
DATA COMMUNICATION

(WORKBOOK)

By,

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MODULE 1: TABLE OF CONTENTS

1.1 DATA COMMUNICATIONS

- 1.1.1 Components
- 1.1.2 Data Representation
- 1.1.3 Direction of Data Flow

1.2 NETWORKS

- 1.2.1 Network Criteria
- 1.2.2 Physical Structures
 - 1.2.2.1 Type of Connection
 - 1.2.2.2 Physical Topology
 - 1.2.2.2.1 Bus Topology
 - 1.2.2.2.2 Star Topology
 - 1.2.2.2.3 Ring Topology
 - 1.2.2.2.4 Mesh Topology

1.3 NETWORK TYPES

- 1.3.1 Local Area Network
- 1.3.2 Wide Area Network
 - 1.3.2.1 Internetwork
- 1.3.3 LAN vs. WAN
- 1.3.4 Switching
 - 1.3.4.1 Circuit-Switched Network
 - 1.3.4.2 Packet-Switched Network
- 1.3.5 The Internet
- 1.3.6 Accessing the Internet

1.4 STANDARDS AND ADMINISTRATION

- 1.4.1 Internet Standards
 - 1.4.1.1 Maturity Levels
 - 1.4.1.2 Requirement Levels
- 1.4.2 Internet Administration

1.5 PROTOCOL LAYERING

- 1.5.1 Scenarios
 - 1.5.1.1 Protocol Layering
- 1.5.2 Principles of Protocol Layering
- 1.5.3 Logical Connections

1.6 TCP/IP PROTOCOL SUITE

- 1.6.1 Layered Architecture
- 1.6.2 Layers in the TCP/IP Protocol Suite
- 1.6.3 Description of Each Layer
- 1.6.4 Encapsulation and Decapsulation
- 1.6.5 Addressing 42
- 1.6.6 Multiplexing and Demultiplexing

1.7 THE OSI MODEL

- 1.7.1 OSI versus TCP/IP
- 1.7.2 Lack of OSI Model's Success

1.8 DATA AND SIGNALS

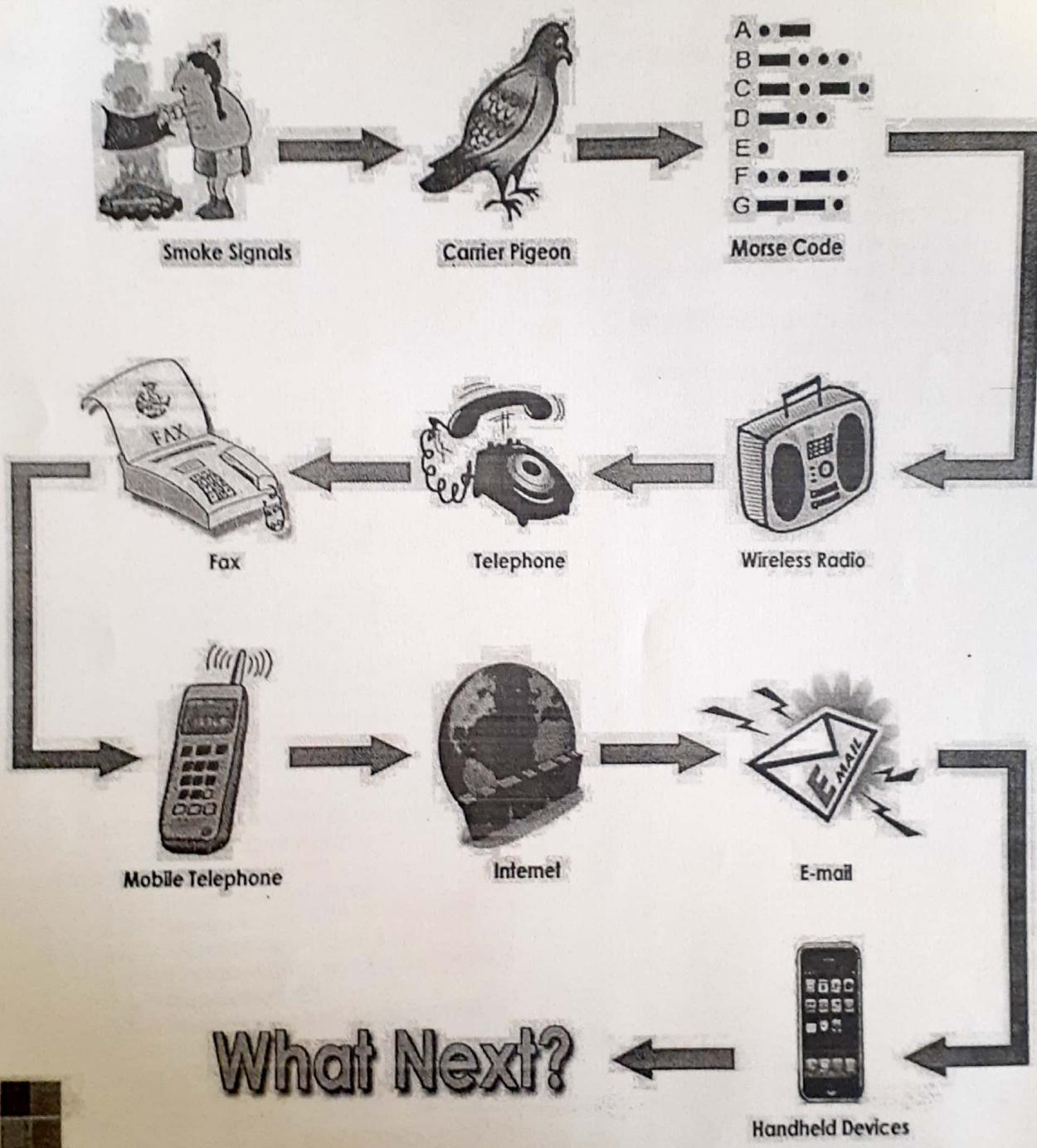
- 1.8.1 Analog and Digital Data
- 1.8.2 Analog and Digital Signals
- 1.8.3 Periodic and Nonperiodic

1.9 DIGITAL SIGNALS

- 1.9.1 Bit Rate
- 1.9.2 Bit Length
- 1.9.3 Digital Signal as a Composite Analog Signal

- 1.9.4 Transmission of Digital Signals
 - 1.9.4.1 Baseband Transmission
 - 1.9.4.2 Broadband Transmission (Using Modulation)
- 1.10 TRANSMISSION IMPAIRMENT
 - 1.10.1 Attenuation
 - 1.10.1.1 Decibel
 - 1.10.2 Distortion
 - 1.10.3 Noise
 - 1.10.3.1 Signal-to-Noise Ratio (SNR)
- 1.11 DATA RATE LIMITS
 - 1.11.1 Noiseless Channel: Nyquist Bit Rate
 - 1.11.2 Noisy Channel: Shannon Capacity
- 1.12 PERFORMANCE
 - 1.12.1 Bandwidth
 - 1.12.2 Throughput
 - 1.12.3 Latency (Delay)
 - 1.12.4 Bandwidth-Delay Product
 - 1.12.5 Jitter
- 1.13 DIGITAL-TO-DIGITAL CONVERSION
 - 1.13.1 Line Coding
 - 1.13.1.1 Characteristics
 - 1.13.2 Line Coding Schemes
 - 1.13.2.1 Unipolar Scheme
 - 1.13.2.2 Polar Schemes
 - 1.13.2.3 Bipolar Schemes (or Multilevel Binary)

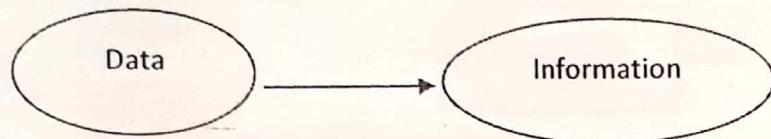
Communication Timeline



MODULE 1

Data

Information



Communication

DATA COMMUNICATIONS

- Data communication is defined as exchange of data between 2 or more devices over a transmission medium like wire cable.
- A communication-system is made up of
 -
 -
- For data-communication, the communicating-devices must be part of a communication-system.
- Four Fundamental Characteristics of a communication-system:

1) Delivery

2) Accuracy

3) Timeliness

4) Jitter



Components of Communication System

- Five components of a communication-system (Figure 1.1):

- 1) Message
- 2) Sender
- 3) Receiver
- 4) Transmission-Medium
- 5) Protocol

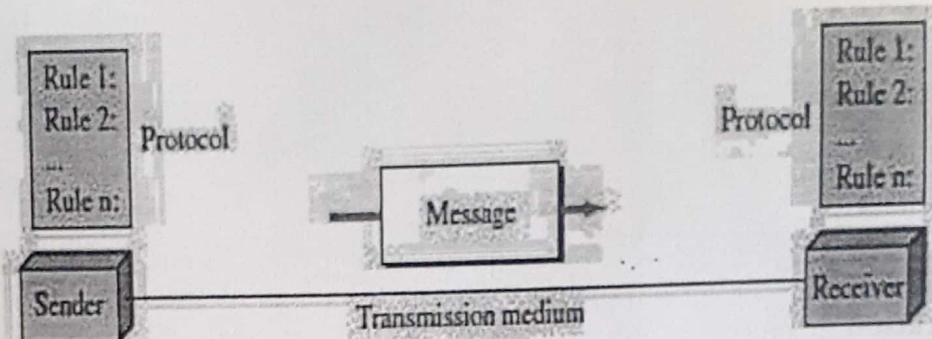


Figure 1.1 *Five components of data communication*

1) Message

2) Sender

3) Receiver

4) Transmission Medium

5) Protocol

Data Representation

Five different forms of information:

1) Text

2) Number

3) Image

4) Audio

5) Video

Direction of Data Flow

- Three ways of data-flow between 2 devices (Figure 1.2):
 - 1) Simplex
 - 2) Half-duplex
 - 3) Full-duplex

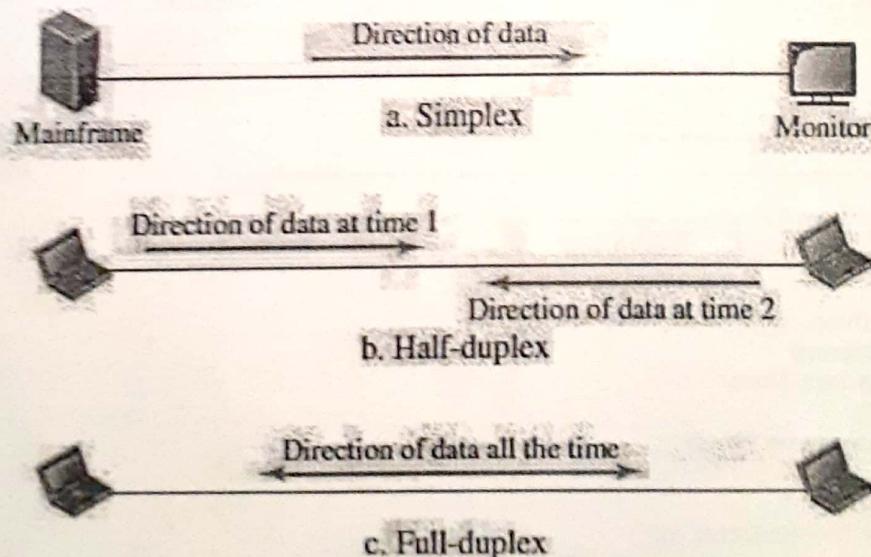


Figure 1.2 Data flow (simplex, half-duplex, and full-duplex)

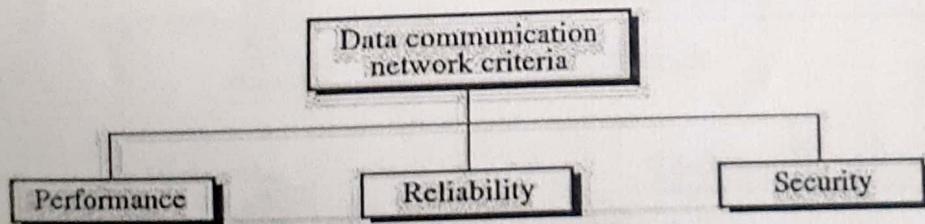
1) Simplex

2) Half Duplex

3) Full Duplex

NETWORKS

Network Criteria



- A network must meet following 3 criteria's:

1) Performance

- i) Transit Time

- ii) Response Time

2) Reliability

➤ Reliability is measured by

- frequency of network-failure
- time taken to recover from a network-failure
- network's robustness in a disaster

➢ More the failures are, less is the network's reliability.

3) Security

➢ Security refers to the protection of data from the unauthorized access or damage.

➢ It also involves implementing policies for recovery from data-losses.

Physical Structures

Type of Connection

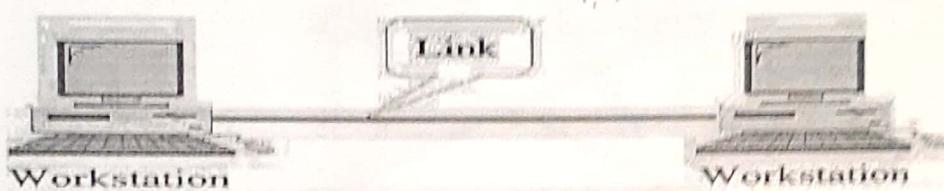
- Two types of connections

1) Point-to-Point

➢ Only two devices are connected by a dedicated-link (Figure 1.3a).

➢ Entire-capacity of the link is reserved for transmission between those two devices.

➢ For example: Point-to-Point connection b/w remote-control & TV for changing the channels.

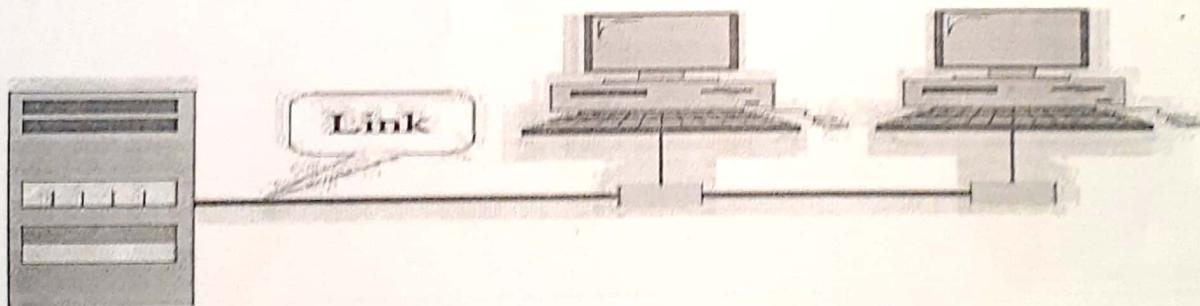


2) Multipoint (Multi-Drop)

➢ Three or more devices share a single link.

➢ The capacity of the channel is shared, either spatially or temporally (Figure 1.3b).

