Computer Networks

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- Data Communication

When we communicate, we share information, which can be done either locally or remotely...

Local communication typically happens face-to-face, while remote communication occurs over a distance...

The term "telecommunication" which encompasses telephony, telegraphy and television, refers to communication over long distances (Tele = Far)

Data communications involve the exchange of data between two devices through a transmission medium, such as a wire cable.

Effectiveness of data communication system depends on four fundamental characteristics.

- Delivery: The system must deliver data to the correct destination. Data should be received by the intended device or user and only by that device or user.

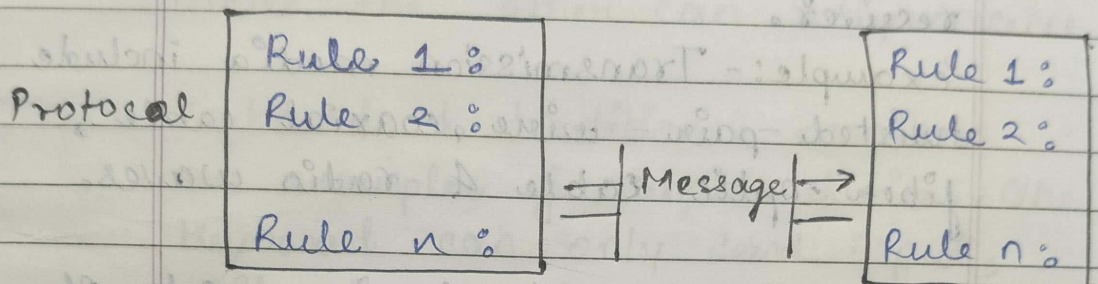
- Accuracy : The system must deliver the data accurately. Data that have been altered during transmission and left uncorrected are unusable.

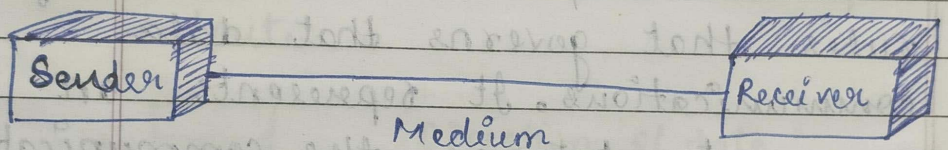
- Timeliness : The system must deliver data in a timely manner. Data delivered late are useless. For video & audio, timely delivery means delivering data as they are produced, in the same order, & w/o significant delay. This type of delivery is known as real-time transmission.

- Jitter : Jitter refers to the variation in packet arrival time, representing the uneven delay in the delivery of audio or video packets.
Example - if video packets are sent every 30 mins but some arrive with 30 mins delay and others with a 40 mins delay, the result is uneven video quality.

Components of Communication

A data communications system has five components:





- **Message :** It is the information (data) to be communicated.
  Common forms of information include text, numbers, pictures, audio & video.

- **Sender :** The sender is the device that transmits the data message. It can be a computer, workstation, telephone handset, video camera, or other similar devices.

- **Receiver :** The receiver is the device that receives the message. It can be a computer, workstation, telephone handset,

television, or other similar devices.

- Transmission medium: It is the physical path through which a message travels from sender to receiver.
  Example:- Transmission media include twisted-pair-wire, coaxial cable, fiber-optic cable & radio waves.
- Protocol: A protocol is a set of rules that governs that data communications. It represents an agreement between the communicating devices on how data should be transmitted & received.

~~Communication~~

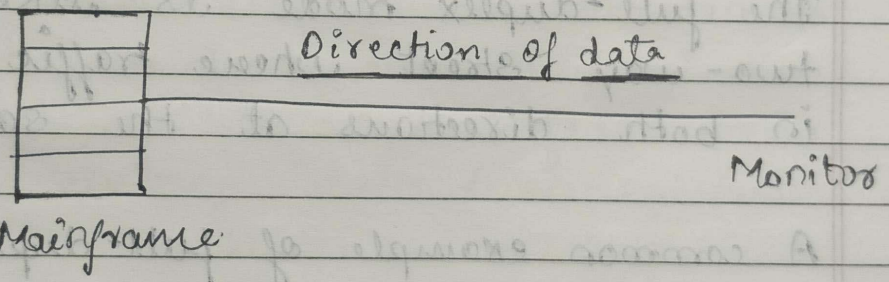
Data Flow Mode

Communication b/w two devices can be simplex, half duplex or full-duplex

- **Simplex**

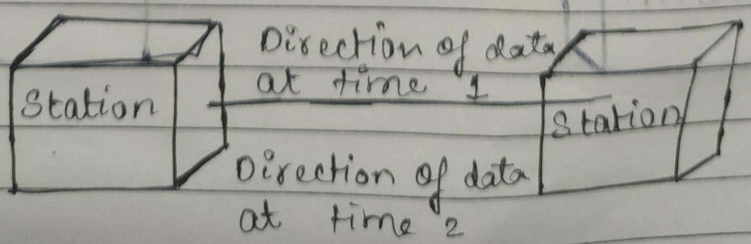
In simplex mode, communication is unidirectional, similar to a one-way street. Only one of the two devices on a link can transmit, while the other can only receive.

