} \qquad \text{and} \qquad T = \frac{1}{f}}$$

Periodic and Non-periodic

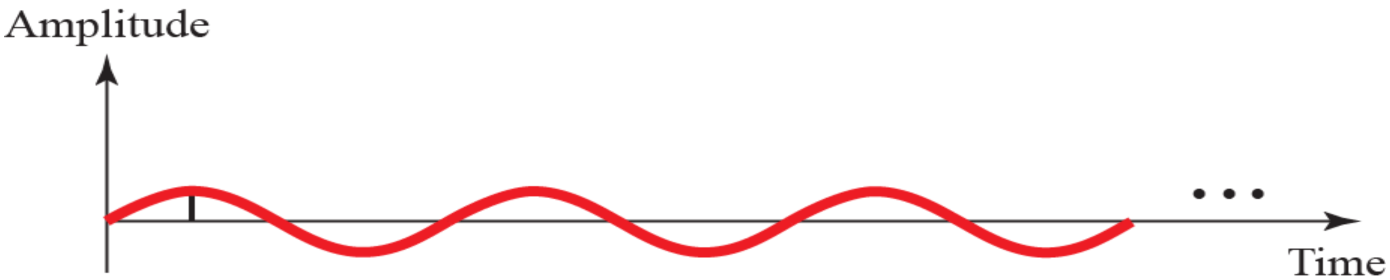


The sine wave is the most fundamental form of a periodic analog signal

Periodic and Non-periodic

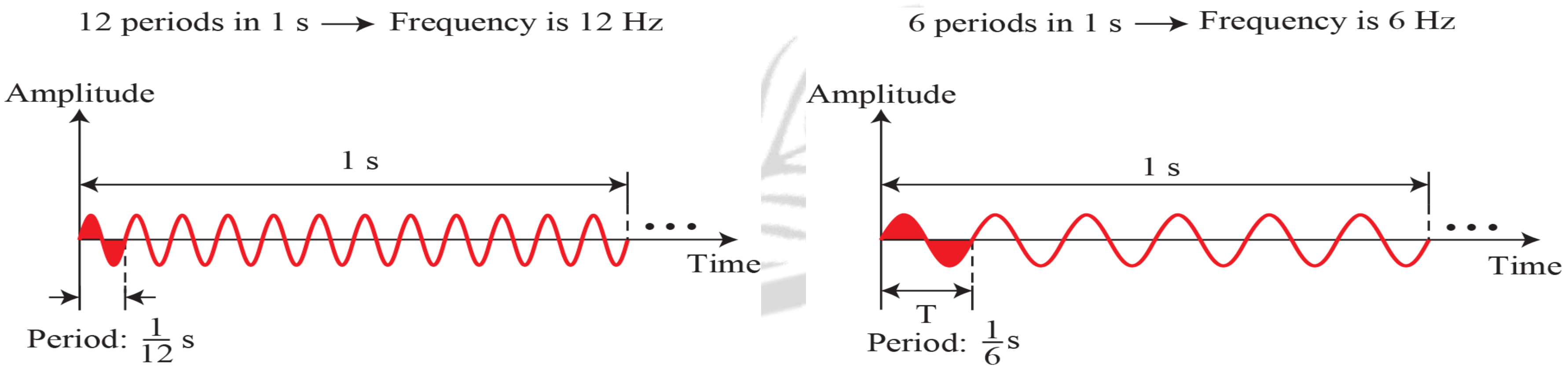


a. A signal with high peak amplitude



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:

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

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 Hz = 10^{-3} kHz).

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

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

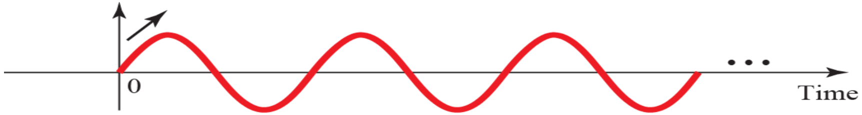
Frequency

- 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

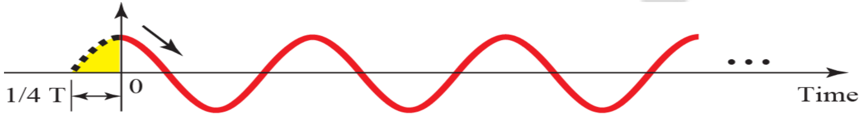
  - If a signal does not change at all, its frequency is zero
  - If a signal changes instantaneously, its frequency is infinite

Phase

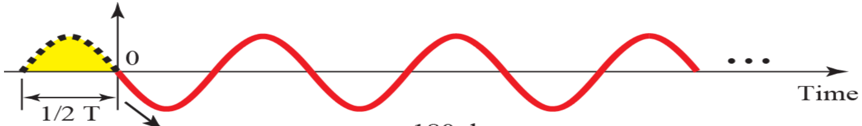
- The term <u>PHASE</u>, or <u>PHASE SHIFT</u>, describes the position of the waveform relative to time 0
- A complete cycle is defined as 360 degrees of phase
- Phase difference , also called phase angle , in degrees is conventionally defined as a number greater than -180, and less than or equal to +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

$$
\begin{aligned}
&1/6 * 360 \\
&= 60° \\
&= 60 \ * 2\Pi/360 \text{ rad} \\
&= \Pi/3 \text{ rad}
\end{aligned}
$$