- i) If link is used simultaneously by many devices, then it is spatially shared connection.
- ii) If user takes turns while using the link, then it is time shared (temporal) connection.
(spatially → space or temporally → time)



Physical Topology

- The physical-topology defines how devices are connected to make a network.
- Four basic topologies are:

- 1) Mesh
- 2) Star
- 3) Bus and
- 4) Ring

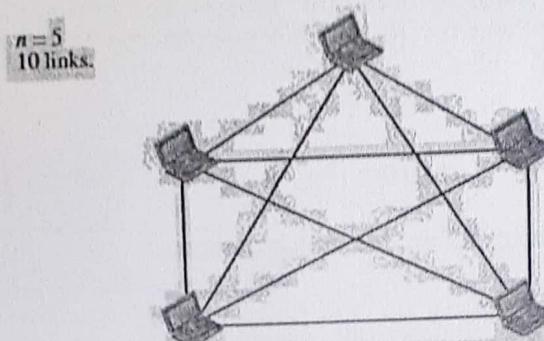
Mesh Topology

Figure 1.7 A fully connected mesh topology (five devices)

- Advantages

- Disadvantages:

Star Topology

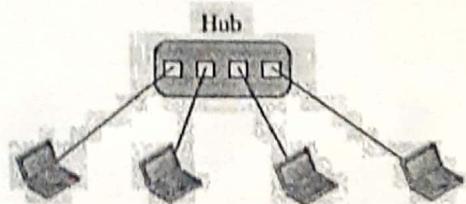
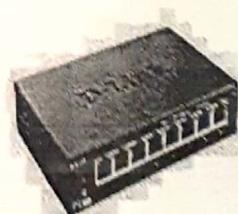


Figure 1.5 A star topology connecting four stations

- Advantages:



HUB

- Disadvantages:

Bus Topology

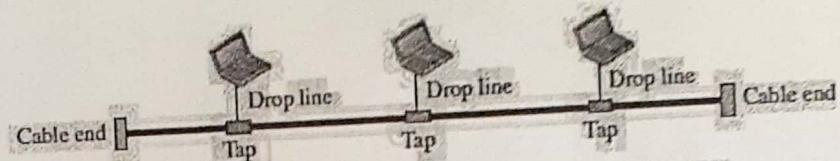


Figure 1.4 A bus topology connecting three stations

- Advantages:

- Disadvantages:

Ring Topology

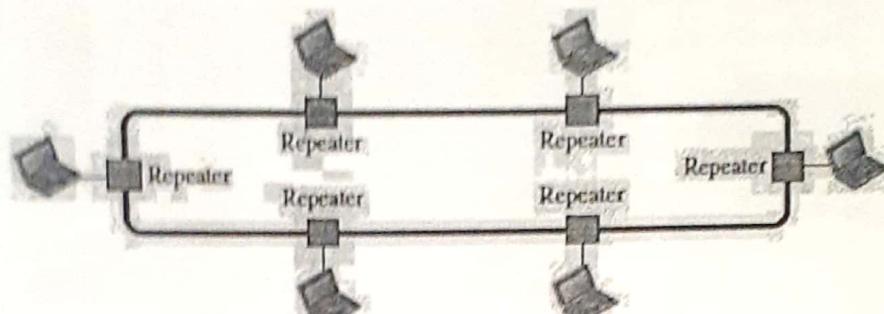
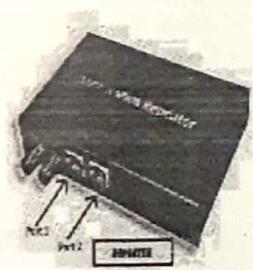


Figure 1.6 A ring topology connecting six stations

- Advantages:



- Disadvantages:

Two problems for building large networks

- How can we extend / increase the capacity of the basic networks ? (#nodes, #links, length of the links)
- How can we interconnect two different networks (example hub to Mesh, ring to a bus, etc...)

Solution to both the problems

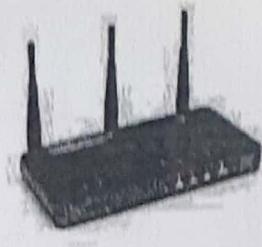
Interconnection Devices – Repeaters, Hubs, switches, Bridges, Routers, Gateways

Simple Length Extension =

- Length Extension + Filtering =

Length Extension + Filtering + Interconnection of two different topologies =

Interconnection of two different protocols =



Network Types

- Two popular types of networks:
 - 1) LAN (Local Area Network) &
 - 2) WAN (Wide Area Network)

LAN

- LAN is used to connect computers in a single office, building or campus (Figure 1.8).
- LAN is usually privately owned network.
- A LAN can be simple or complex.
 - 1) Simple: LAN may contain 2 PCs and a printer.
 - 2) Complex: LAN can extend throughout a company.
- Each host in a LAN has an address that uniquely defines the host in the LAN.
- A packet sent by a host to another host carries both source host's and destination host's addresses.
- LANs use a smart connecting switch.
- The switch is able to
 - recognize the destination address of the packet &
 - guide the packet to its destination.
- The switch
 - reduces the traffic in the LAN &
 - allows more than one pair to communicate with each other at the same time.
- Advantages:
 - 1) **Resource Sharing**
 - Computer resources like printers and hard disks can be shared by all devices on the network.
 - 2) **Expansion**
 - Nowadays, LANs are connected to WANs to create communication at a wider level.

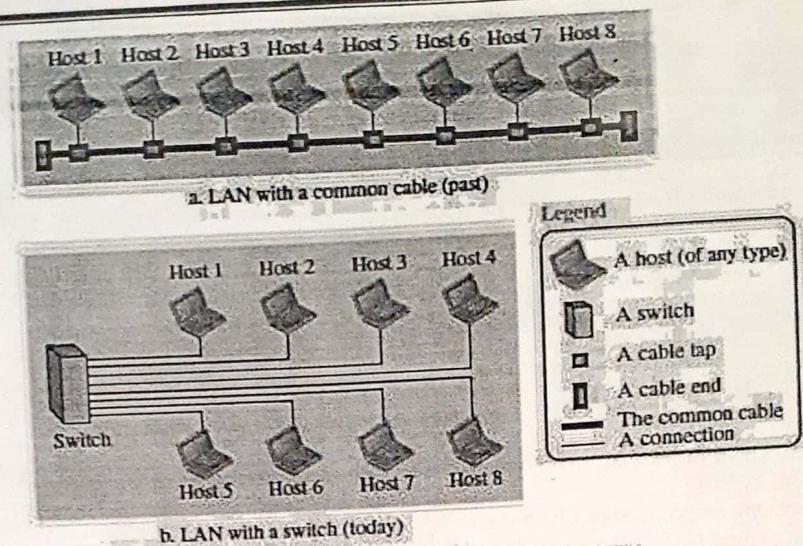


Figure 1.8 An isolated LAN in the past and today

WAN

- WAN is used to connect computers anywhere in the world.
- WAN can cover larger geographical area. It can cover cities, countries and even continents.
- WAN interconnects connecting devices such as switches, routers, or modems.
- Normally, WAN is
 - created & run by communication companies (Ex: BSNL, Airtel)
 - leased by an organization that uses it.
- A WAN can be of 2 types:

1) Point-to-Point WAN

- A point-to-point WAN is a network that connects 2 communicating devices through a transmission media (Figure 1.9).

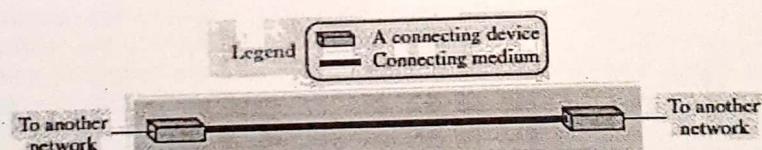


Figure 1.9 A point-to-point WAN

2) Switched WAN

- A switched WAN is a network with more than two ends.
- The switched WAN can be the backbones that connect the Internet.
- A switched WAN is a combination of several point-to-point WANs that are connected by switches (Figure 1.10).

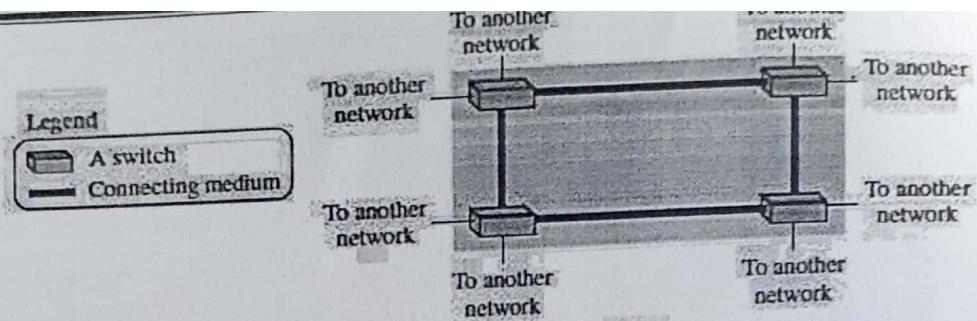


Figure 1.10 A switched WAN

Internetwork

- A network of networks is called an internet. (Internet → inter-network) (Figure 1.12).
- For example (Figure 1.11):
 - Assume that an organization has two offices,
 - i) First office is on the east coast &
 - ii) Second office is on the west coast.
 - Each office has a LAN that allows all employees in the office to communicate with each other.
 - To allow communication between employees at different offices, the management leases a point-to-point dedicated WAN from a ISP and connects the two LANs.
 - (ISP → Internet service provider such as a telephone company ex: BSNL).

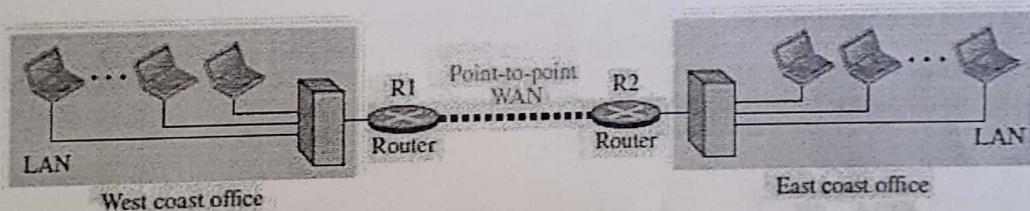


Figure 1.11 An internetwork made of two LANs and one point-to-point WAN

- When a host in the west coast office sends a message to another host in the same office, the router blocks the message, but the switch directs the message to the destination.
- On the other hand, when a host on the west coast sends a message to a host on the east coast, router R1 routes the packet to router R2, and the packet reaches the destination.

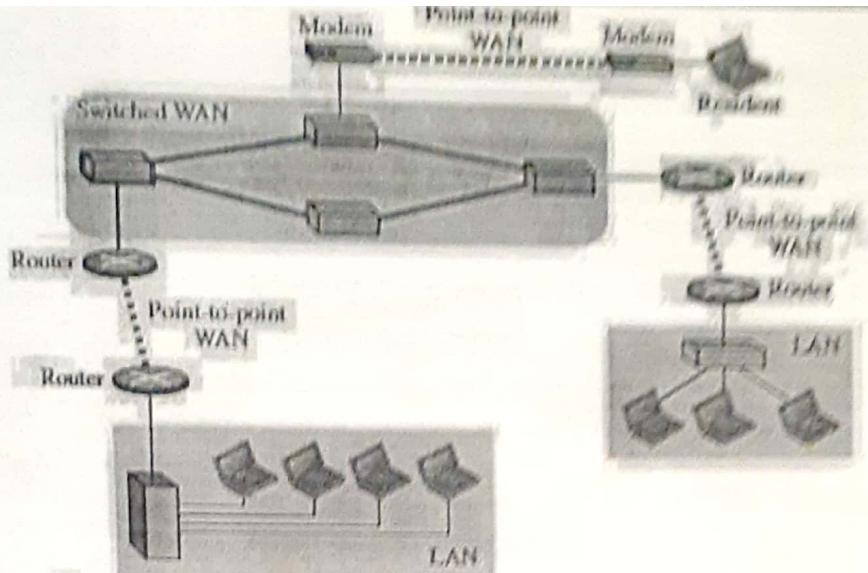


Figure 1.12 A heterogeneous network made of four WANs and three LANs

1.3.3 LAN vs. WAN

Parameters	LAN	WAN
Expands to	Local Area Network	Wide Area Network
Meaning	LAN is used to connect computers in a single office, building or campus	WAN is used to connect computers in a large geographical area such as countries
Ownership of network	Private	Private or public
Range	Small: up to 10 km	Large: Beyond 100 km
Speed	High: Typically 10, 100 and 1000 Mbps	Low: Typically 1.5 Mbps
Propagation Delay	Short	Long
Cost	Low	High
Congestion	Less	More
Design & maintenance	Easy	Difficult
Fault Tolerance	More Tolerant	Less Tolerant
Media used	Twisted pair	Optical fiber or radio waves
Used for	College, Hospital	Internet
Interconnects	LAN interconnects hosts	WAN interconnects connecting devices such as switches, routers, or modems

1.3.4 Switching

- An internet is a switched network in which a switch connects at least two links together.
 - A switch needs to forward data from a network to another network when required.

The two types of switched networks are 1) circuit-switched and 2) packet-switched networks.

3.3.1.1 Circuit Switched Network

- Two types of switched networks

1.3.4.1 Circuit Switched Network

 - A dedicated connection, called a circuit, is always available between the two end systems.
 - The switch can only make it active or inactive.

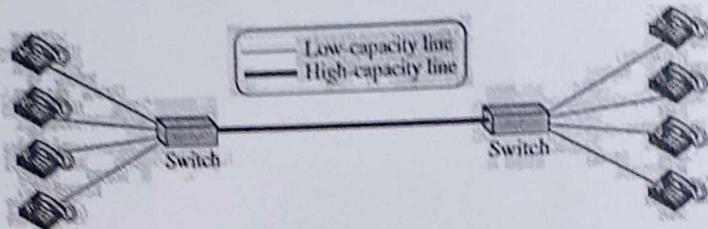


Figure 1.13 A circuit-switched network

- As shown in Figure 1.13, the 4 telephones at each side are connected to a switch.
 - The switch connects a telephone at one side to a telephone at the other side.
 - A high-capacity line can handle 4 voice communications at the same time.
 - The capacity of high line can be shared between all pairs of telephones.
 - The switch is used for only forwarding.

- #### ➤ Advantage:

A circuit-switched network is efficient only when it is working at its full capacity.

- #### ➤ Disadvantage:

Most of the time, the network is inefficient because it is working at partial capacity.

1.3.4.2 Packet Switched Network

- In a computer network, the communication between the 2 ends is done in blocks of data called packets.
 - The switch is used for both storing and forwarding because a packet is an independent entity that can be stored and sent later.