Keyboards & traditional monitors are examples of simplex devices. The keyboard can only send input, while the monitor can only display output.



- **Half-Duplex**

In half-duplex mode, each station can both transmit and receive, but not simultaneously. When one device is sending the other can only receive, and vice versa.



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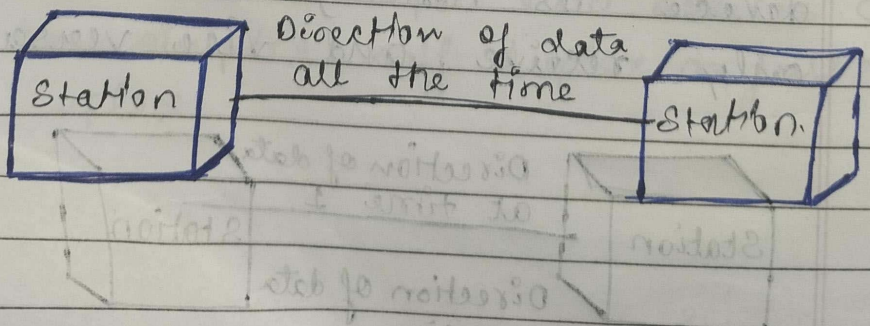
The half-duplex mode is similar to a one-lane road with traffic allowed in both directions.

Ex:- Walkie-talkies and CB (citizens band) radios.

- Full Duplex
- In full-duplex mode (also called duplex) both devices can transmit & receive simultaneously.

The full-duplex mode is like a two-way street where traffic flows in both directions at the same time.

A common example of full-duplex communication is the telephone network. When two people are conversing on a telephone line, both can talk and listen simultaneously.



Network

A network is a set of devices (often referred to as nodes) connected by communication links. A node can be a computer, printer, or any other device capable of sending and/or receiving data generated by other nodes on the network.

Network criteria

A network must meet several criteria, with the most important being performance, reliability & security.

- **Performance**
  - It is measured by transit time & response time. Transit time is the amount of time required for a message to travel from one device to another, while response time is the elapsed time between an inquiry and a response.
  - The performance of a network depends on several factors, including the no. of users, the type of transmission medium, the capabilities of the connected hardware

and the efficiency of the software.

- Reliability

In addition to the accuracy of delivery, network reliability is measured by the frequency of failures, the time it takes for a link to recover from a failure, and the network's robustness in the event of a catastrophe.

- Security

Network security issues include protecting data from unauthorized access, safeguarding data from damage & corruption, and implementing policies & procedures for recovering from breaches & data losses.

Delays in Network

1) Transmission Delay:
The time taken to transmit a packet from the host to the transmission medium is called transmission delay.

Given that B is the bandwidth in bits per second (bps) and L is the size of the data in bits, the transmission delay T_t is calculated as:

$$T_t = \frac{L}{B}$$

Suppose packet length (L) = 80 Bytes
Bandwidth (B) = 2 Kbps
L b - bits
B - Bytes

$$T_t = \frac{80 \times 8 \text{ bits}}{2 \times 10^3 \text{ bits/sec}}$$

$$= \frac{320}{1000}$$

$$= 320 \times 10^{-3} = 320 \text{ ms}$$

2) Propagation delay:
After a packet is transmitted into the medium, it must travel through the medium to reach the destination. The time taken for the last bit of the packet to reach the destination is called propagation delay.

$$T_p = \frac{\text{Distance}}{\text{Velocity}}$$

Suppose distance b/w two hosts A & B = 10,000 km.

Distance between

speed = 3×10^8 m/s

$$T_p = \frac{10,000 \times 10^3 \text{ m}}{3 \times 10^8 \text{ m/s}}$$

$$T_p = \frac{10^7}{3 \times 10^8}$$

$$T_p = \frac{10^{-1}}{3}$$

$$T_p = \frac{1}{30} = 0.033$$

3] Queueing delay:

When a packet arrives at the destination, it is not processed immediately. Instead, it may have to wait in a queue within a buffer. The time, the packet spends waiting in this queue before being processed is called a queueing delay.

Generally, queuing delay cannot be precisely calculated because there is

no specific formula for it.

This delay depends on the following factors:

- Queue Size: A larger queue size will result in a higher queueing delay. If the queue is empty, the delay will be minimal or nonexistent.
- Packet Arrival Rate: If more packets arrive in a short time interval, the queuing delay will be higher.
- Number of Servers/ Links: Fewer servers or links will generally result in a greater queuing delay.

4) Processing delay:
Once the packet is received, it undergoes processing, which is referred to as processing delay.

This delay represents the time required for the processor to handle the data packet, including tasks such as determining where to

forward the packets update the TTL (Time to live), and performing header checksum calculations.