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

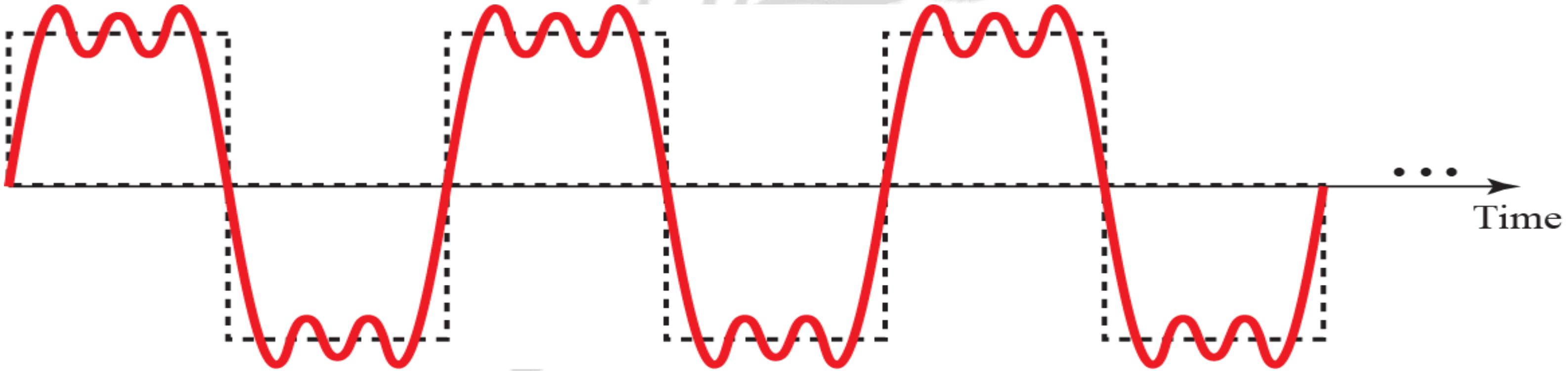
- A single-frequency sine wave is not useful in data communications
- We need to send a composite signal, a signal made of many simple sine waves
- According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases

Composite Signals and Periodicity

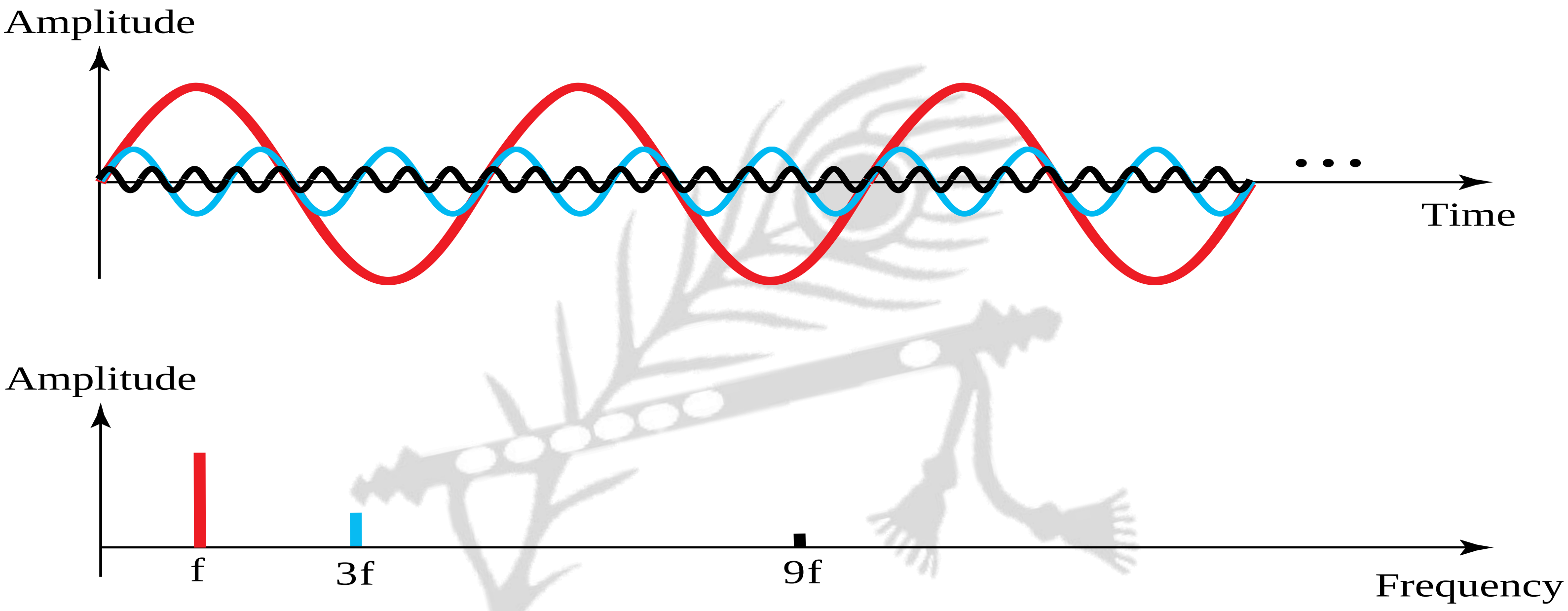
- If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies
- If the composite signal is non-periodic, the decomposition gives a combination of sine waves with continuous frequencies