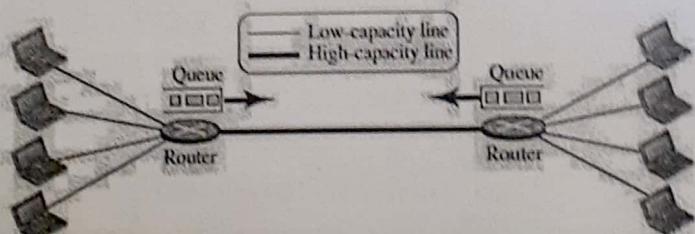


Figure 1.14 A packet-switched network

- As shown in Figure 1.14, the 4 computers at each side are connected to a router.
 - A router has a queue that can store and forward the packet.
 - The high-capacity line has twice the capacity of the low-capacity line.
 - If only 2 computers (one at each site) need to communicate with each other, there is no waiting for the packets.
 - However, if packets arrive at one router when high-capacity line is at its full capacity,

- However,
the pack

the packets should be stored and forwarded, advantages:

- #### Advantages:

A packet-switched network is more efficient than a circuit-switched network because it uses bandwidth more effectively.

1.3.5 The Internet Today

* A network of networks is called an internet. (Internet → inter-network)

• Internet is made up of (Figure 1.15)

- 1) Backbones
- 2) Provider networks &
- 3) Customer networks

1) Backbones

- Backbones are large networks owned by communication companies such as BSNL and Airtel.
- The backbone networks are connected through switching systems, called peering points.

2) Provider Networks

- Provider networks use the services of the backbones for a fee.
- Provider networks are connected to backbones and sometimes to other provider networks.

3) Customer Networks

- Customer networks actually use the services provided by the Internet.
- Customer networks pay fees to provider networks for receiving services.

• Backbones and provider networks are also called Internet Service Providers (ISPs).

• The backbones are often referred to as international ISPs.

The provider networks are often referred to as national or regional ISPs.

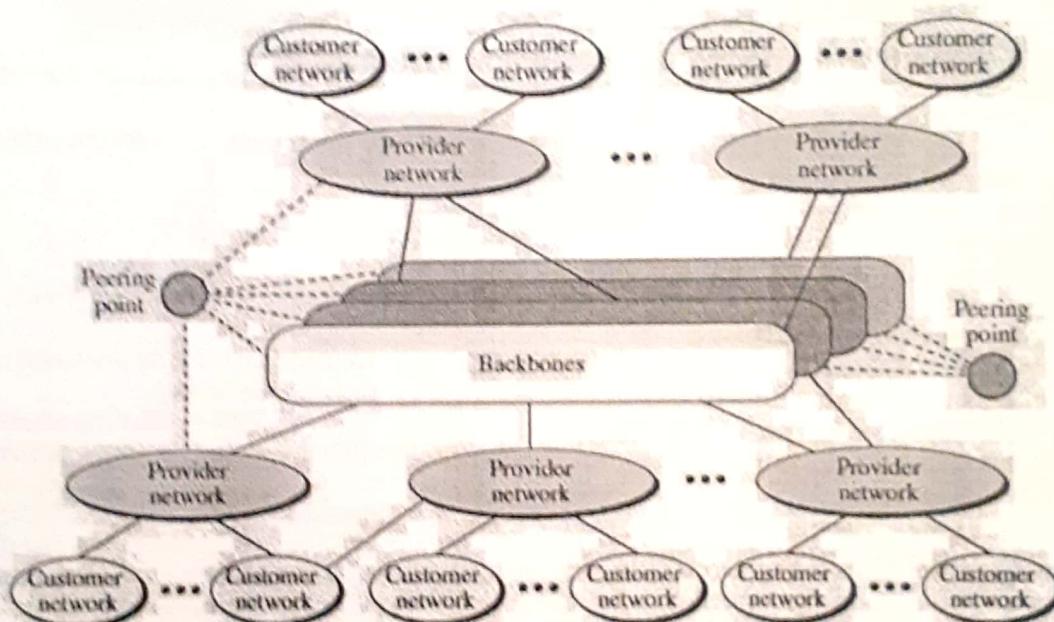


Figure 1.15 The Internet today

1.3.6 Accessing the Internet

- The Internet today is an internetwork that allows any user to become part of it.
- However, the user needs to be physically connected to an ISP.
- The physical connection is normally done through a point-to-point WAN.

1) Using Telephone Networks

- Most residences have telephone service, which means they are connected to a telephone network.
- Most telephone networks have already connected themselves to the Internet.
- Thus, residences can connect to the Internet using a point-to-point WAN.
- This can be done in two ways:

A) Dial-up service

- ☒ A modem can be added to the telephone line.
- ☒ A modem converts data to voice.
- ☒ The software installed on the computer
 - dials the ISP &
 - imitates making a telephone connection.
- ☒ Disadvantages:
 - i) The dial-up service is very slow.
 - ii) When line is used for Internet connection, it cannot be used for voice connection.
 - iii) It is only useful for small residences.

B) DSL Service

- ☒ DSL service also allows the line to be used simultaneously for voice & data communication.
- ☒ Some telephone companies have upgraded their telephone lines to provide higher speed Internet services to residences.

2) Using Cable Networks

- A residence can be connected to the Internet by using cable service.
- Cable service provides a higher speed connection.
- The speed varies depending on the number of neighbors that use the same cable.

3) Using Wireless Networks

- A residence can use a combination of wireless and wired connections to access the Internet.
- A residence can be connected to the Internet through a wireless WAN.

4) Direct Connection to the Internet

- A large organization can itself become a local ISP and be connected to the Internet.
- The organization
 - leases a high-speed WAN from a carrier provider and
 - connects itself to a regional ISP.

1.4.1.2 Requirement Levels

- RFCs are classified into 5 requirement levels:

1) Required

- An RFC labeled required must be implemented by all Internet systems to achieve minimum conformance.
- For example, IP and ICMP are required protocols.

2) Recommended

- An RFC labeled recommended is not required for minimum conformance.
- It is recommended because of its usefulness.
- For example, FTP and TELNET are recommended protocols.

3) Elective

- An RFC labeled elective is not required and not recommended.
- However, a system can use it for its own benefit.

4) Limited Use

- An RFC labeled limited use should be used only in limited situations.
- Most of the experimental RFCs fall under this category.

5) Not Recommended

- An RFC labeled not recommended is inappropriate for general use.
- Normally a historic RFC may fall under this category.

1.4.2 Internet Administration

1) ISOC

- ISOC is a nonprofit organization formed to provide support for Internet standards process (Fig 1.17).
- ISOC maintains and supports other Internet administrative bodies such as IAB, IETF, IRTF, and IANA.

2) IAB

- IAB is the technical advisor to the ISOC.
- Two main purposes of IAB:
 - i) To oversee the continuing development of the TCP/IP Protocol Suite
 - ii) To serve in a technical advisory capacity to research members of the Internet community.

- Another responsibility of the IAB is the editorial management of the RFCs.
- IAB is also the external liaison between the Internet and other standards organizations and forums.
- IAB has 2 primary components: i) IETF and ii) IRTF.

i) IETF

- IETF is a forum of working groups managed by the IESG.
- IETF is responsible for identifying operational problems & proposing solutions to the problems.
- IETF also develops and reviews specifications intended as Internet standards.
- The working groups are collected into areas, and each area concentrates on a specific topic.
- Currently 9 areas have been defined. The areas include applications, protocols, routing, network management next generation (IPng), and security.

ii) IRTF

- IRTF is a forum of working groups managed by the IRSG.
- IRTF focuses on long-term research topics related to Internet protocols, applications, architecture, and technology.

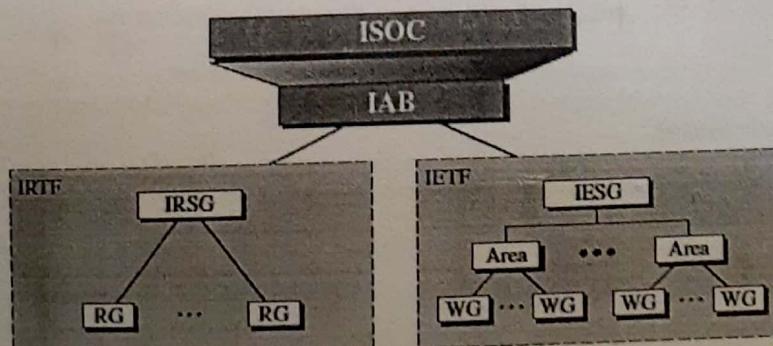


Figure 1.17 Internet administration

NETWORK MODELS

PROTOCOL LAYERING

- A protocol defines the rules that both the sender and receiver and all intermediate devices need to follow to be able to communicate effectively.
- When communication is simple, we may need only one simple protocol.
When communication is complex, we need to divide the task b/w different layers. We need a protocol at each layer, or protocol layering.

First Scenario

- In the first scenario, communication is so simple that it can occur in only one layer (Figure 2.1).
- Assume Maria and Ann are neighbors with a lot of common ideas.
- Communication between Maria and Ann takes place in one layer, face to face, in the same language

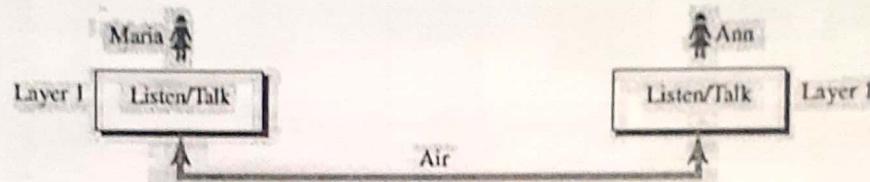


Figure 2.1 A single-layer protocol

Second Scenario

- Maria and Ann communicate using regular mail through the post office (Figure 2.2).
- However, they do not want their ideas to be revealed by other people if the letters are intercepted.
- They agree on an encryption/decryption technique.
- The sender of the letter encrypts it to make it unreadable by an intruder; the receiver of the letter decrypts it to get the original letter.

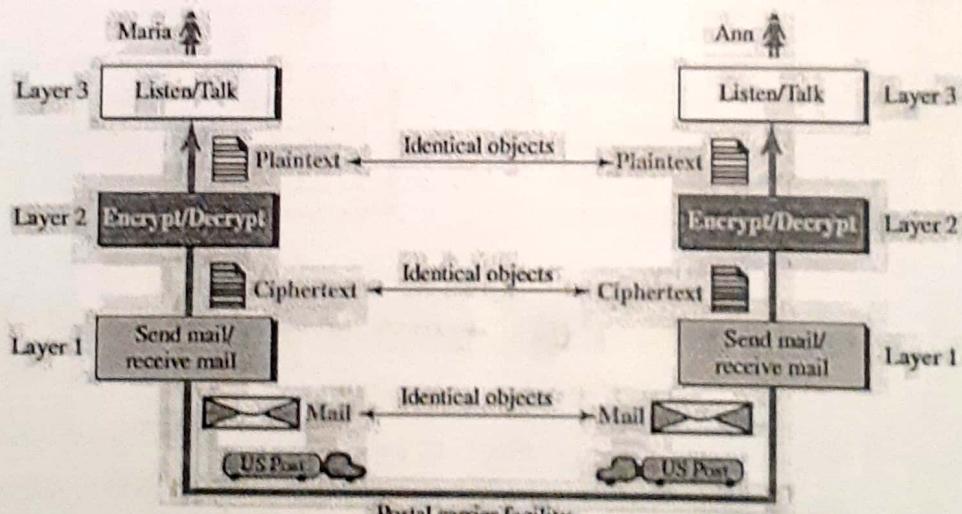


Figure 2.2 A three-layer protocol

Principles of Protocol Layering

1) First Principle

- If we want bidirectional communication, we need to make each layer able to perform 2 opposite tasks, one in each direction.
- For example, the third layer task is to listen (in one direction) and talk (in the other direction).

2) Second Principle

- The two objects under each layer at both sites should be identical.
- For example, the object under layer 3 at both sites should be a plaintext letter.

Logical Connections

- We have layer-to-layer communication (Figure 2.3).
- There is a logical connection at each layer through which 2 end systems can send the object created from that layer.

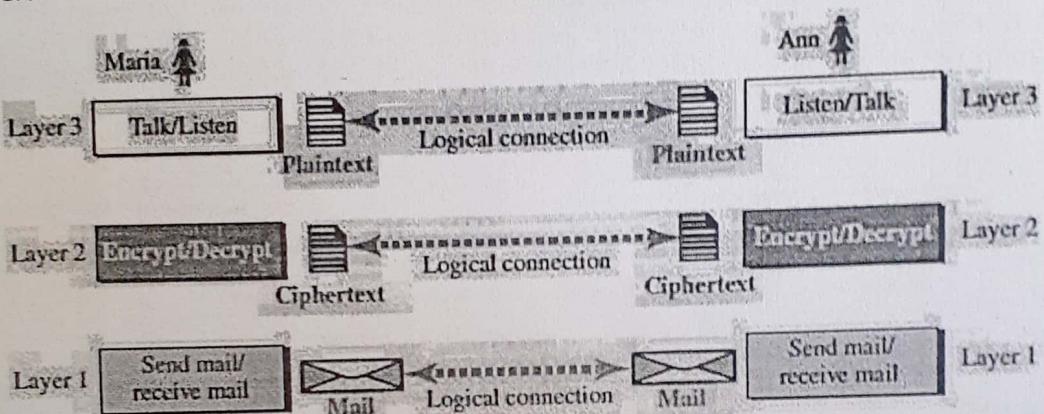
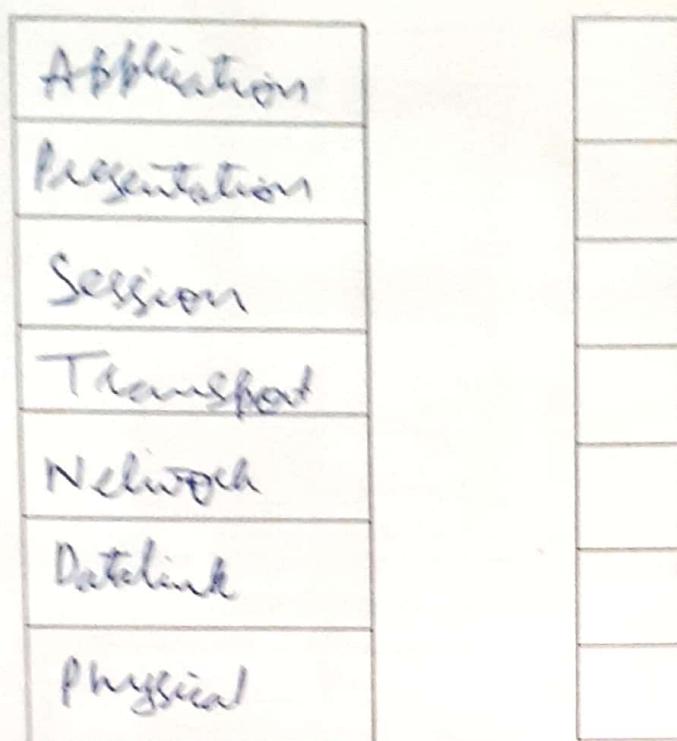


Figure 2.3 Logical connection between peer layers

Network Architecture

1) The ISO/OSI layered Architecture

**Physical Layer**

- Main Responsibility:

Physical-layer (PL) is responsible for movements of individual bits from one node to another.