Processing delay cannot be precisely calculated with a formula, as it depends on the speed of the processor, which varies from one to computer to another.

$$T_{total} = T_t + T_p + T_q + T_{pro}$$

Practice Question

Ques-1 Consider two hosts X and Y connected by a single direct link of rate 10^6 bits/sec. The distance between the two hosts is 10,000 km and the propagation speed along the link is 2×10^8 m/sec. Host X sends a file of 50,000 bytes as one large message to host Y continuously. Let the transmission & propagation delays be p ms and q ms respectively. Then the values of p and q are

$$p(T_t) = \frac{L}{B} = \frac{50,000 \times 8}{10^6}$$

$$= \frac{400000}{10^6} = \frac{40 \times 10^4}{10^6}$$

$$=$$

$= 40 \times 10^{-2}$

$= 40 \times 10^{-2} \times \frac{10^{-3}}{10^{-3}}$

$= 40 \times 10^{-5+3}$

$= 40 \times 10^{1} \times 10^{-3}$

$= 400 \times 10^{-3}$

$= 400\,ms$

a (Pt) $\frac{D}{S} = \frac{10,000 \times 10^3}{2 \times 10^8}$

$= \frac{5000}{10,000} \times 10^{3-8}$

$= 5000 \times 10^{-5}$

$= 5000 \times 10^{-5} \times \frac{10^{-3}}{10^{-3}}$

$= 50 \times 10^{2} \times 10^{-5}$

$= 50 \times 10^{-3}$

$= 50\,ms$

Ques-2 Consider a 100 Mbps link between an earth station (sender) and a satellite (receiver) at an altitude of 2100 km. The signal propagates at a speed of 3×10^8 m/s. The time taken (in ms, rounded off to two decimal places) for the receiver to completely receive a packet of 1000 bytes transmitted by the sender is

Total time = Tt + Pt + Qd + Processing time

$Tt = \frac{L}{B} = \frac{1000 \times 8}{100 \times 10^6} = \frac{8 \times 10^3}{10^8}$

$= 8 \times 10^{3-8}$

$= 8 \times 10^{-5} \times \frac{10^{-3}}{10^{-3}}$

$= 80 \text{ ms}$

$= 8 \times 10^{-8+3}$

$= 8 \times 10^{-3}$

$\frac{}{10^2}$

Tt = 0.08 ms

$Pt = \frac{\text{Distance}}{\text{speed}} = \frac{2100 \times 10^3}{3 \times 10^8}$

$= \frac{2100}{3} \times 10^{3-8}$

$= 700 \times 10^{-5}$

$= 7 \times 10^2 \times 10^{-3}$

$\frac{}{10^2}$

Pt = 7 ms

Total time = 0.08 + 7 = 7.08 ms

Lecture-2

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Introduction to Terminologies of Computer Network

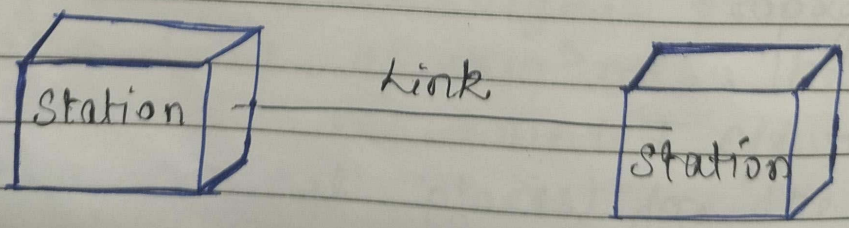
- Types of connection
- Physical Topology
- Categories of Networks
- The Internet
- Protocals

Type of Connections

→ Point-to-Point

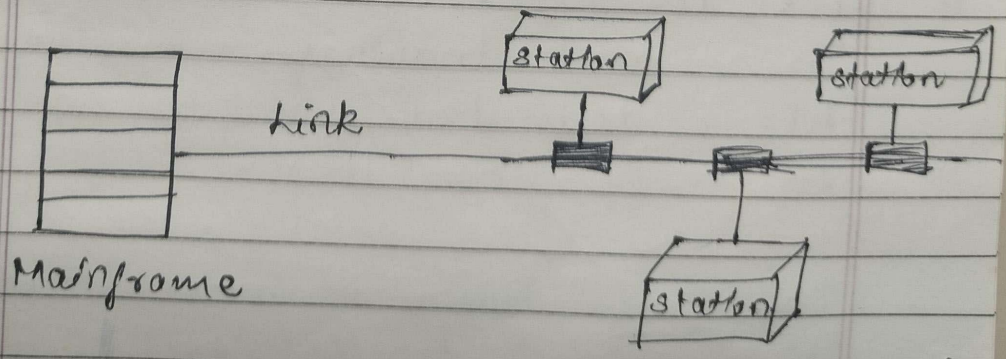
A point-to-point connection provides a dedicated link between two devices. The entire capacity of the link is reserved for transmission between those two devices.