Composite Period Signal

- A Composite Signal is collection of multiple single simple signals

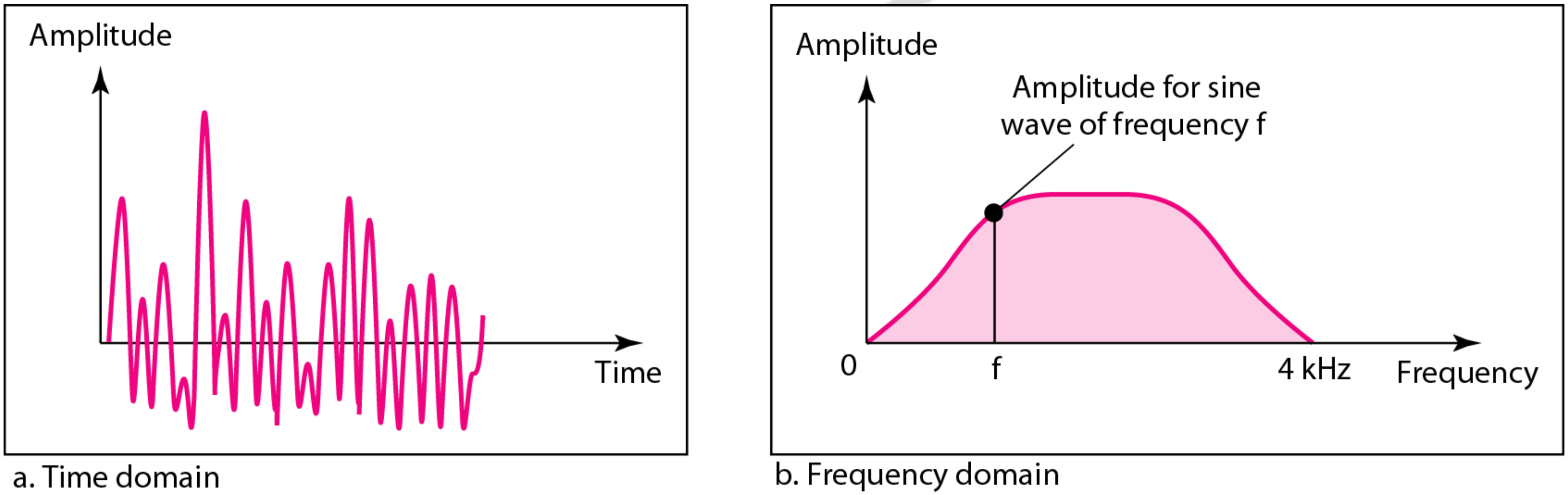


Decomposition of a composite periodic signal



b. Frequency-domain decomposition of the composite signal

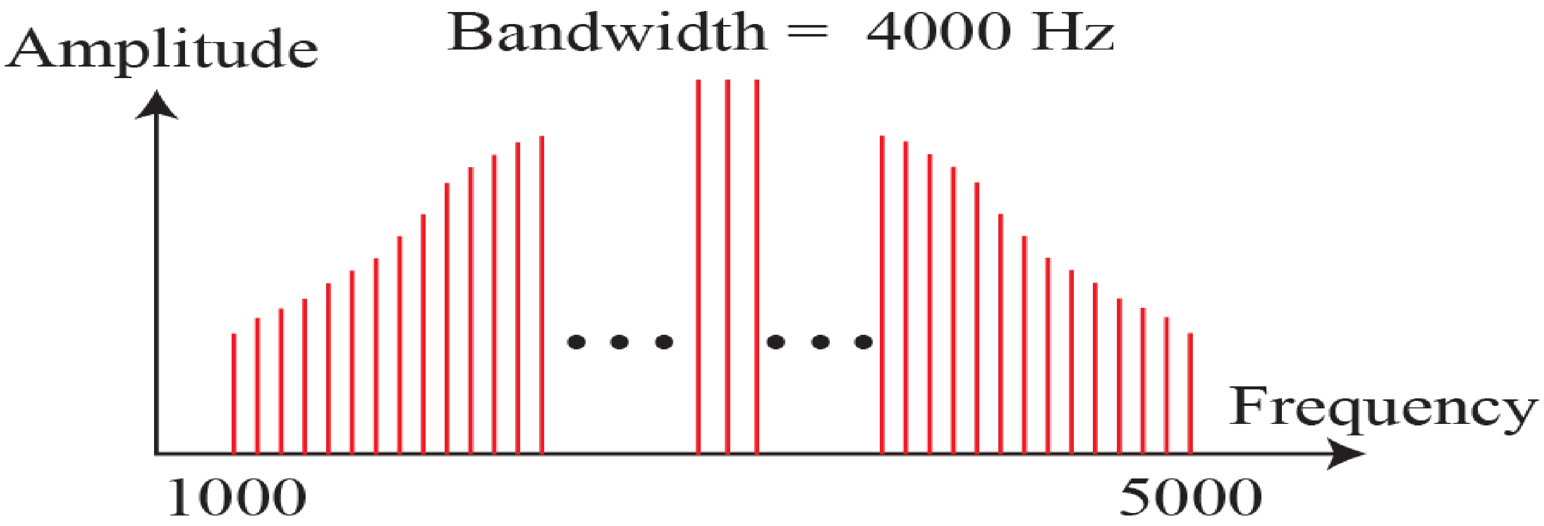
Decomposition of a composite non-periodic signal



Bandwidth

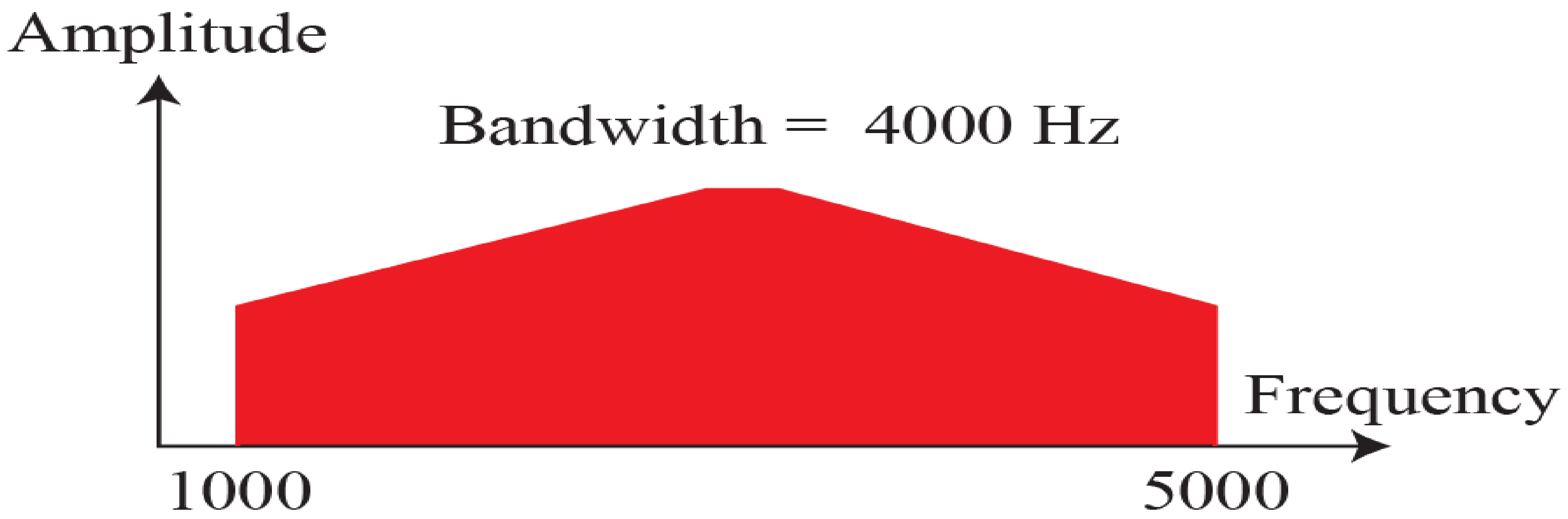
- The range of frequencies contained in a composite signal is its bandwidth
- The bandwidth is normally a difference between two numbers
- Eg:
  - if a composite signal contains frequencies between 1000 and 5000, its bandwidth is 5000 − 1000, or 4000