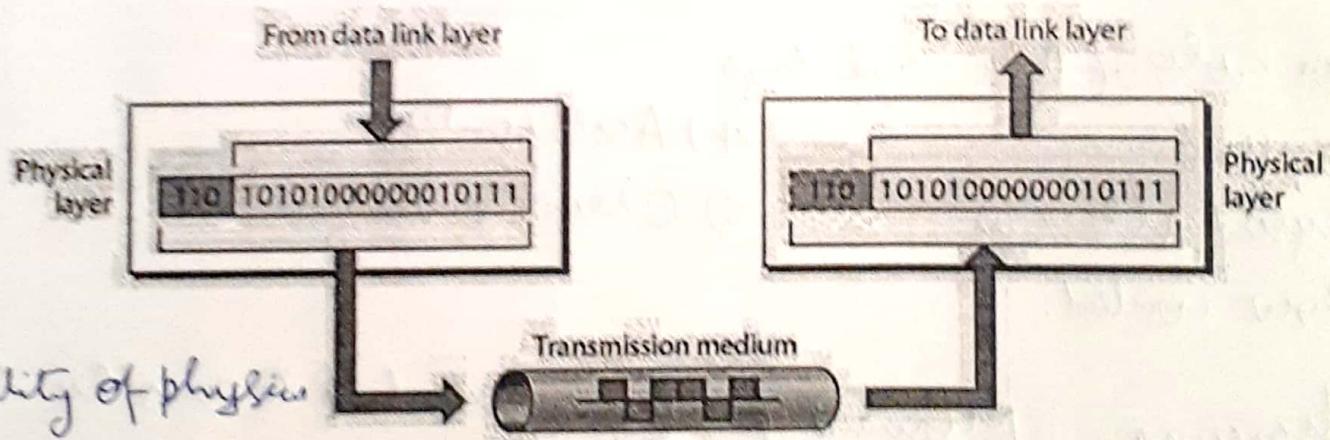


Figure 2.5 Physical layer

- 1) Physical Characteristics interface & medium
- 2) Representation of bits
- 3) Data rate
- 4) Synchronization of bits
- 5) Line configuration

- 6) Physical Topology.
 7) Transmission mode.

Data Link Layer

- Main Responsibility:
 Data-link-layer (DLL) is responsible for moving frames from one node to another node.

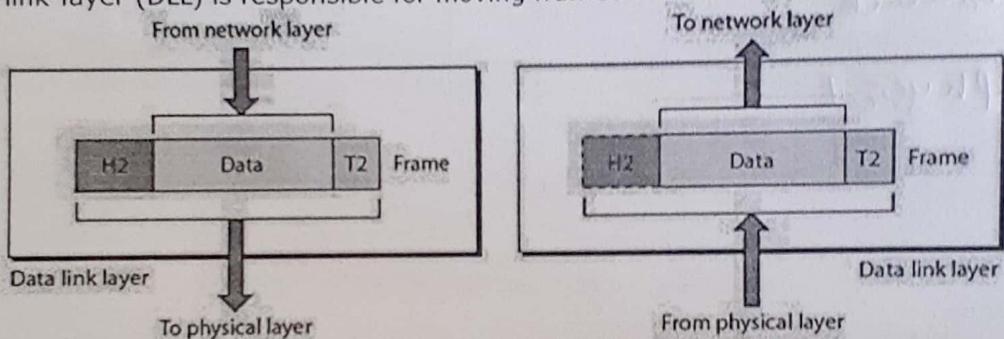


Figure 2.6 Data link layer

Major roles of Data-link layer.

- 1) framing
- 2) Physical Addressing.
- 3) flow control.
- 4) A cell control
- 5) Error control.

framing, Movement of frame from one loop to another loop

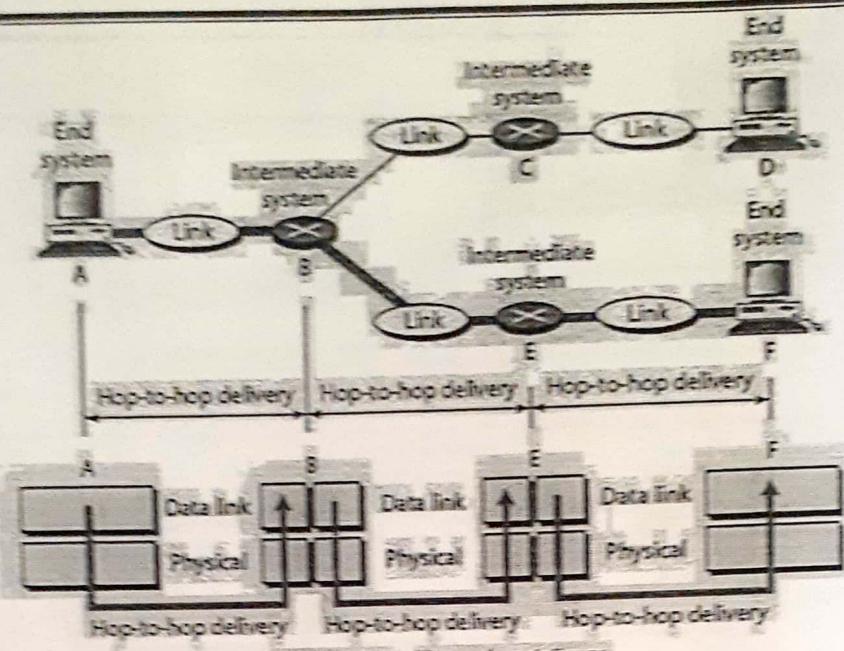


Figure 2.7 Hop-to-hop delivery

Network Layer

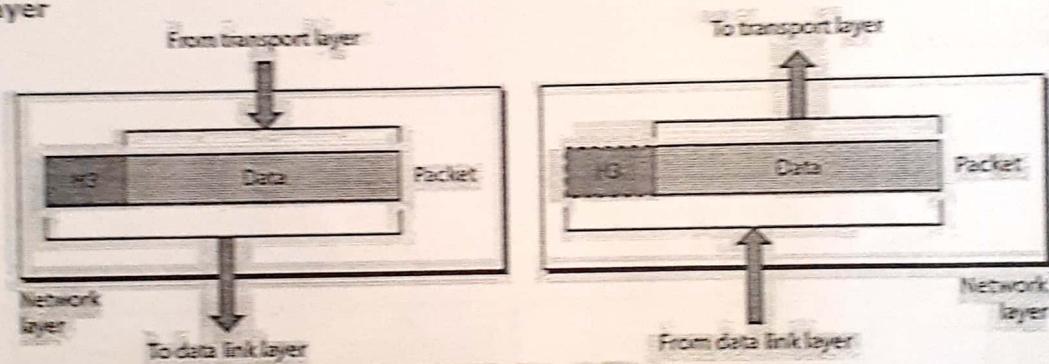


Figure 2.8 Network layer

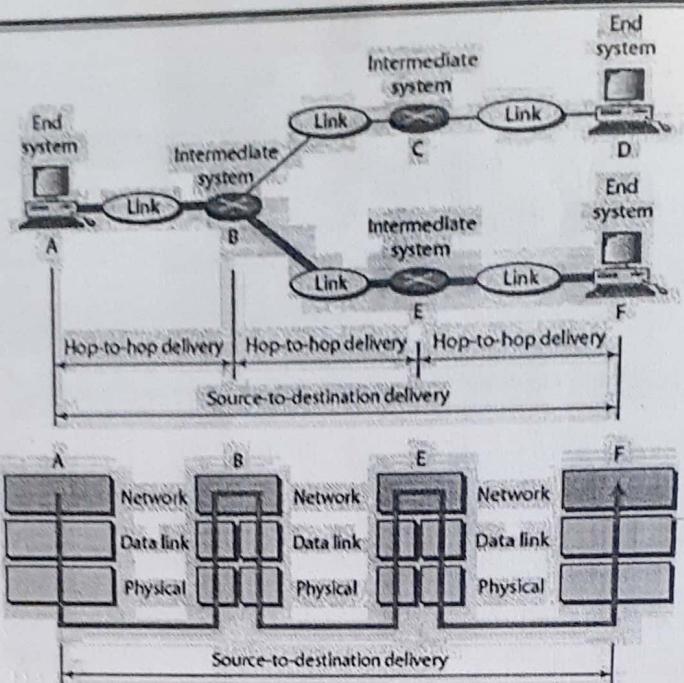


Figure 2.9 Source-to-destination delivery

Transport Layer

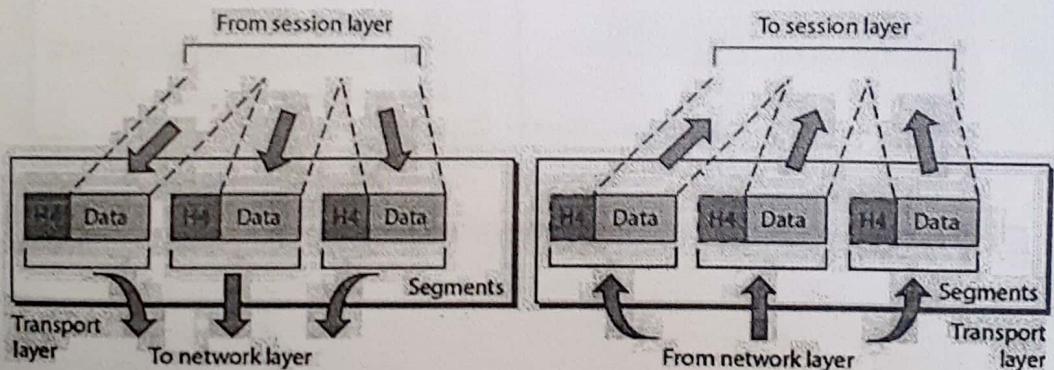


Figure 2.10 Transport layer

- 1) Service point Addressing.
- 2) Segmentation & reassembly.
- 3) Connection control.
- 4) Flow control.
- 5) Error control

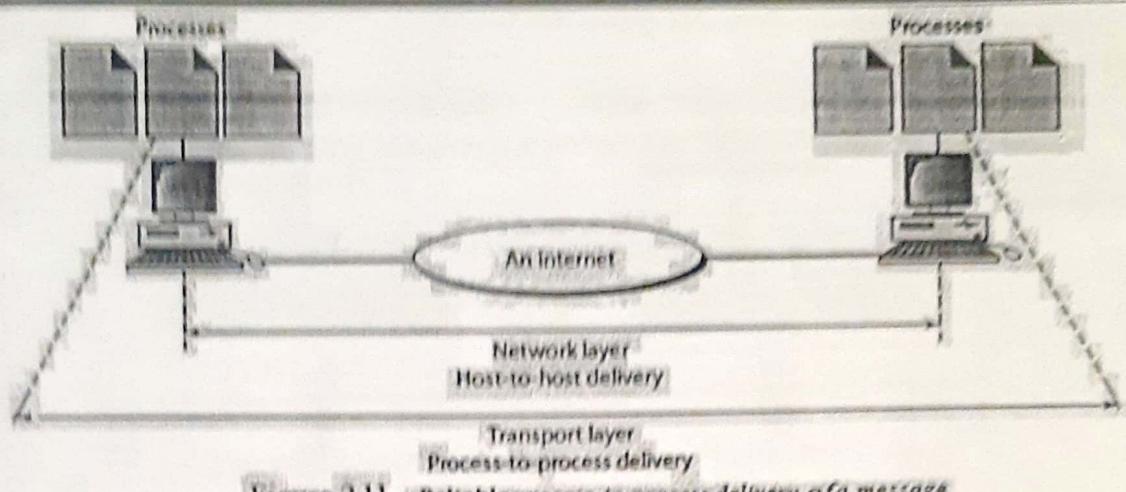


Figure 2.11 Reliable process-to-process delivery of a message.

Service point 1

Session Layer

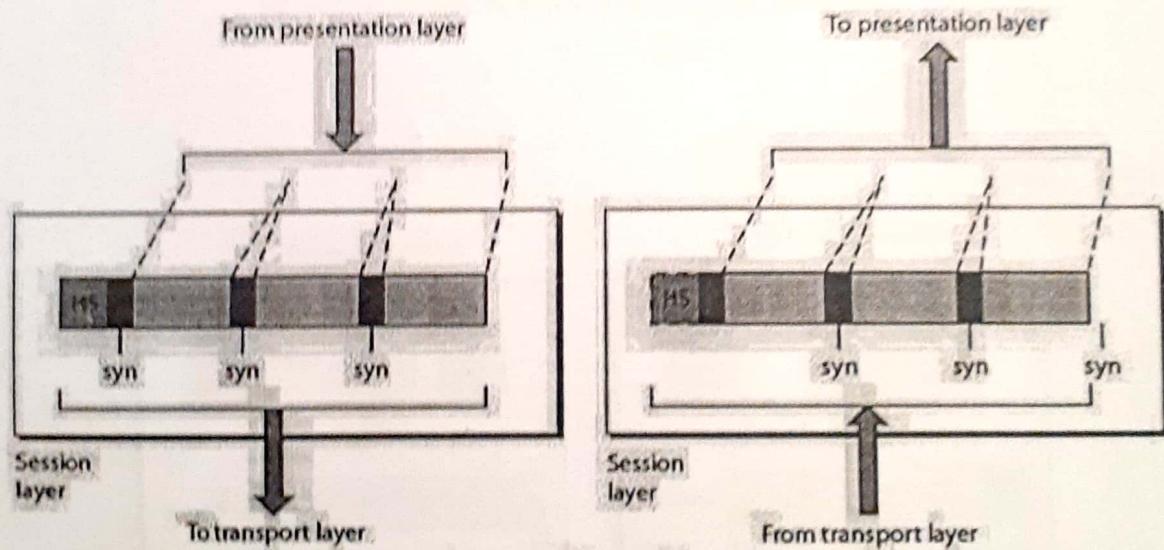


Figure 2.12 Session layer

Dialog Control
Synchronization

Presentation Layer

- Main Responsibility:

Presentation-layer (PL) is concerned with syntax & semantics of the info. exchanged b/w 2 systems.