While most point-to-point connections use a physical length of wire or cable to connect the two ends, other options, such as microwave or satellite links, are also possible.



Point-to-Point (Example)
When you change television channels using an infrared remote control you establish a point-to-point connection blw the remote control and the television's control.

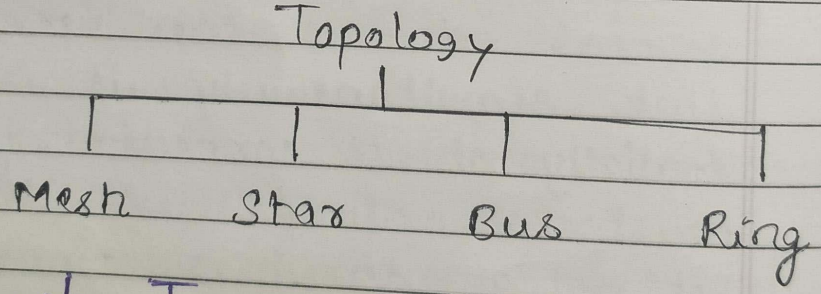
→ Multipoint
A multipoint (multidrop) connection is one in which more than two specific devices share a single link. In this environment, the channel's capacity is shared, either spatially or temporally. If several devices can use the link simultaneously it is a spatially shared connection. If users must take turns using the link it is a timeshare connection.



Physical Topology

The term physical topology refers to the way in which a network is laid out physically. Two or more devices connect to a link; two or more links form a topology.

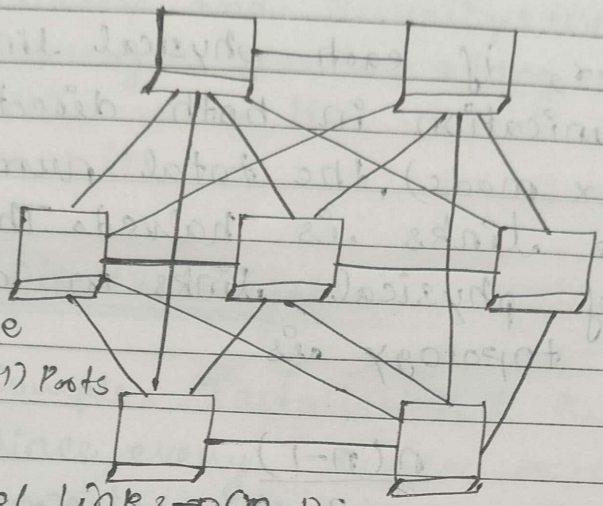
The topology of a network is the geometric representation of the relationship of all the links and linking devices (usually called nodes) to one another.



Mesh Topology

In a mesh topology, every device has a dedicated point to point link to every other device.

The term 'dedicated' means that each link carries traffic exclusively b/w the two devices it connects.

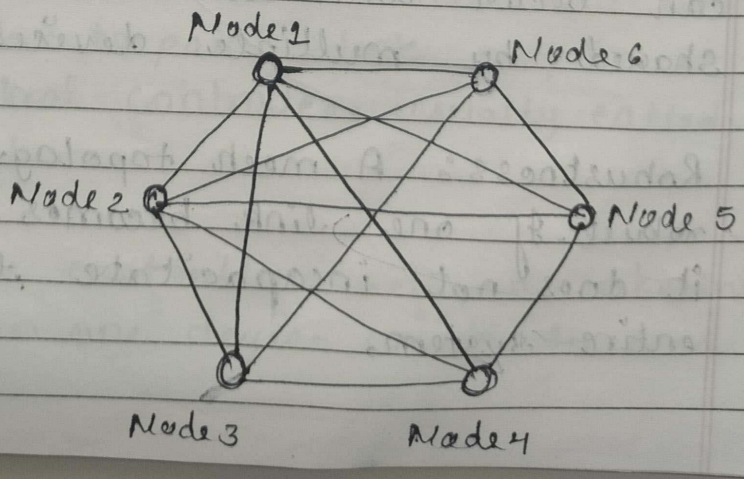


N = 7

Each device requires (n-1) ports

Total no. of links = $\frac{n(n-1)}{2}$

Ques To find the no. of physical links in a fully connected mesh network with n nodes, we first consider that each node must be connected to every other node. Node 1 must be connected to n-1 nodes, node 2 also be connected to n-1 nodes, and finally node n must be connected to n-1 nodes. We need (n-1) physical links.



- However, if each physical link allows communication in both directions (duplex mode), the total number of unique links is halved. Thus the no. of physical links in a mesh topology is

$$\frac{n(n-1)}{2}$$

$n = 5$

Each device require port = $n-1 = 4$

Total links = $\frac{n(n-1)}{2} = \frac{5 \times 4}{2} = 10$

→ **Advantages**

- Dedicated links: The use of dedicated links guarantees that each connection can carry its own data load, thus eliminating the traffic problems that can occur when links must be shared by multiple devices.