Bandwidth



a. Bandwidth of a periodic signal

Bandwidth



b. Bandwidth of a nonperiodic signal

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,

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

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,

$$B = f_h - f_l$$

$$20 = 60 - f_l$$

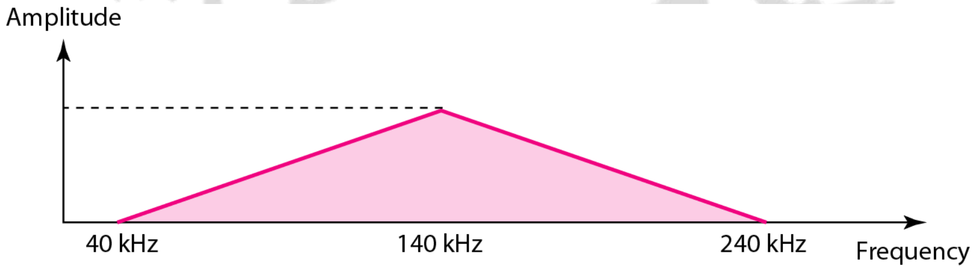
$$f_l = 40 \text{ Hz}$$

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



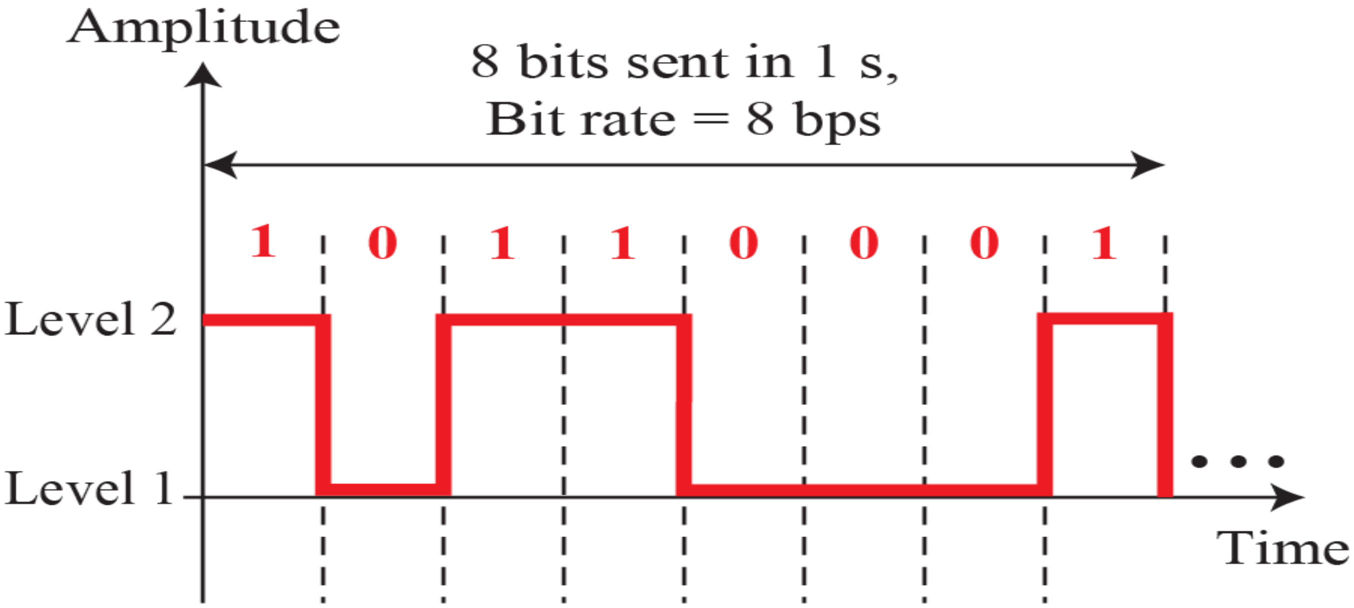
Fourier Analysis

- 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

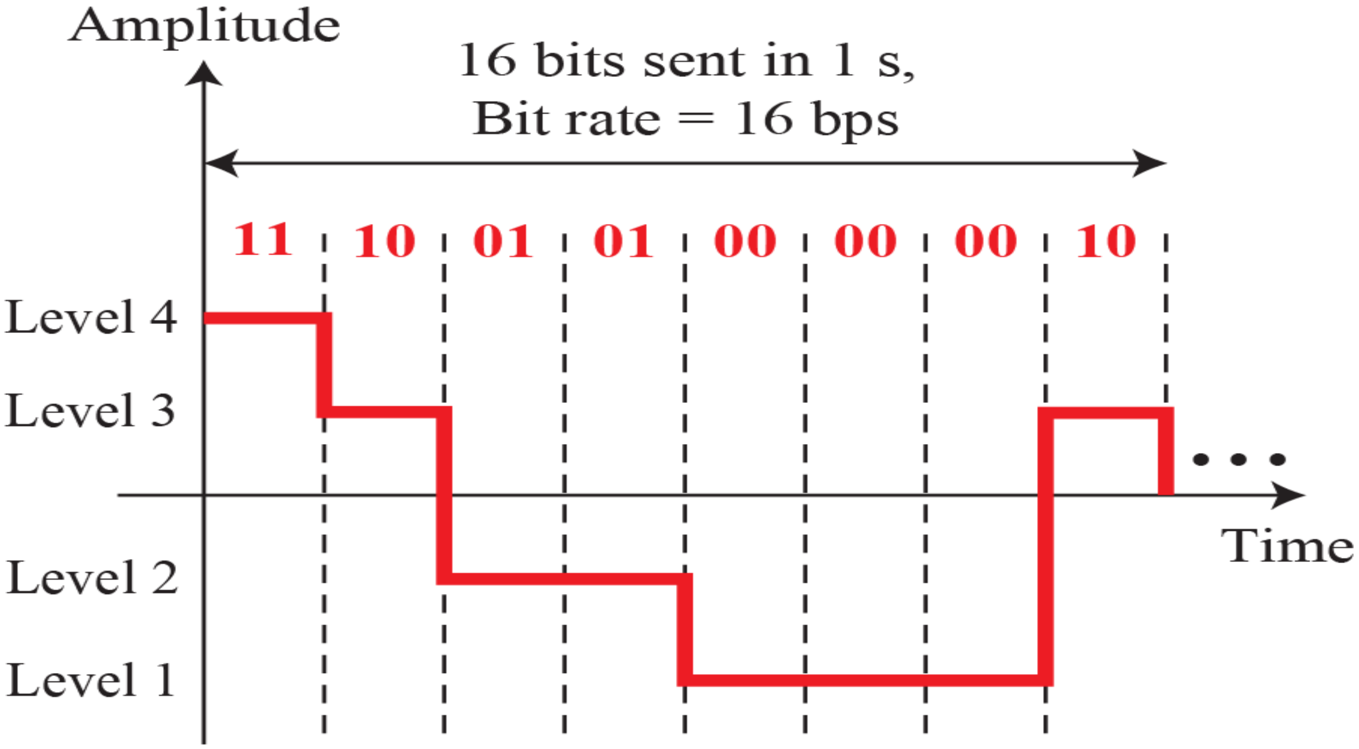
- In addition to being represented by an analog signal, information can also be represented by a digital signal
- Eg:
  - 1 can be encoded as a positive voltage and a 0 as zero voltage
- A digital signal can have more than two levels