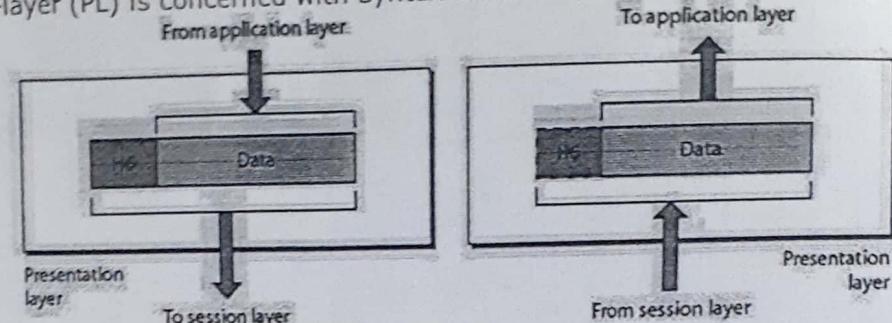


Figure 2.13 Presentation layer

- 1) Encryption
- 2) Compression
- 3) Translation

Application Layer

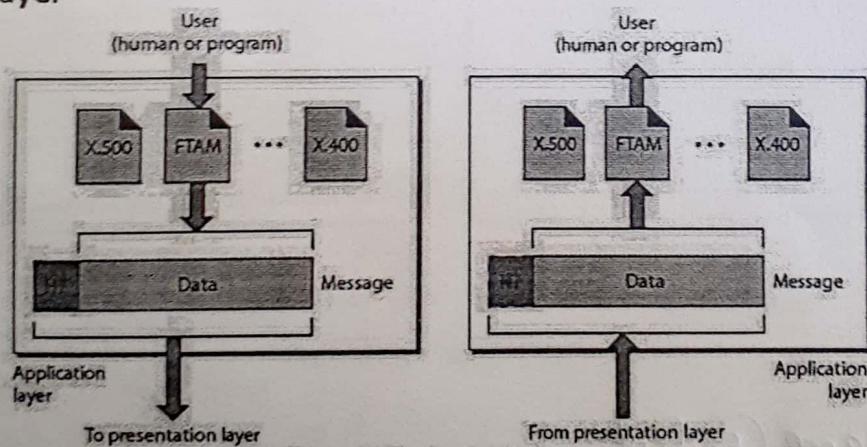
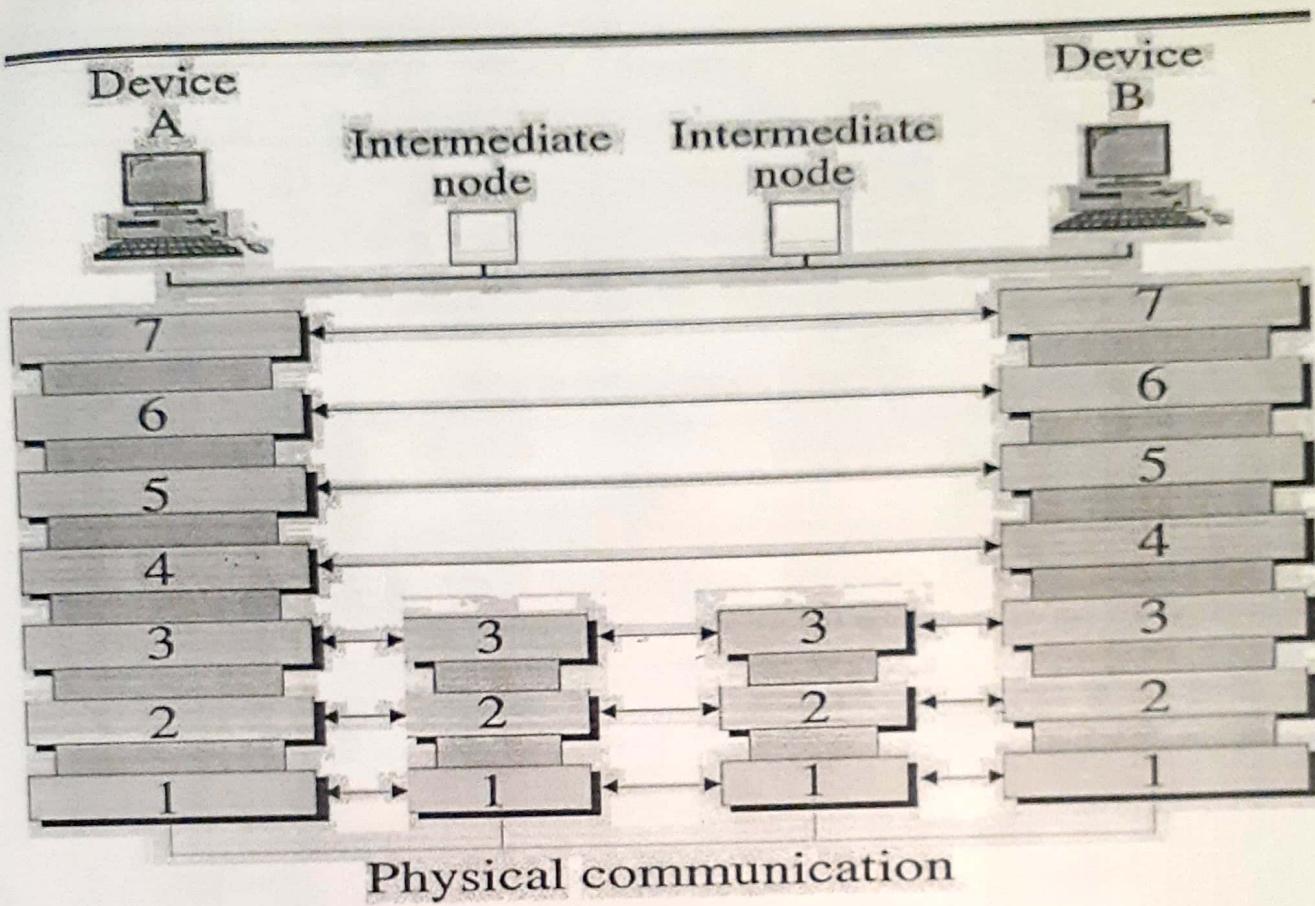


Figure 2.14 Application layer

Interface between user & device.

ISO is the organization OSI is the model.



TCP/IP PROTOCOL SUITE

- TCP/IP is a protocol-suite used in the Internet today.
- Protocol-suite refers a set of protocols organized in different layers.
- It is a hierarchical protocol made up of interactive modules, each of which provides a specific functionality.
- The term hierarchical means that each upper level protocol is supported by the services provided by one or more lower level protocols.

1.6.1 Layered Architecture

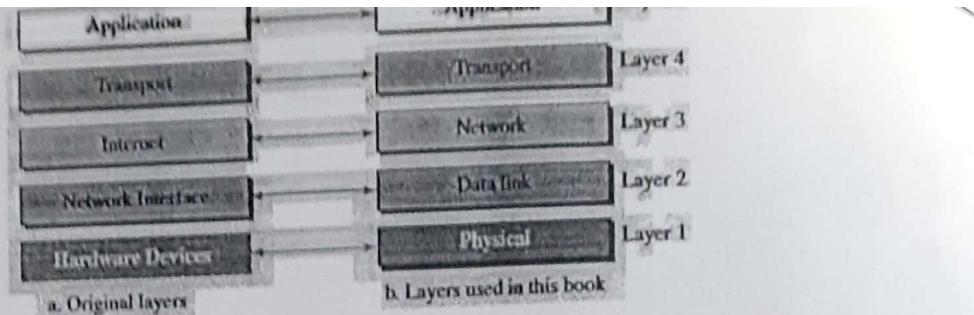


Figure 2.4 Layers in the TCP/IP protocol suite

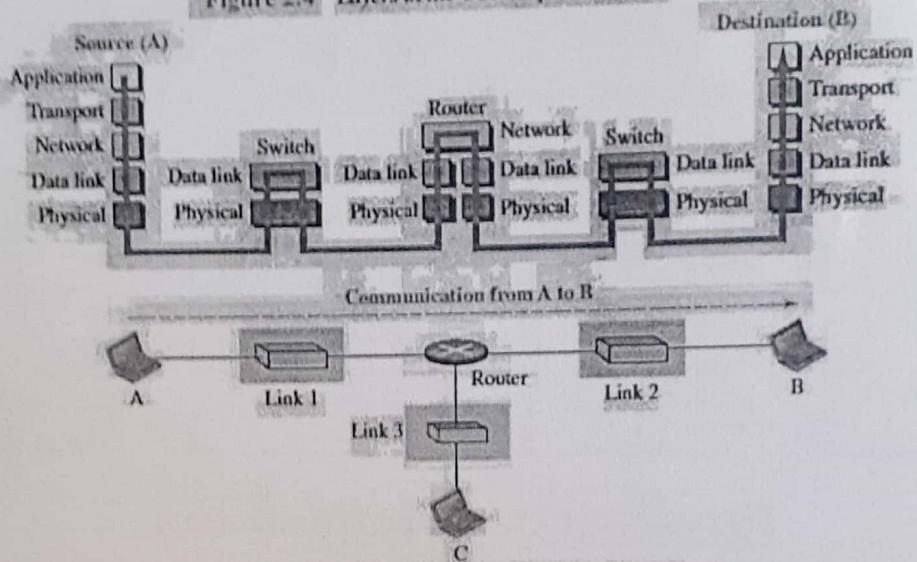


Figure 2.5 Communication through an internet

- Let us assume that computer A communicates with computer B (Figure 2.4).
- As the Figure 2.5 shows, we have five communicating devices:
 - 1) Source host(computer A)
 - 2) Link-layer switch in link 1
 - 3) Router
 - 4) Link-layer switch in link 2
 - 5) Destination host (computer B).
- Each device is involved with a set of layers depending on the role of the device in the internet.
- The two hosts are involved in all five layers.
- The source host
 - creates a message in the application layer and
 - sends the message down the layers so that it is physically sent to the destination host.
- The destination host
 - receives the message at the physical layer and
 - then deliver the message through the other layers to the application layer.
- The router is involved in only three layers; there is no transport or application layer.
- A router is involved in n combinations of link and physical layers.
where $n = \text{number of links the router is connected to.}$
- The reason is that each link may use its own data-link or physical protocol.
- A link-layer switch is involved only in two layers: i) data-link and ii) physical.

1.6.2 Layers in the TCP/IP Protocol Suite

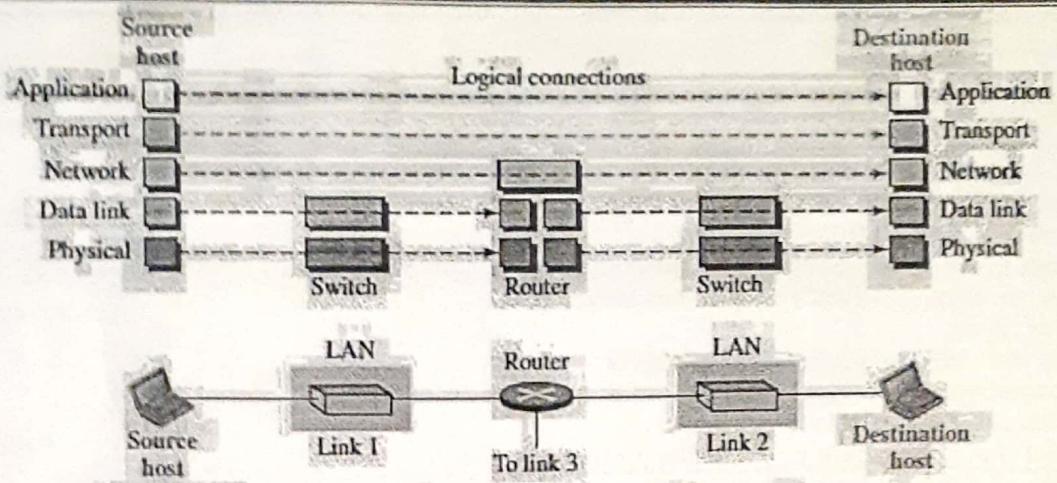


Figure 2.6 Logical connections between layers of the TCP/IP protocol suite

- As shown in the figure 2.6, the duty of the application, transport, and network layers is end-to-end.
- However, the duty of the data-link and physical layers is hop-to-hop. A hop is a host or router.
- The domain of duty of the top three layers is the internet.
The domain of duty of the two lower layers is the link.
- In top 3 layers, the data unit should not be changed by any router or link-layer switch.
In bottom 2 layers, the data unit is changed only by the routers, not by the link-layer switches.

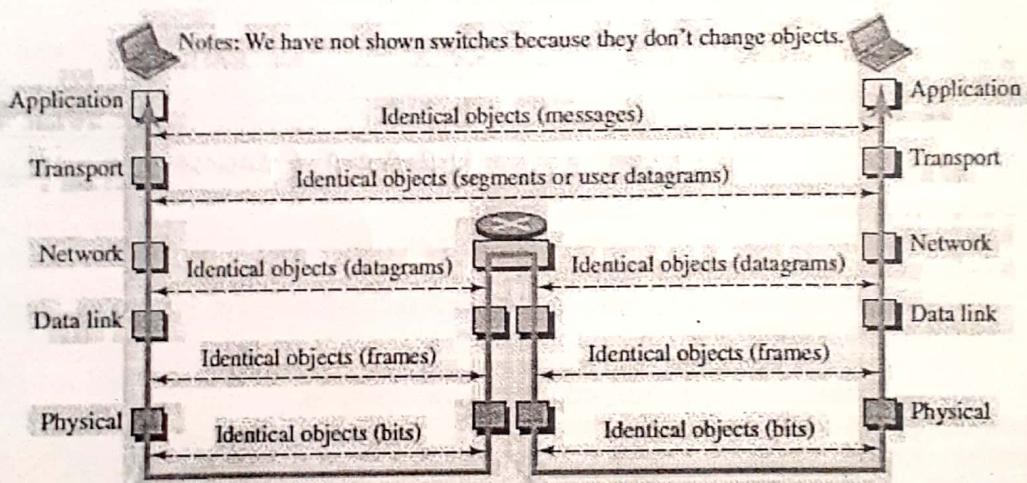


Figure 2.7 Identical objects in the TCP/IP protocol suite

- Identical objects exist between two hops. Because router may fragment the packet at the network layer and send more packets than received (Figure 2.7).
- The link between two hops does not change the object.

1.6.3 Description of Each Layer

Physical Layer

- The physical layer is responsible for movements of individual bits from one node to another node.
- Transmission media is another hidden layer under the physical layer.
- Two devices are connected by a transmission medium (cable or air).
- The transmission medium does not carry bits; it carries electrical or optical signals.
- The physical layer
 - receives bits from the data-link layer &
 - sends through the transmission media.

Data Link Layer

- Data-link-layer (DLL) is responsible for moving frames from one node to another node over a link.
- The link can be wired LAN/WAN or wireless LAN/WAN.
- The data-link layer
 - gets the datagram from network layer
 - encapsulates the datagram in a packet called a frame.
 - sends the frame to physical layer.
- TCP/IP model does not define any specific protocol.
 - DLL supports all the standard and proprietary protocols.
 - Each protocol may provide a different service.
 - Some protocols provide complete error detection and correction; some protocols provide only error correction.

Network Layer

- The network layer is responsible for source-to-destination transmission of data.
- The network layer is also responsible for routing the packet.
- The routers choose the best route for each packet.
- Why we need the separate network layer?
 - 1) The separation of different tasks between different layers.
 - 2) The routers do not need the application and transport layers.