- Robustness: A mesh topology is robust. If one link becomes unusable, it does not incapacitate the entire system.

- Privacy and Security: When every message travels along a dedicated line, only the intended recipient sees it.

→ Disadvantages

- Complex Installation & Reconnection: Since every device must be connected to every other device, installation and reconnection can be complex and challenging.

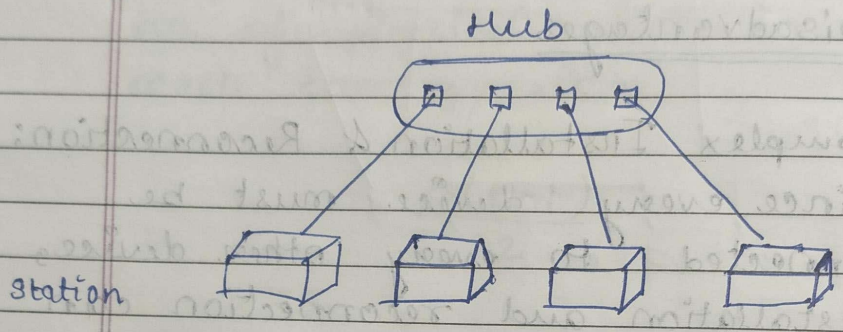
- High Cost:
The cost of implementation of a mesh topology is generally high due to the large number of required connections and cables.

▶ Star Topology

Here, each device has a dedicated point-to-point link only to a central controller, usually called a hub.

The controller acts an intermediary when one device wants to send data

to another, it sends the data to the controller, which then relays the data to the intended recipient.



- Each device require only 1 port
- Total no. of links = n

Advantages

- A star topology is less expensive than a mesh topology.
- It is easy to install & reconfigure.
- It is robustness, if one link fails, only that link is affected. All other links remain active.
- Fault identification & fault isolation is easy.

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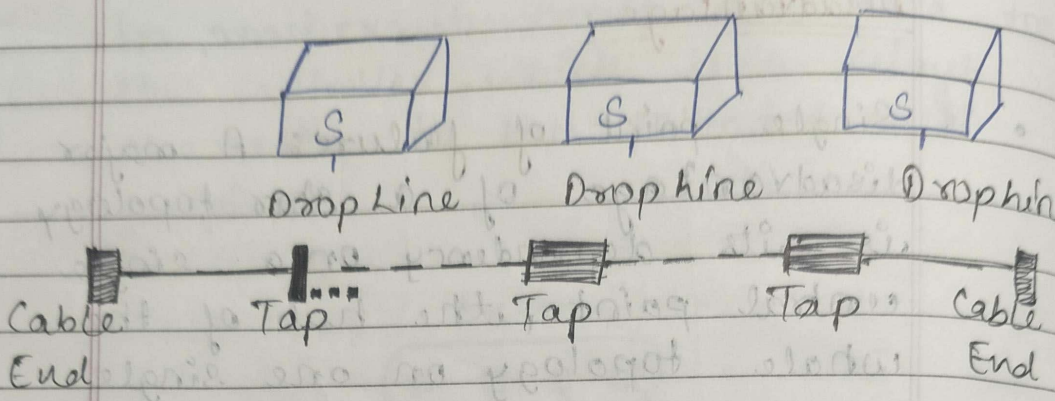
Disadvantage

- Single point of failure: A major disadvantage of a star topology is its dependency on a single central point, the hub of the whole topology on one single point, the hub. If the hub fails, the entire network is goes down.
- Cabling Requirements: Although a star topology requires far less cabling than a mesh topology each node must be connected to the central hub. As a result, star topology can require more cabling compared to some other topologies, such as ring or bus.

Bus Topology

A bus topology is multipoint where one long cable acts as a backbone to link all the devices in a network.

- Nodes are connected to the bus cable by drop lines and taps.



As a signal travels along the backbone, some of its energy is transformed into heat. Therefore, it becomes weaker as it travels further. For this, reason there is a limit on the number of taps a bus can support.

Advantage

- Ease of installation
- Lower cost as compare to mesh and star topology.

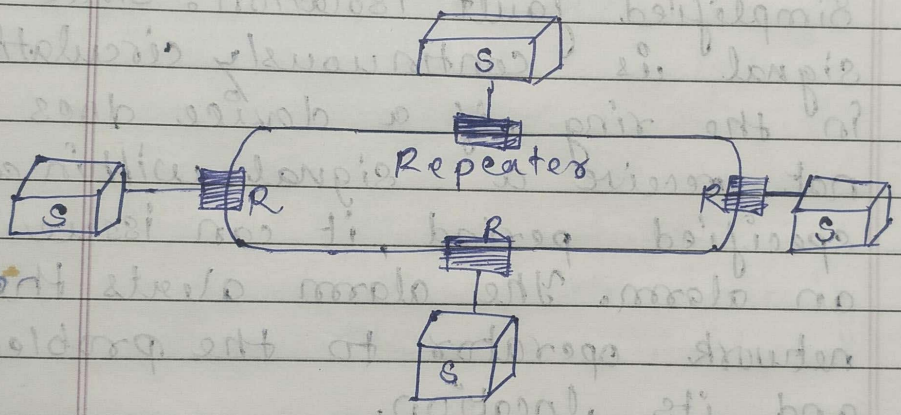
Disadvantage

- Difficult reconnection and fault isolation.
- Signal reflection at the taps can cause degradation in quality. This degradation can be controlled by limiting

the no. and spacing of devices connected to a given length of cable.