Digital Signal



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 causes

Attenuation | Distortion | Noise

Impairment

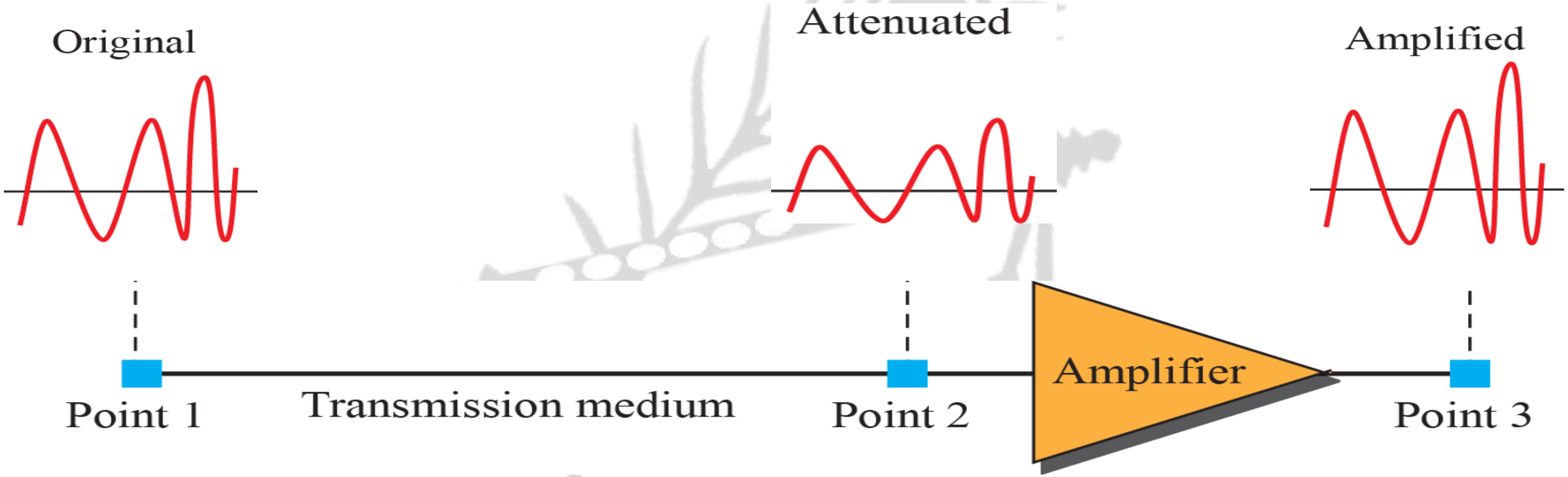
Attenuation

- 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

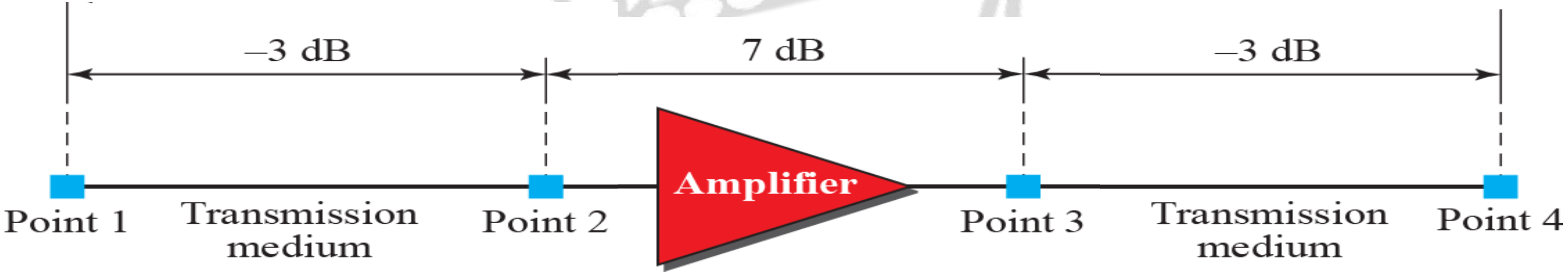
$$
\begin{aligned}
& 10 \log_{10} P_2/P_1 \\
&= 10 \log_{10} (10\, P_1/P_1) \\
&= 10 \log_{10} (10) \\
&= 10\ (1) \\
&= 10 \text{ dB}
\end{aligned}
$$

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

Solution

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

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

$$10 \log_{10} P_2/P_1 = -1.5$$
$$\log_{10} P_2/P_1 = -0.15$$
$$P_2/P_1 = 10^{-0.15} = 0.7$$
$$P_2 = 0.7P_1$$
$$P_2 = 0.7*2 = 1.4 \text{ mW}$$