- TCP/IP model defines 5 protocols:

- | | |
|---|---|
| 1) IP (Internetworking Protocol)
3) ICMP (Internet Control Message Protocol) | 2) ARP (Address Resolution Protocol)
4) IGMP (Internet Group Message Protocol) |
|---|---|

1) IP

- IP is the main protocol of the network layer.
- IP defines the format and the structure of addresses.
- IP is also responsible for routing a packet from its source to its destination.
- It is a connection-less & unreliable protocol.
 - i) Connection-less means there is no connection setup b/w the sender and the receiver.
 - ii) Unreliable protocol means
 - IP does not make any guarantee about delivery of the data.
 - Packets may get dropped during transmission.
- It provides a best-effort delivery service.
- Best effort means IP does its best to get the packet to its destination, but with no guarantees.
- IP does not provide following services
 - flow control
 - error control
 - congestion control services.
- If an application requires above services, the application should rely only on the transport-layer protocol.

2) ARP

- ARP is used to find the physical-address of the node when its Internet-address is known.
- Physical address is the 48-bit address that is imprinted on the NIC or LAN card.
- Internet address (IP address) is used to uniquely & universally identify a device in the internet.

3) ICMP

- ICMP is used to inform the sender about datagram-problems that occur during transit.

4) IGMP

- IGMP is used to send the same message to a group of recipients.

Transport Layer

- TL protocols are responsible for delivery of a message from a process to another process.
- The transport layer

- gets the message from the application layer
 - encapsulates the message in a packet called a segment and
 - sends the segment to network layer.
 - TCP/IP model defines 3 protocols:
 - 1) TCP (Transmission Control Protocol)
 - 2) UDP (User Datagram Protocol) &
 - 3) SCTP (Stream Control Transmission Protocol)
- 1) TCP**
- TCP is a reliable connection-oriented protocol.
 - A connection is established b/w the sender and receiver before the data can be transmitted.
 - TCP provides
 - flow control
 - error control and
 - congestion control
- 2) UDP**
- UDP is the simplest of the 3 transport protocols.
 - It is an unreliable, connectionless protocol.
 - It does not provide flow, error, or congestion control.
 - Each datagram is transported separately & independently.
 - It is suitable for application program that
 - needs to send short messages &
 - cannot afford the retransmission.
- 3) SCTP**
- SCTP provides support for newer applications such as voice over the Internet.
 - It combines the best features of UDP and TCP.

Application Layer

- The two application layers exchange messages between each other.
- Communication at the application layer is between two processes (two programs running at this layer).
- To communicate, a process sends a request to the other process and receives a response.
- Process-to-process communication is the duty of the application layer.
- TCP/IP model defines following protocols:
 - 1) SMTP is used to transport email between a source and destination.
 - 2) TELNET is used for accessing a site remotely.
 - 3) FTP is used for transferring files from one host to another.
 - 4) DNS is used to find the IP address of a computer.
 - 5) SNMP is used to manage the Internet at global and local levels.
 - 6) HTTP is used for accessing the World Wide Web (WWW).

(FTP → File Transfer Protocol
 (DNS → Domain Name System
 (SNMP → Simple Network Management Protocol

SMTP → Simple Mail Transfer Protocol
 HTTP → Hyper Text Transfer Protocol
 TELNET → Terminal Network)

1.6.4 Encapsulation and Decapsulation

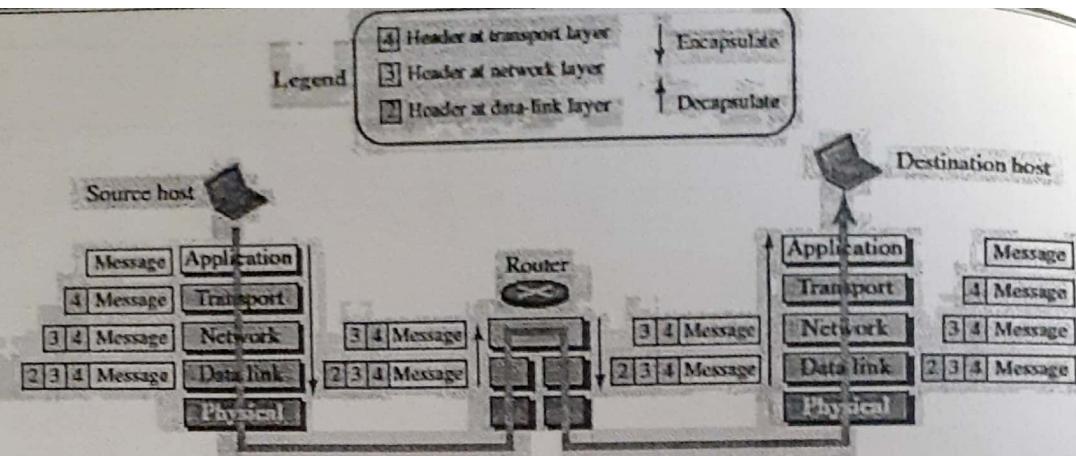


Figure 2.8 Encapsulation/Decapsulation

A) Encapsulation at the Source Host

- At the source, we have only encapsulation (Figure 2.8).

- At the application layer, the data to be exchanged is referred to as a message.
 - A message normally does not contain any header or trailer.
 - The message is passed to the transport layer.
- The transport layer takes the message as the payload.
 - TL adds its own header to the payload.
 - The header contains
 - identifiers of the source and destination application programs
 - information needed for flow, error control, or congestion control.
 - The transport-layer packet is called the segment (in TCP) and the user datagram (in UDP).
 - The segment is passed to the network layer.
- The network layer takes the transport-layer packet as payload.
 - NL adds its own header to the payload.
 - The header contains
 - addresses of the source and destination hosts
 - some information used for error checking of the header &
 - fragmentation information.
 - The network-layer packet is called a datagram.
 - The datagram is passed to the data-link layer.
- The data-link layer takes the network-layer packet as payload.
 - DLL adds its own header to the payload.
 - The header contains the physical addresses of the host or the next hop (the router).
 - The link-layer packet is called a frame.
 - The frame is passed to the physical layer for transmission

B) Decapsulation and Encapsulation at the Router

- At the router, we have both encapsulation & decapsulation and because the router is connected to two or more links.

- Data-link layer
 - receives frame from physical layer
 - decapsulates the datagram from the frame and
 - passes the datagram to the network layer.
- The network layer
 - inspects the source and destination addresses in the datagram header and
 - consults forwarding table to find next hop to which the datagram is to be delivered.
- The data-link layer of the next link
 - encapsulates the datagram in a frame and
 - passes the frame to the physical layer for transmission.

C) Decapsulation at the Destination Host

- At the destination host, each layer

- Demultiplexing means a protocol can decapsulate and deliver a packet to several next-higher layer protocols (one at a time).
 - 1) At transport layer, either UDP or TCP can accept a message from several application-layer protocols.
 - 2) At network layer, IP can accept
 - a segment from TCP or a user datagram from UDP.
 - a packet from ICMP or IGMP.
 - 3) At data-link layer, a frame may carry the payload coming from IP or ARP.

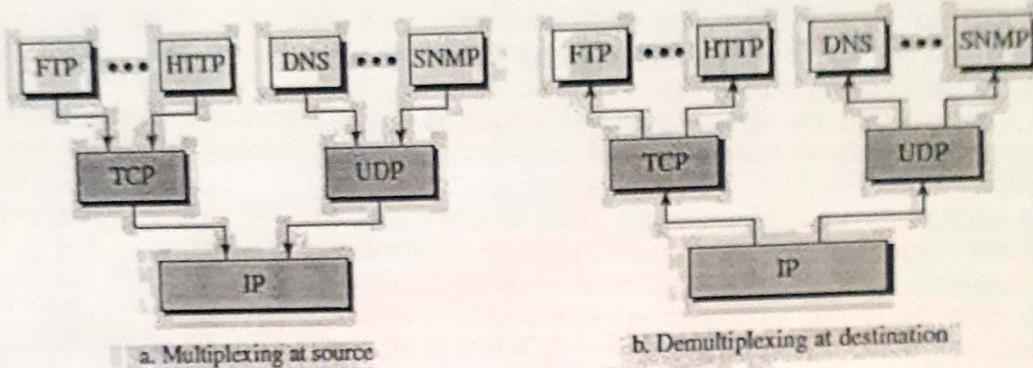


Figure 2.10 Multiplexing and demultiplexing

- decapsulates the packet received from lower layer
- removes the payload and
- delivers the payload to the next-higher layer

1.6.5 Addressing

- We have logical communication between pairs of layers.
- Any communication that involves 2 parties needs 2 addresses: source address and destination address.
- We need 4 pairs of addresses (Figure 2.9):
 - 1) At the application layer, we normally use names to define
 - site that provides services, such as vtunotesbysri.com, or
 - e-mail address, such as vtunotesbysree@gmail.com.
 - 2) At the transport layer, addresses are called port numbers.
 - Port numbers define the application-layer programs at the source and destination.
 - Port numbers are local addresses that distinguish between several programs running at the same time.
 - 3) At the network-layer, addresses are called IP addresses.
 - IP address uniquely defines the connection of a device to the Internet.
 - The IP addresses are global, with the whole Internet as the scope.
 - 4) At the data link-layer, addresses are called MAC addresses
 - The MAC addresses defines a specific host or router in a network (LAN or WAN).
 - The MAC addresses are locally defined addresses.

Packet names	Layers	Addresses
Message	Application layer	Names
Segment / User datagram	Transport layer	Port numbers
Datagram	Network layer	Logical addresses
Frame	Data-link layer	Link-layer addresses
Bits	Physical layer	

Figure 2.9 Addressing in the TCP/IP protocol suite

1.6.6 Multiplexing and Demultiplexing

- Multiplexing means a protocol at a layer can encapsulate a packet from several next-higher layer protocols (one at a time) (Figure 2.10).

OSI MODEL

- OSI model was developed by ISO.
- ISO is the organization, OSI is the model.
- Purpose: OSI was developed to allow systems with diff. platforms to communicate with each other.
- Platform means hardware, software or operating system.
- OSI is a network-model that defines the protocols for network communications.
- OSI has 7 layers as follows (Figure 2.11):
 - 1) Application Layer
 - 2) Presentation Layer
 - 3) Session Layer
 - 4) Transport Layer
 - 5) Network Layer
 - 6) Data Link Layer
 - 7) Physical Layer
- Each layer has specific duties to perform and has to co-operate with the layers above & below it.

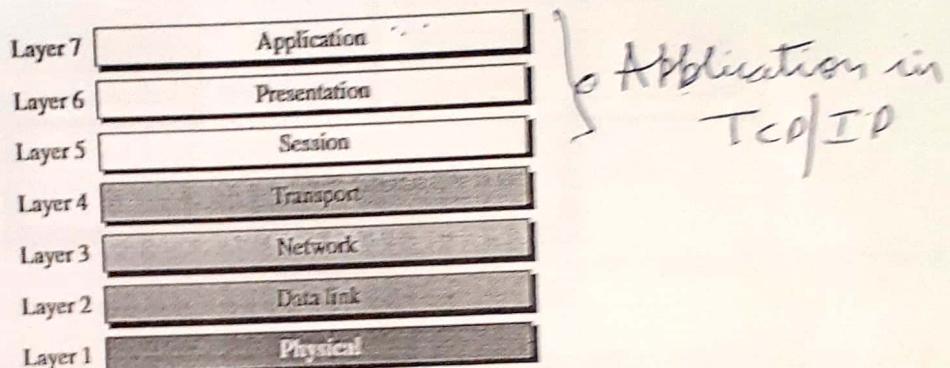


Figure 2.11 The OSI model

1.7.1 OSI vs. TCP/IP

- 1) The four bottommost layers in the OSI model & the TCP/IP model are same (Figure 2.12). However, the Application-layer of TCP/IP model corresponds to the Session, Presentation & Application Layer of OSI model.
Two reasons for this are:
 - 1) TCP/IP has more than one transport-layer protocol.
 - 2) Many applications can be developed at Application layer
- 2) The OSI model specifies which functions belong to each of its layers.
In TCP/IP model, the layers contain relatively independent protocols that can be mixed and matched depending on the needs of the system.

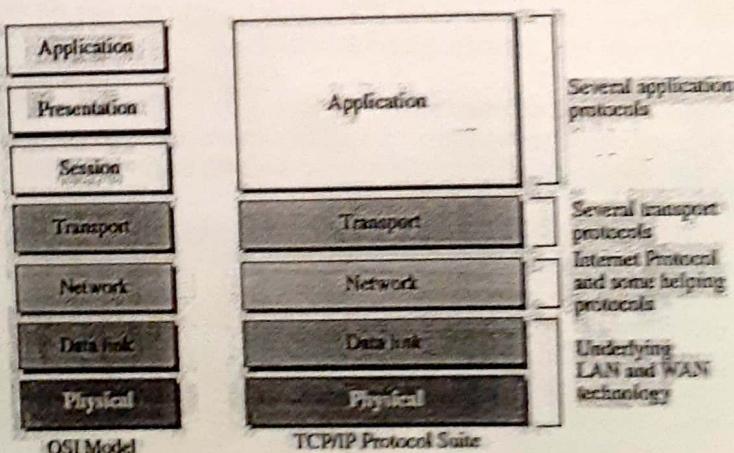


Figure 2.12 TCP/IP and OSI model

1.7.2 Lack of OSI Model's Success

- OSI was completed when TCP/IP was fully in place and a lot of time and money had been spent on the suite; changing it would cost a lot.
- Some layers in the OSI model were never fully defined.
- When OSI was implemented by an organization in a different application, it did not show a high enough level of performance

LAYERS IN THE OSI MODEL (Detailed OSI layers not in syllabus, it's for your reference)

Physical Layer

- Main Responsibility:

Physical-layer (PL) is responsible for movements of individual bits from one node to another node.

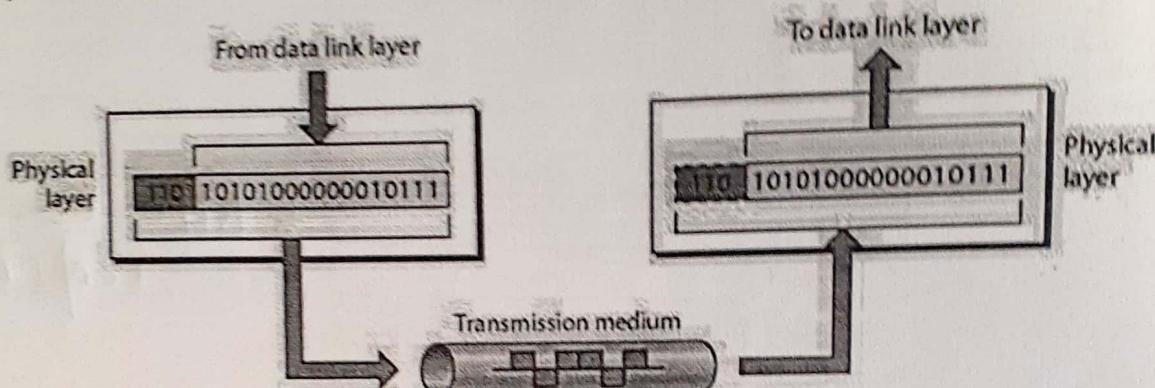


Figure 2.5 Physical layer

- Other responsibilities of Physical-layer (Figure 2.5):

1) Physical Characteristics of Interfaces and Medium

- PL defines the mechanical/electrical characteristics of the interface & transmission-medium i.e. Mechanical → cable, plugs, pins

Electrical → modulation, signal strength, voltage levels

- PL also defines the type of transmission-medium. (Wired or wireless).