- Single point failure : A fault or break in the bus cable stops all transmission.

Ring Topology



- In a ring topology, each device has a dedicated point-point-point connection with only the two devices on either side of it.

- A signal is passed along the ring in one direction, from device to device, until it reaches its destination. Each device in the ring incorporates a repeater.

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Advantage

- A ring is relatively easy to install & reconfigure. Each device is linked to only its immediate neighbors (either physically or logically). To add or delete a device requires changing only two connections.

- Simplified fault isolation: Since a signal is continuously circulating in the ring, if a device does not receive a signal within a specified period, it can issue an alarm. The alarm alerts the network operator to the problem and its location.

Disadvantage

- Unidirectional traffic can be a disadvantage.

- Network disruption: In a simple ring, a break in the ring (such as a disabled station) can disrupt the entire network.

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The Internet

In the mid-1960s, mainframe computers in research organizations were standalone devices. Computers from different manufacturers were unable to communicate with one another.

The Advanced Research Projects Agency (ARPA) in the Department of Defense (DoD) was interested in finding a way to connect computers so that the researches they funded could share their findings, thereby reducing costs & eliminating duplication of effort.

By 1969, ARPANET became a reality. Four nodes located at the University of California & the University of Utah, were connected via Interface Message Processor (IMPs) to form a network. Software called the Network Control Protocol (NCP) facilitated communication b/w the hosts.

- Millions of connected computing devices:

  hosts = end systems

  - Running network apps
  - Communication links
    - fiber, copper, radio, satellite
    - Transmission rate = bandwidth
  - Routers: forward packets (chunks of data)

- Protocols control the sending & receiving of msgs.
  E.g. → TCP, IP, HTTP, FTP, PPP

  - Internet: 'networks of networks'
    - Loosely hierarchical
    - Public internet versus private intranet

  - Internet standards
    - RFC: Request for comments.
    - IETF: Internet Engineering Task Force.

Protocols

A protocol is a set of rules that govern data communications.

The key elements of a protocol are syntax, semantics, and timing.

→ Syntax....

It refers to the structure or format of the data, which means the order in which it is presented.

- Example - a simple protocol might expect the first 8 bits of data to represent the sender's address, the next 8 bits to represent the receiver's address, and the remaining portion of the stream to be the message itself.

→ Semantics.....

It refers to the meaning of each section of bits. It involves determining how is a particular pattern should be interpreted, and what action should be taken based on that interpretation.

- Example - does an address indicate the route to be taken or the final destination of the message?

→ Timing.....

It refers to two key characteristics: when data should be sent & how fast it can be sent.

- Example - if a sender produces data at 100 Mbps while the receiver can only process data at only 1 Mbps, the transmission rate overwhelms the receiver, leading of data lost.

Lecture-3

Network Models, Layering Protocal & their Services

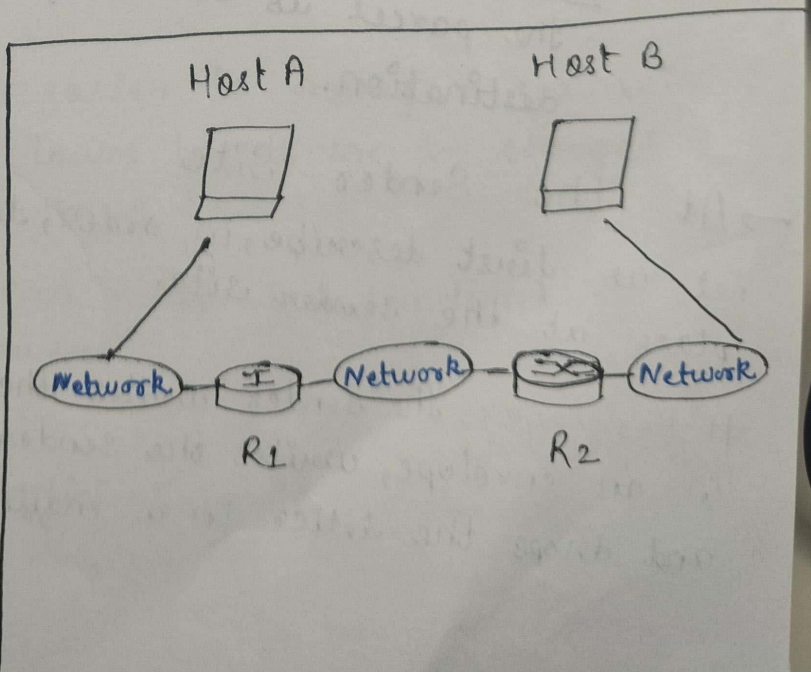
- layering
- OSI model
- TCP/IP Protocal Suite Model

Layering

Networks are Complex!