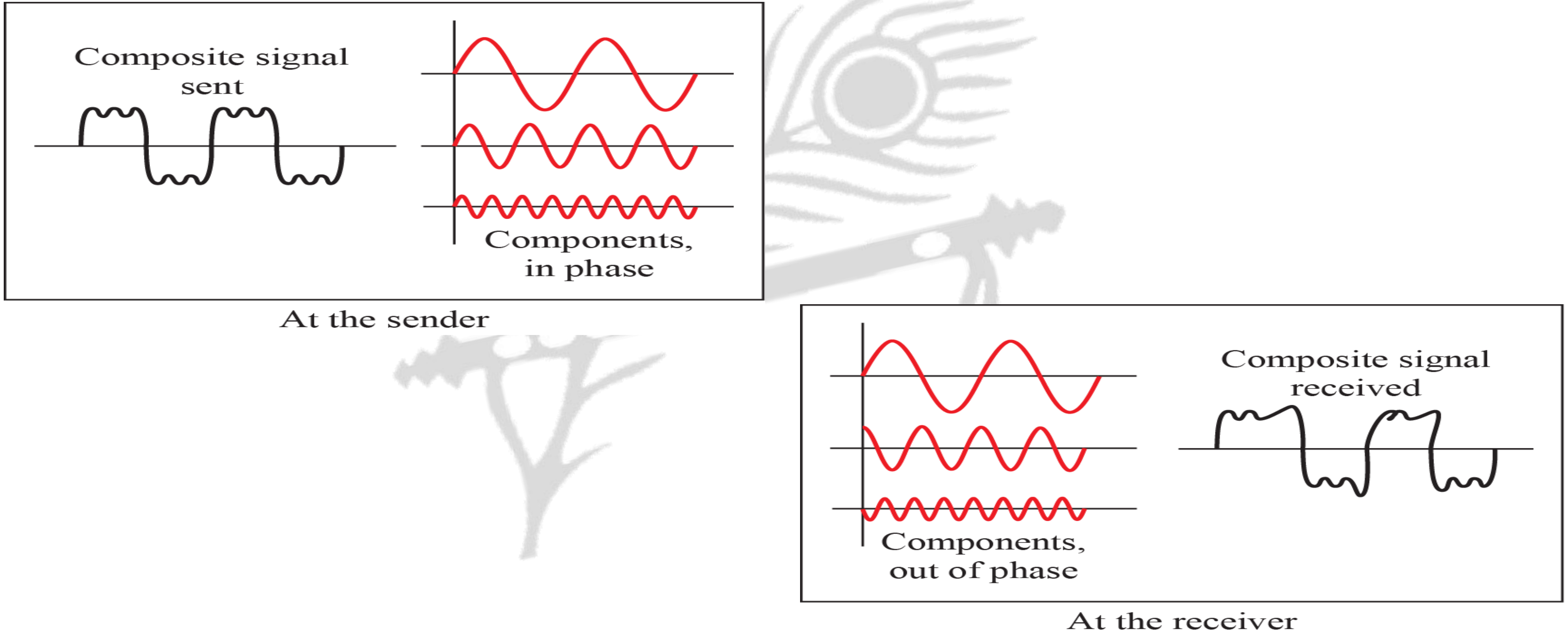
Impairment

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



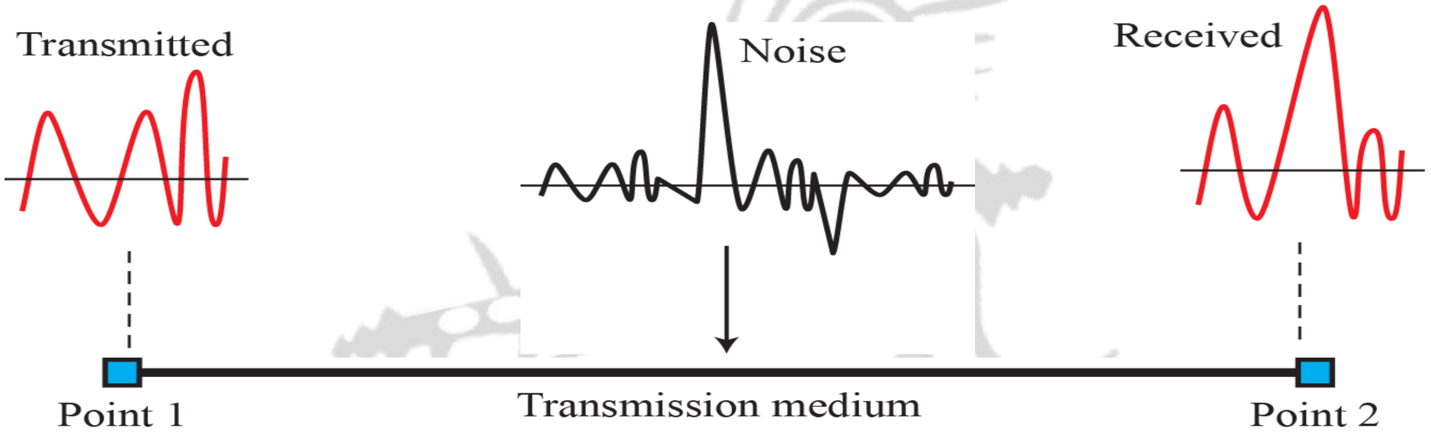
Impairment

Noise

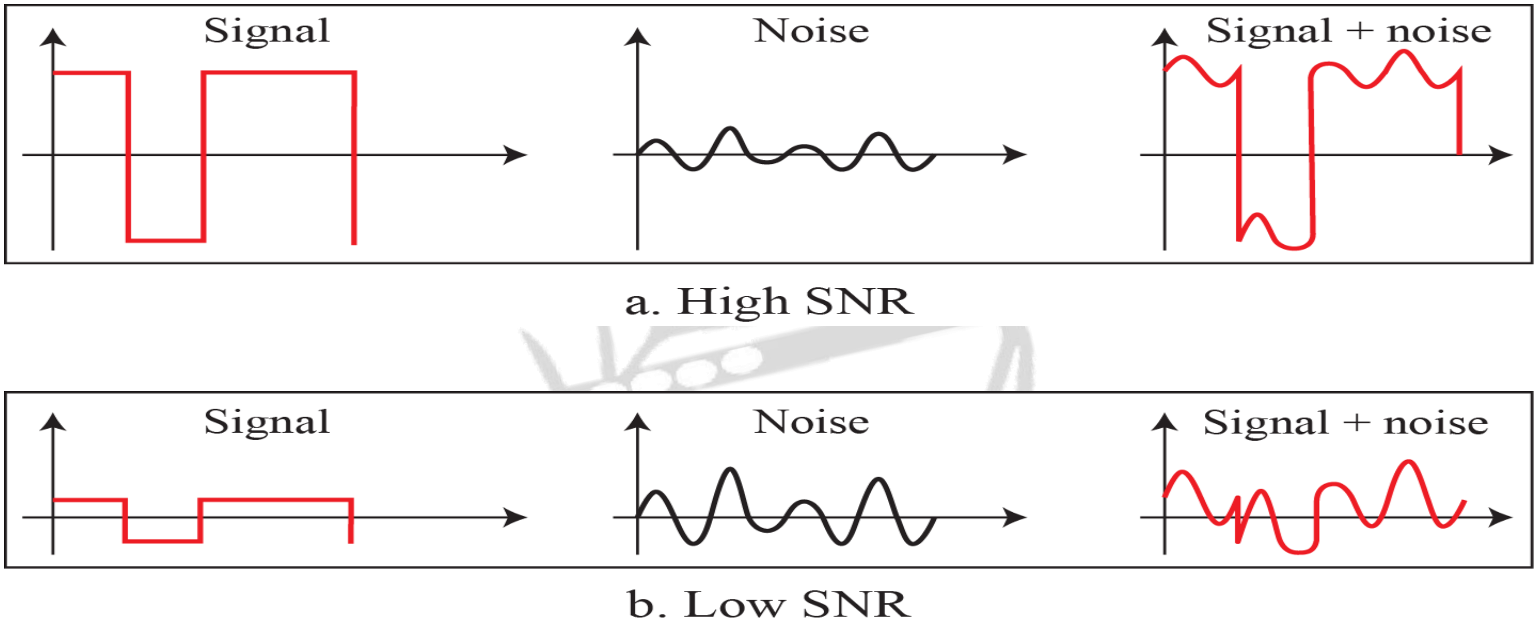
- Noise is another cause of impairment
- Several types of noise, such as thermal noise, induced noise, crosstalk, etc may corrupt the signal
  - Thermal noise is the random motion of electrons in a wire, which creates an extra signal not originally sent by the transmitter
  - Induced noise comes from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



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:

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

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

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

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

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

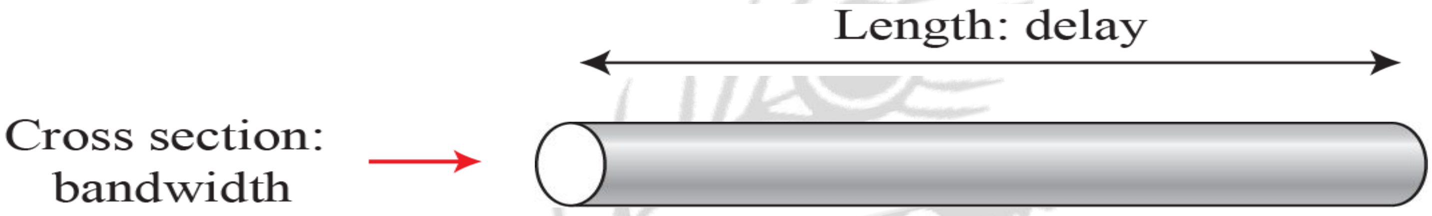
- The throughput is a measure of how fast we can actually send data through a network

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)