2) Representation of Bits

- PL defines the type of encoding i.e. how 0s and 1s are changed to signals.

- Data consists of a stream of bits: 0s or 1s.

- Bits must be encoded into signals for transmission.

3) Data Rate

- PL defines the transmission-rate.

- Transmission-rate refers to the number of bits sent per second.

4) Synchronization of Bits

- PL deals with the synchronization of the transmitter and receiver.

- The sender and receiver are synchronized at bit-level.

5) Line Configuration

- PL defines the nature of the connection.

- i) In a point-to-point configuration, a dedicated-link is used to connect between 2 devices
- ii) In a multipoint configuration, a shared-link is used to connect between 2 or more devices.

6) Physical Topology

- PL defines the type of topology used for connecting the devices in the network.

- Topologies can be mesh, star, ring or bus.

7) Transmission Mode

- PL defines the direction of data-transfer between 2 devices.

- i) Simplex: Only one device can send; the other device can only receive.
- ii) Half-duplex: Two devices can send and receive, but not at the same time.
- iii) Full-duplex: Two devices can send and receive at the same time.

Data Link Layer

- Main Responsibility:

Data-link-layer (DLL) is responsible for moving frames from one node to another node.

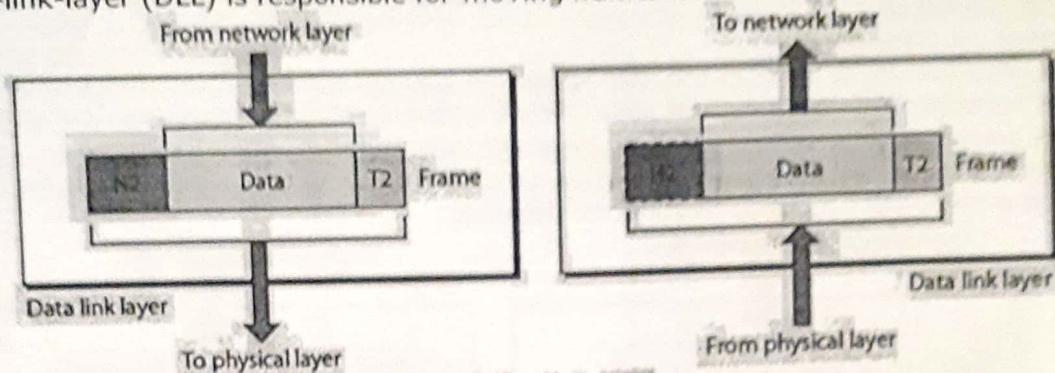


Figure 2.6 Data link layer

- Other responsibilities of data-link-layer (Figure 2.6 & 2.7):

1) Framing

➢ DLL receives & divides the stream of bits from network-layer into frames.

2) Physical-addressing

➢ DLL appends a header to the frame coming from the network-layer.

➢ Header contains the physical-address of sender & receiver of the frame.

3) Flow Control

➢ DLL provides flow-control.

➢ Flow-control ensures that source sends the data at a speed at which destination can receive it.

➢ If there is an overflow at the receiver-side, the data will be lost.

4) Error Control

➢ DLL provides error-control.

➢ Error-control is process of identification or correction of error occurred in the transmitted data.

➢ Error-control uses mechanisms to

→ detect damaged-frames

→ retransmit lost-frames

→ recognize duplicate frames.

➢ Normally, error control information is present in the trailer of a frame.

5) Access Control

➢ DLL provides access-control.

➢ Access-control determines which device has right to send the data in a multipoint connection.

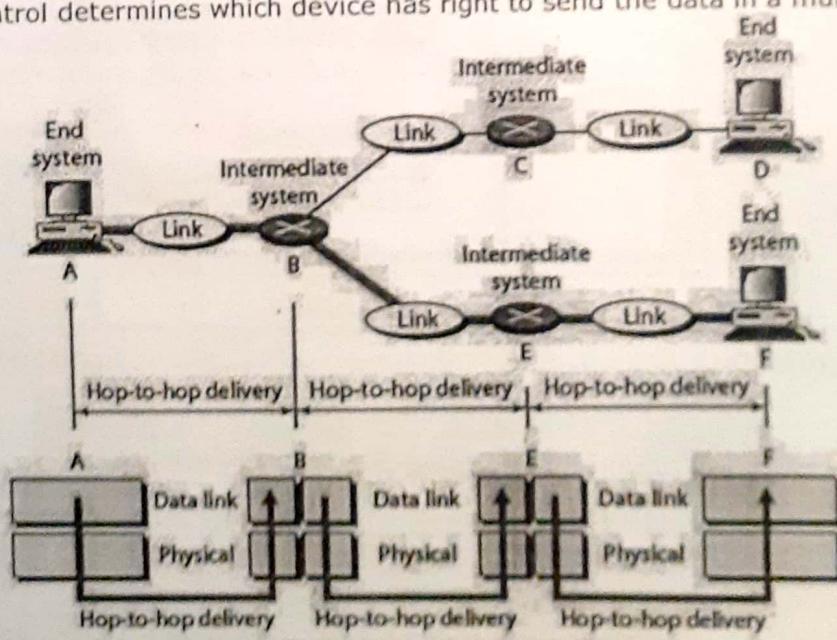


Figure 2.7 Hop-to-hop delivery

Network Layer

- Main Responsibility:
Network-layer (NL) is responsible for source-to-destination delivery of a packet, possibly across multiple-networks.
- Data-link-layer vs. Network-layer:
 - 1) The data-link-layer ensures the delivery of the packet between 2 systems on the same link.
 - 2) The network-layer ensures that each packet gets from the source to the final destination.
- If 2 systems are connected to the same link, there is no need for a network-layer.
However, if the 2 systems are attached to different links, there is often a need for the network-layer to accomplish source-to-destination delivery.

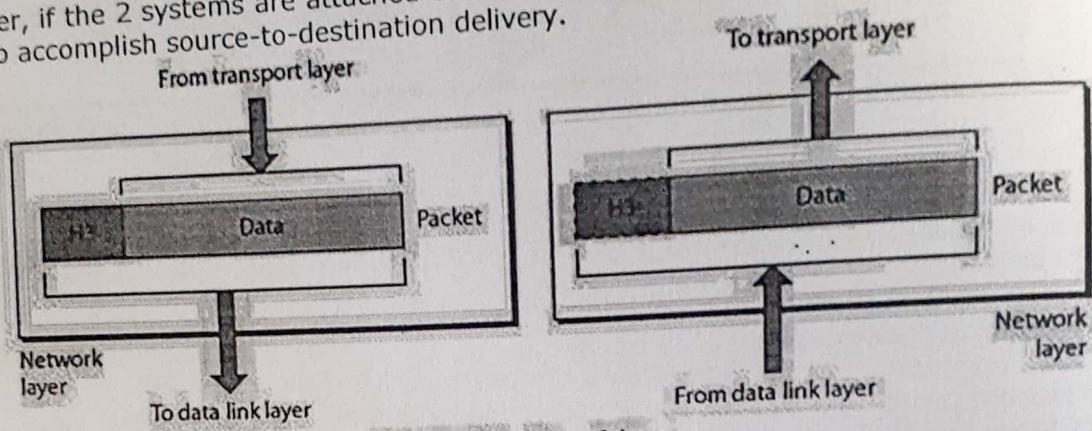


Figure 2.8 Network layer

- Other responsibilities of network-layer (Figure 2.8 & 2.9):

1) Logical Addressing

- NL appends a header to the packet coming from the transport-layer.
- The header contains the IP addresses of the sender and receiver.
- An IP address is a universally unique address in the network.
- NL uses IP address to recognize devices on the network.

2) Routing

- NL provides routing of packets.
- Routing is the process of finding the best path from a source to a destination.
- Routers/gateways are used for routing the packets to their final destination.
- NL is concerned with circuit, message or packet switching.

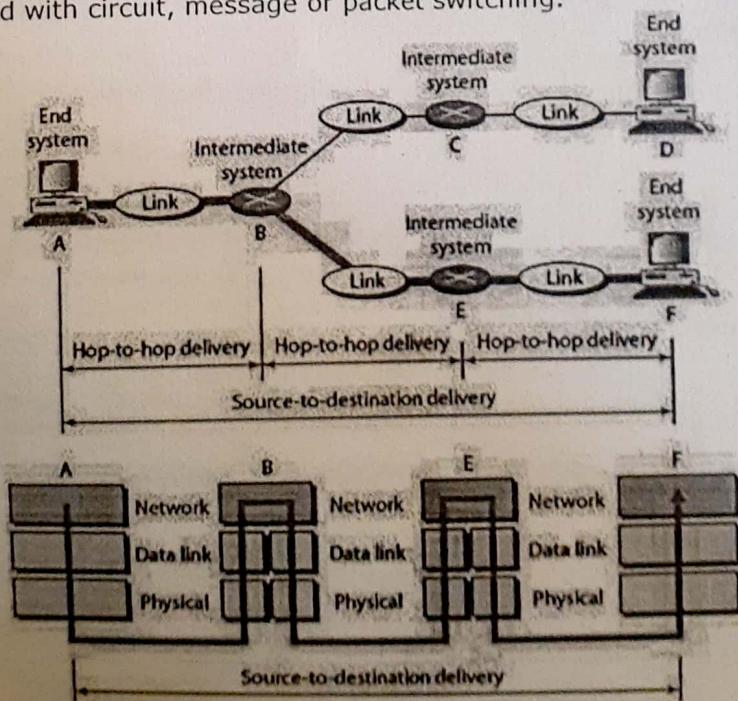


Figure 2.9 Source-to-destination delivery

Transport Layer

- Main Responsibility:

- Transport-layer (TL) is responsible for process-to-process delivery of the entire message.
- Process-to-process delivery means delivery from a specific process on one computer to a specific process on the other computer.
- A process is an application program running on a host.
- Network-layer vs. Transport-layer:
 - 1) Network-layer ensures source-to-destination delivery of individual packets.
 - 2) Transport-layer ensures that the whole message arrives in order

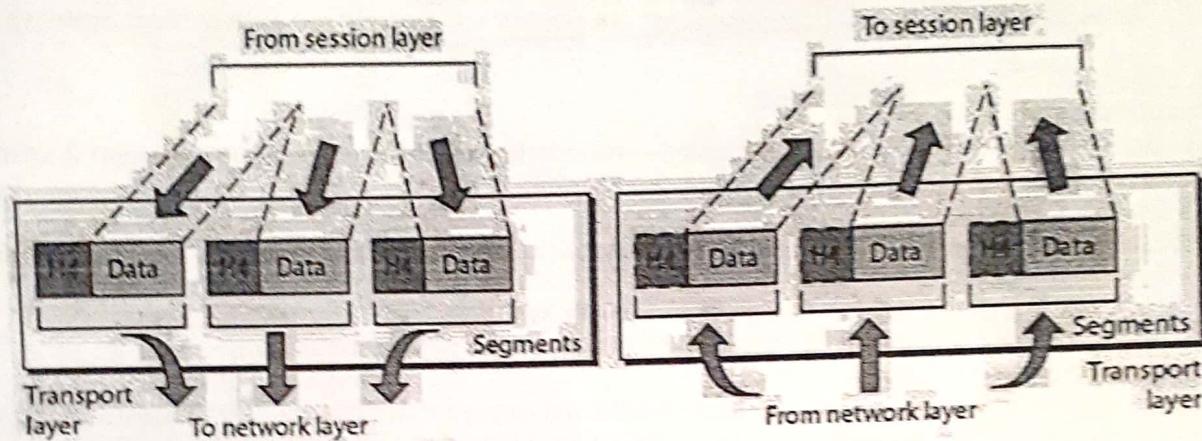


Figure 2.10 Transport layer

- Other responsibilities of transport-layer (Figure 2.10 & 2.11):

- 1) Service Point Addressing**

- NL appends a header to the segments coming from the network-layer.
- Header contains the port-address of the sender and receiver.
- Network-layer vs. Transport-layer:
 - The network-layer gets each packet to the correct computer.
 - The transport-layer gets the entire message to the correct process on that computer.

- 2) Segmentation & Reassembly**

- A message is divided into segments.
- Each segment contains a sequence-number.
- At receiver, the sequence-numbers are used to
 - rearrange the segments in proper order
 - identify lost/duplicate segments

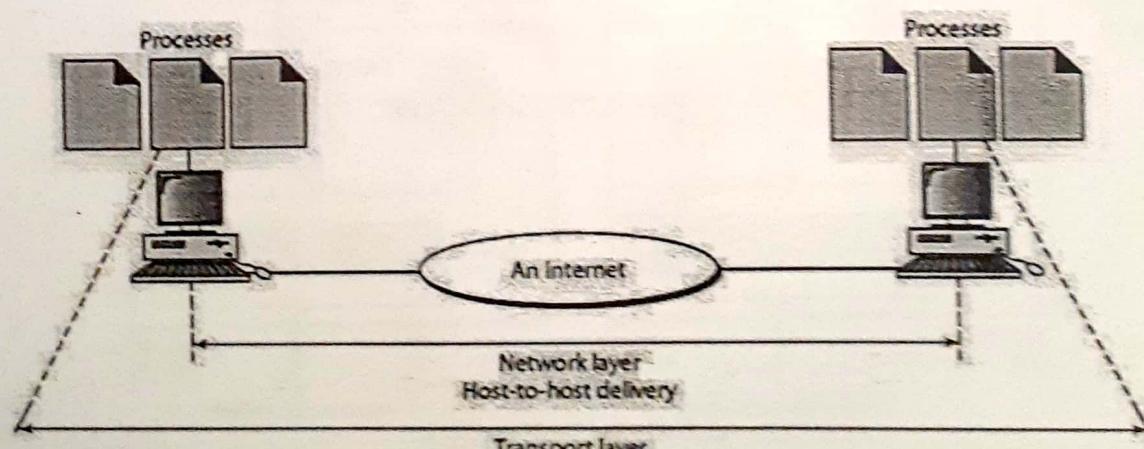


Figure 2.11 Reliable process-to-process delivery of a message

3) Connection Control

- TL can be either i) connectionless or ii) connection-oriented.
 - i) In connectionless, TL
 - treats each segment as an independent packet and
 - delivers the segment to the transport-layer at the destination-machine.
 - ii) In connection-oriented, TL
 - first, makes a connection with the destination-machine.
 - then, delivers the packets to the destination-machine.