A network is a combination of hardware & software that sends data from one location to another. The hardware consists of the physical equipment that carries signals from one point of the network to another. The hardware consists of the physical ~~equippment that~~. The software consists of instruction sets that make possible the services that we expect from a network.

- Hosts
- Routers
- Links of various media
- Applications
- Protocals



Layering of a Postal Mail

Sender

Receiver

The letter is written, put in an envelope, and dropped in a mailbox

The letter is carried from the mailbox to a post office

The letter is delivered to a carrier by the post office.

Higher Layers

Middle Layers

Lower Layers

The letter is picked up, removed from the envelope, and read.

The letter is carried from the post office to the mailbox.

The letter is delivered from the carrier to the post office.

The parcel is carried from the source to the destination.

→ At the Sender Site

Let us first describe, in order, the activities that take place at the sender site.

Higher Layer: The sender writes the letter, inserts the letter in an envelope, writes the sender and receiver addresses, and drops the letter in a mailbox.

Middle Layer: The letter is picked up by a letter carrier and delivered to the post offices.

Lower Layer: The letter is sorted at the post office, a carrier transports the letter.

→ At the Receiver Site

Lower Layer: The carrier transports the letter to the post office.

Middle Layer: The letter is sorted & delivered to the recipient's mailbox.

Higher Layer: The receiver picks up the letter, opens the envelope, and reads it.

Layering

A technique to organize a network system into a succession of logically distinct entities, such that the service provided by one entity is Solely based on the service provided by the previous (lower level) entity.

- Advantages
  - Modularity - protocols easier to manage & maintain.
  - Abstract functionality - Lower layers can be changed without affecting the upper layers.
  - Reuse - upper layers can reuse the functionality provided by lower layers.
- Disadvantages

  Information hiding - inefficient implementations.

Network Models / Standardized Protocol Architectures

- Required for devices to communicate
- Two standards:
  - OSI Reference model
  - TCP/IP protocol suite

OSI - The Model

- Open Systems Interconnection (OSI) is a layered model
- Developed by the International Organization for Standardization (ISO).
- A theoretical system delivered too late! and has Seven Layers.
- Each layer performs a subset of the required communication functions.
- Each layer relies on the next lower layer to perform more primitive functions.
- Each layer provides services to the next higher layer.
- Changes in one layer should not require changes in other layers.

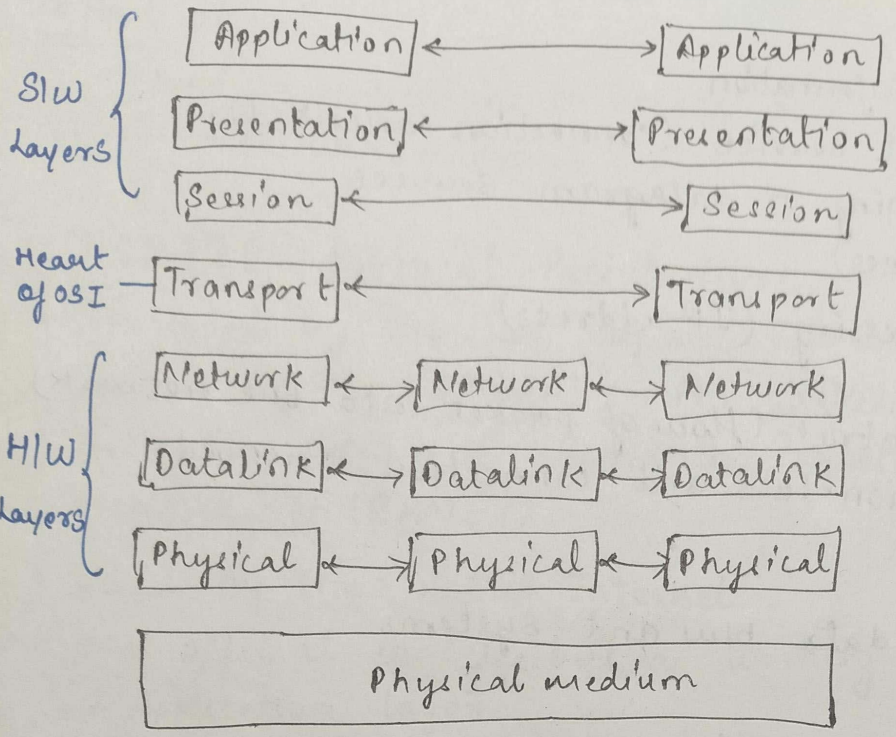
ISO OSI Reference Model

→ Seven Layers

- Lower three layers are peer-to-peer
- Next four layers are end-to-end.