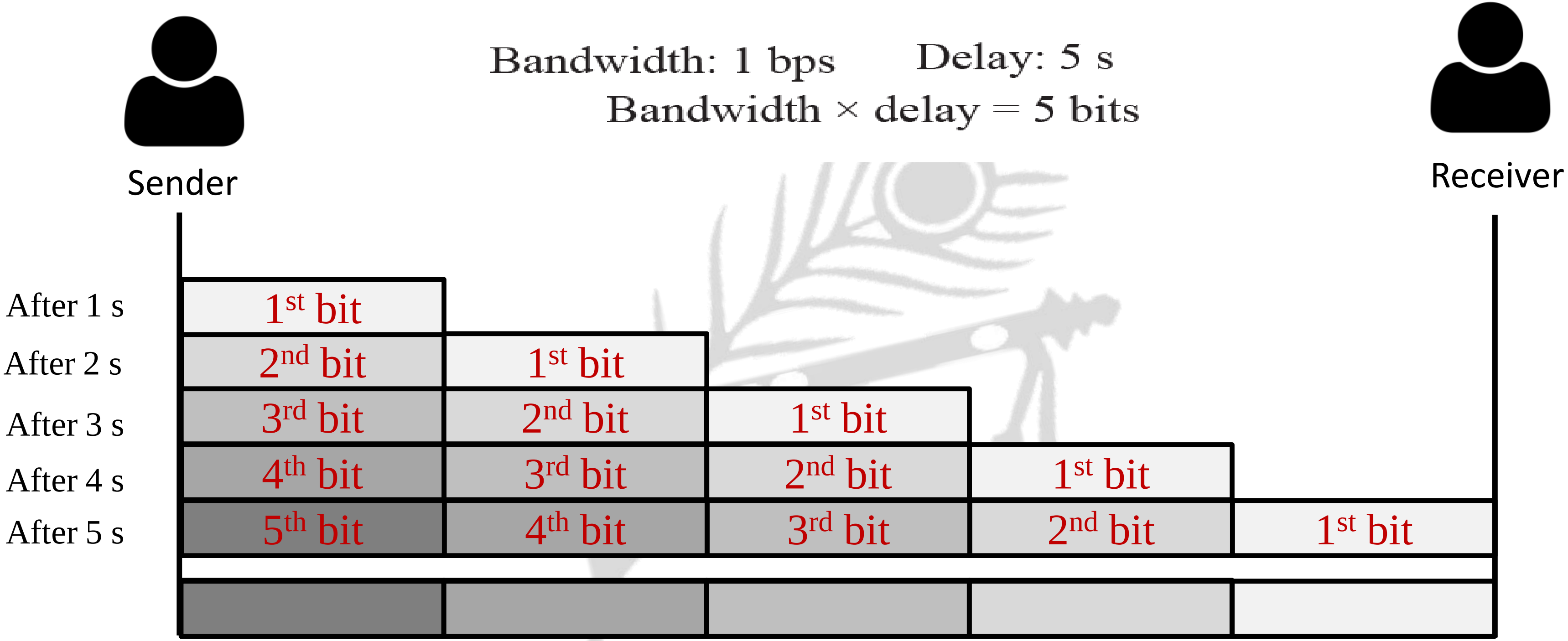
Bandwidth-Delay

- Bandwidth and delay are two performance metrics of a link

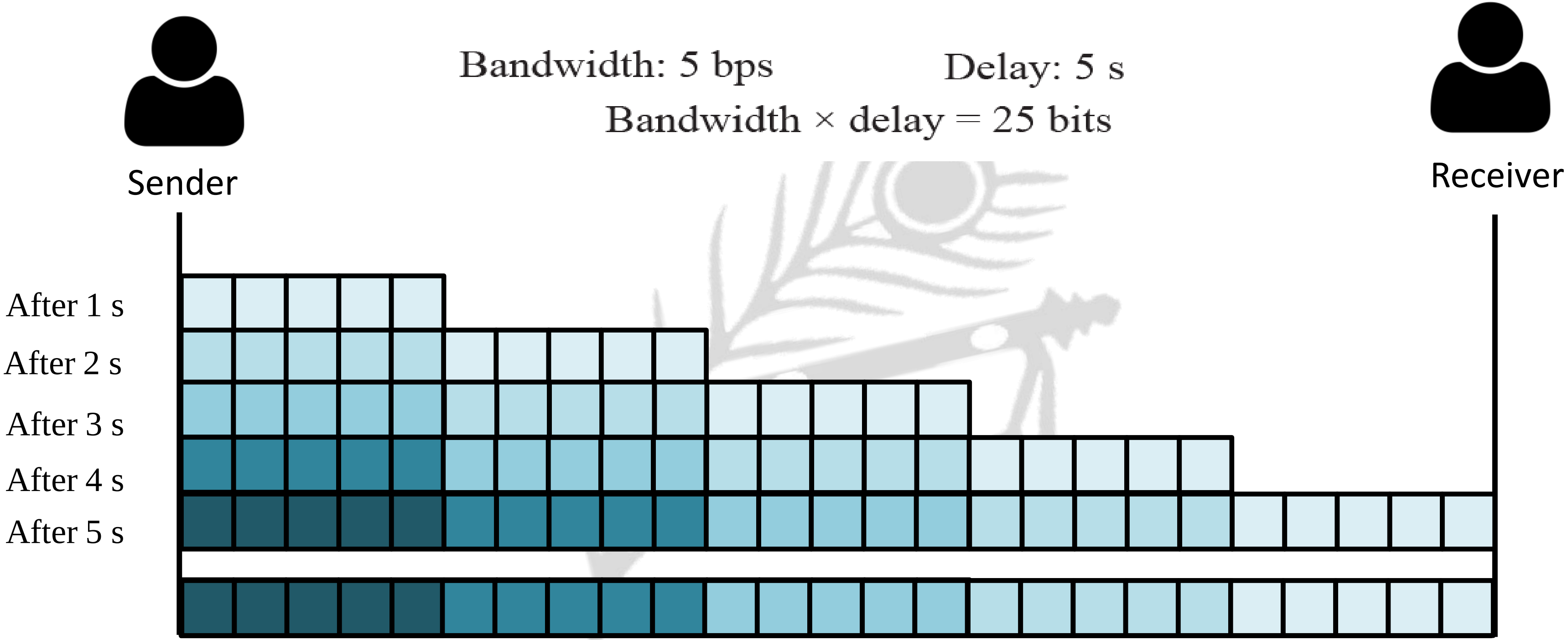


Volume = bandwidth × delay

Bandwidth-Delay



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

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

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

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

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