- Physical

  Physical interface b/w devices.
  - Mechanical (joins 1/more signal conductor, circuits)
  - Electrical (Representation of bits and bit rate)
  - Functional (fn performed by individual circuits).
  - Procedural (sequence of events)



- Modulation & Demodulation.
- Raw bit stream
- Modem : broadly used to refer to any module that performs the fn above.
- Bits synchronization.

→ Data Link Layer

- Means of activating, maintaining and deactivating a reliable link.
- Segmenting mechanism
- Framing (Header & Trailer)
- Error detection
- Data synchronization (b/w Transmitter & Receiver)
- Flow control
- Error control.
- Higher Layers may assume error-free transmission.

- **Network Layer**
  - Transport of information.
  - Virtual circuit service (connection oriented).
  - Packet switching or datagram service (connection less)
  - Logical addressing (IP address)
  - Routing
  - Congestion control (flow of packet into the network)
  - Both connection-less and connection oriented.
- **Transport**
  - Exchange of data b/w end systems.
  - Error free
  - In sequence (segment)
  - No Losses
  - No duplicates
  - Quality of service (Throughput, transit, delay, error rate).
  - End-end process communication.
- **Session**
  - Control of dialogues b/w applications/ Dialogue discipline.
  - Grouping
  - Synchronization / check points
  - Recovery
- **Presentation**
  - Data formats
  - Architectures specific (Big-endian or little-endian)
  - Provide conversion from one encoding schema to another encoding schema.
  - Data compression
  - Encryption

- Application
  - Means for applications to access OSI environment.
  - Email, web browsers

TCP/IP Protocol Architecture

- Developed by the US Defense Advanced Research Project Agency (DARPA) for its packet switched network Advanced Research Projects Agency Network (ARPANET)
- Used by the global Internet.
- No official model but a working one.
  - Application layer
  - Host-to-Host or transport layer
  - Internet layer
  - Data link/Network access layer
  - Physical layer

Physical Layer

- Similar to OSI model physical layer.
- Physical interface b/w data transmission device (e.g. computer) and transmission medium or network.
- Characteristics of transmission medium.
- Signal levels
- Data rates

Network Access/Data Link Layer (1)

- Data Link Control (Logical Link Control) Sub Layer
- Means of activating, maintaining and deactivating
- A reliable link
- framing (Header)
- Error detection & control
- Media Access Control (MAC) sub layer.

- Allocation of channel.
- Physical addressing (MAC address)
- Higher layers do not need to know about underlying technology.
- Virtual point-point links b/w pairs of station

IP Layer

- Exchange of data b/w end system and network.
- Destination address provision
- Systems may be attached to different networks
- Datagram
- Routing functions across multiple networks
- Implemented in end systems and routers.
- Invoking services like priority.
- Connection less service
- Fragmentation
- Routing & IP addresses
- ARP and RARP

Transport Layer (TCP/UDP)

- Connection-less and connection oriented service.
- Reliable delivery of data.
- Segments
- Congestion control
- Ordering of delivery (Reassembling)
- Architecture specific (Big-endian or little-endian)
- Addressing (Port no. or SAP)
- UDP (TFTP, NFS, DNS)
- TCP (SMTP, HTTP, FTP)
- Error Control

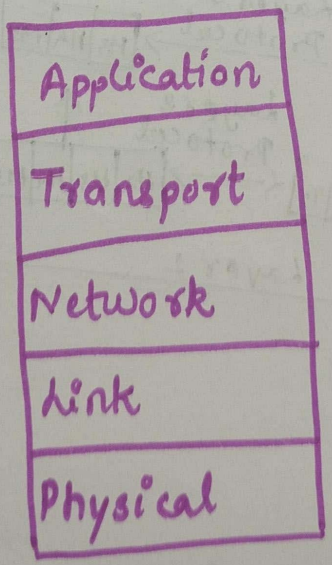
Application Layer

- Support for user applications
- File Transfer
  - User applications
  - Reliable data transfer for UDP users
  - Network management

Examples :- http, SMTP, FTP, etc.

Internet Protocol Stack

- Application : supporting network applications
  - FTP, SMTP, HTTP
- Transport : process-process data transfer
  - TCP, UDP
- Network : routing of datagrams from source to destination
  - IP, routing protocols
- Link : data transfer b/w neighboring network elements.
  - PPP, Ethernet
- Physical : bits "on the wire"



Network Access / Data Link Layer (1)

- Data link control (Logical link control) Sub layer
- Means of activating, maintaining and deactivating
- A reliable link
- Framing (Header)
- Error detection and control
- Media Access Control (MAC) sub layer
- Allocation of channel
- Physical addressing (MAC address)

Encapsulation → Screenshot

Protocol Hierarchies (2)

Information flow supporting virtual communication in layer 5.