4) Flow Control & Error Control

- Like DLL, TL is responsible for flow-control & error-control.
 - However, flow-control & error-control are performed end-to-end rather than node-to-node.

Session Layer

- Main Responsibility:
 - Session-layer (SL) establishes, maintains, and synchronizes the interaction between 2 systems.
- Other responsibilities of session-layer (Figure 2.12):

1) Dialog Control

- SL allows 2 systems to start communication with each other in half-duplex or full-duplex.

2) Synchronization

- SL allows a process to add checkpoints into stream of data.

- The checkpoint is a way of informing the status of the data transfer.

- For example:

A checkpoint after first 500 bits of data will ensure that those 500 bits are not sent again in case of retransmission at 650th bit. (Checkpoints → Synchronization Points)

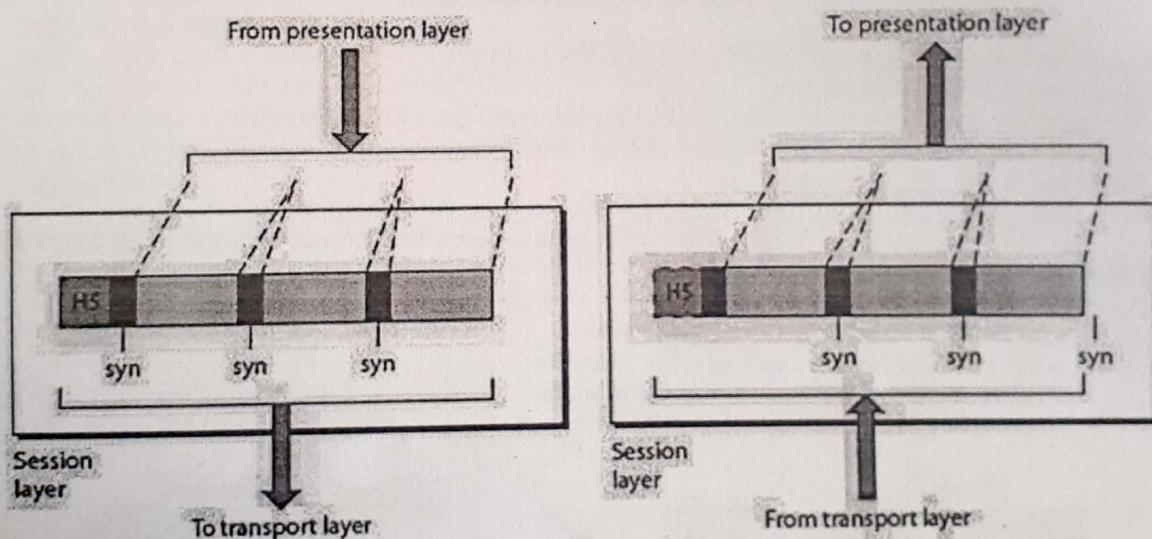


Figure 2.12 Session layer

Presentation Layer

- Main Responsibility:

Presentation-layer (PL) is concerned with syntax & semantics of the info. exchanged b/w 2 systems.

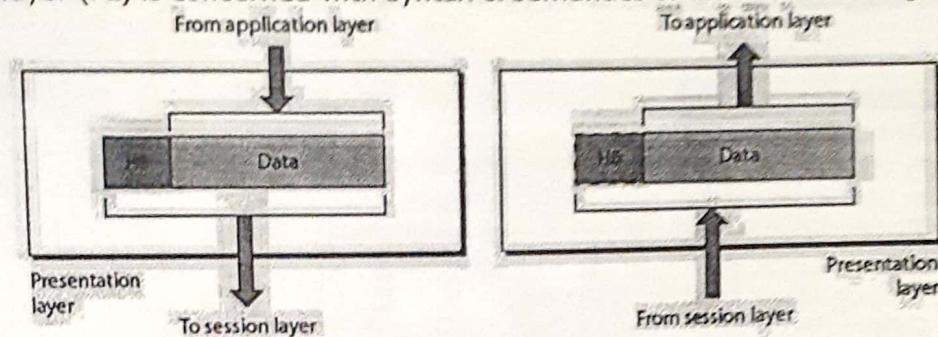


Figure 2.13 Presentation layer

- Other responsibilities of presentation-layer (Figure 2.13):

1) Translation

- PL translates data between
 - format the network requires and
 - format the computer understands.
- PL is responsible for interoperability between encoding methods as different computers use different encoding-methods.

2) Encryption

- PL performs
 - encryption at the sender and
 - decryption at the receiver.
- Encryption means the sender transforms the original information to another.
- Decryption means the receiver transforms the encrypted-message back to its original form.

3) Compression

- PL carries out data compression to reduce the size of the data to be transmitted.
- Data compression reduces the number of bits contained in the information.
- Data compression ensures faster data transfer.
- Data compression is important in transmitting multimedia such as audio, video, etc.

Application Layer

- Main Responsibility: The application-layer (AL)

- provides services to the user
- enables the user to access the network.

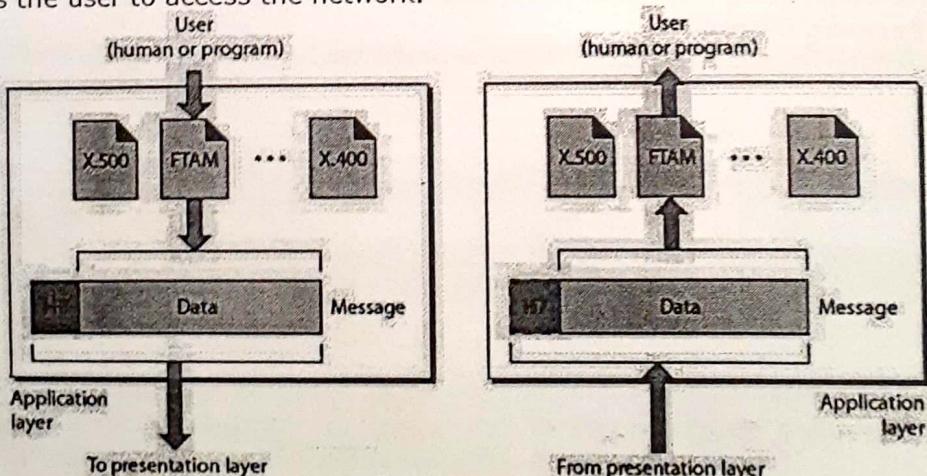


Figure 2.14 Application layer

- Other responsibilities of application-layer (Figure 2.14):

- Mail Services
- Directory Services
- File Transfer, Access, and Management

MODULE 1(CONT.): DATA AND SIGNALS

1.8 DATA AND SIGNALS

1.8.1 Analog & Digital Data

- To be transmitted, data must be transformed to electromagnetic-signals.
- Data can be either analog or digital.

1) **Analog Data** refers to information that is continuous.

➢ For example:

The sounds made by a human voice.

2) **Digital Data** refers to information that has discrete states.

➢ For example:

Data are stored in computer-memory in the form of 0s and 1s.

1.8.2 Analog & Digital Signals

- Signals can be either analog or digital (Figure 3.2).

1) **Analog Signal** has infinitely many levels of intensity over a period of time.

2) **Digital Signal** can have only a limited number of defined values.

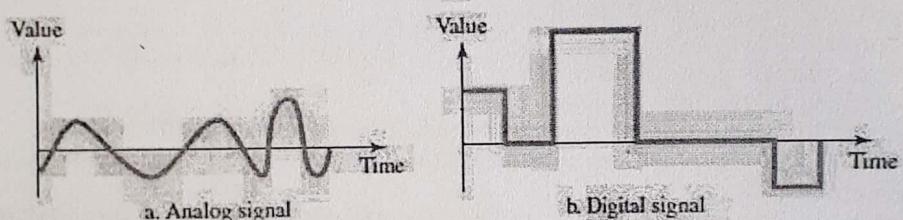


Figure 3.2 Comparison of analog and digital signals

1.8.3 Periodic & Non-Periodic Signals

- The signals can take one of 2 forms: periodic or non-periodic.

1) Periodic Signal

- Signals which repeat itself after a fixed time period are called Periodic Signals.
- The completion of one full pattern is called a cycle.

2) Non-Periodic Signal

- Signals which do not repeat itself after a fixed time period are called Non-Periodic Signals.

1.9 DIGITAL SIGNALS

- Information can be represented by a digital signal.

- For example:

1) 1 can be encoded as a positive voltage.

0 can be encoded as a zero voltage (Figure 3.17a).

2) A digital signal can have more than 2 levels (Figure 3.17b).

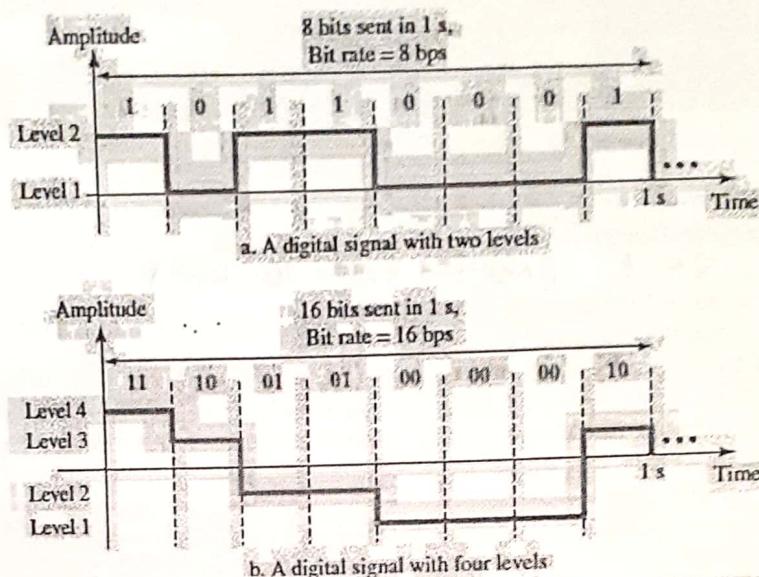


Figure 3.17 Two digital signals: one with two signal levels and the other with four signal levels

Example 1.1

A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the following formula. Each signal level is represented by 3 bits.

$$\text{Number of bits per level} = \log_2 8 = 3$$

C

1.9.1 Bit Rate

- The bit rate is the number of bits sent in 1s.
- The bit rate is expressed in bits per second (bps).

Example 1.2

Assume we need to download text documents at the rate of 100 pages per second. What is the required bit rate of the channel?

Solution

A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits, the bit rate is

$$100 \times 24 \times 80 \times 8 = 1,536,000 \text{ bps} = 1.536 \text{ Mbps}$$

Example 1.3

A digitized voice channel, as we will see in Chapter 4, is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?

Solution

The bit rate can be calculated as

$$2 \times 4000 \times 8 = 64,000 \text{ bps} = 64 \text{ kbps}$$

Example 1.4

What is the bit rate for high-definition TV (HDTV)?

Solution

HDTV uses digital signals to broadcast high quality video signals. The HDTV screen is normally a ratio of 16:9 (in contrast to 4:3 for regular TV), which means the screen is wider. There are 1920 by 1080 pixels per screen, and the screen is renewed 30 times per second. Twenty-four bits represents one color pixel. We can calculate the bit rate as

$$1920 \times 1080 \times 30 \times 24 = 1,492,992,000 \approx 1.5 \text{ Gbps}$$

1.9.2 Bit Length

- The bit length is the distance one bit occupies on the transmission medium.

$$\text{Bit length} = \text{propagation speed} \times \text{bit duration}$$

$$l = s \cdot t \quad (\text{normal speed equation})$$

1.9.3 Digital Signal as a Composite Analog Signal

- A digital signal is a composite analog signal.
- A digital signal, in the time domain, comprises connected vertical and horizontal line segments.
- A digital signal, in the time domain, comprises connected vertical and horizontal line segments.
 - 1) A vertical line in the time domain means a frequency of infinity (sudden change in time).
 - 2) A horizontal line in the time domain means a frequency of zero (no change in time).
- Fourier analysis can be used to decompose a digital signal.
 - 1) If the digital signal is periodic, the decomposed signal has a frequency domain representation with an infinite bandwidth and discrete frequencies (Figure 3.18a).
 - 2) If the digital signal is non-periodic, the decomposed signal has a frequency domain representation with an infinite bandwidth and continuous frequencies (Figure 3.18b).

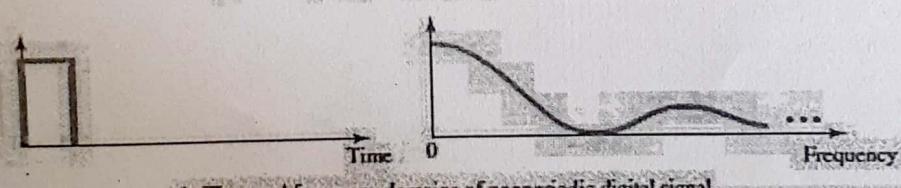
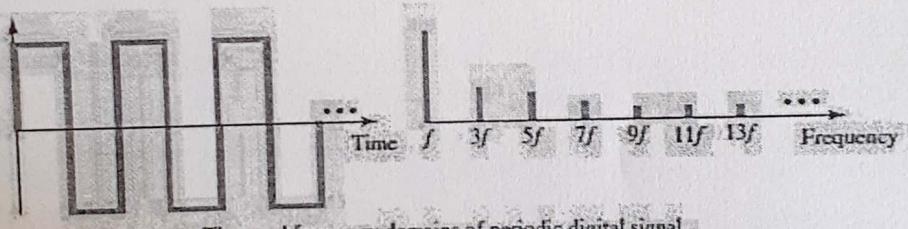


Figure 3.18 The time and frequency domains of periodic and nonperiodic digital signals

1.9.4 Transmission of Digital Signals

- Two methods for transmitting a digital signal:
 - 1) Baseband transmission
 - 2) Broadband transmission (using modulation).

1.9.4.1 Baseband Transmission

- Baseband transmission means sending a digital signal over a channel without changing the digital signal to an analog signal (Figure 3.19).

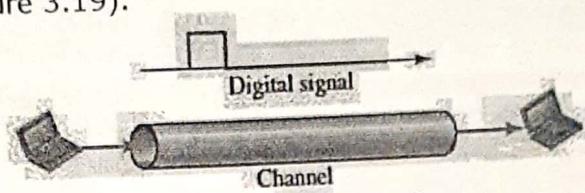


Figure 3.19 Baseband transmission

- Baseband transmission requires that we have a low-pass channel.
- Low-pass channel means a channel with a bandwidth that starts from zero.
- For example, we can have a dedicated medium with a bandwidth constituting only one channel.

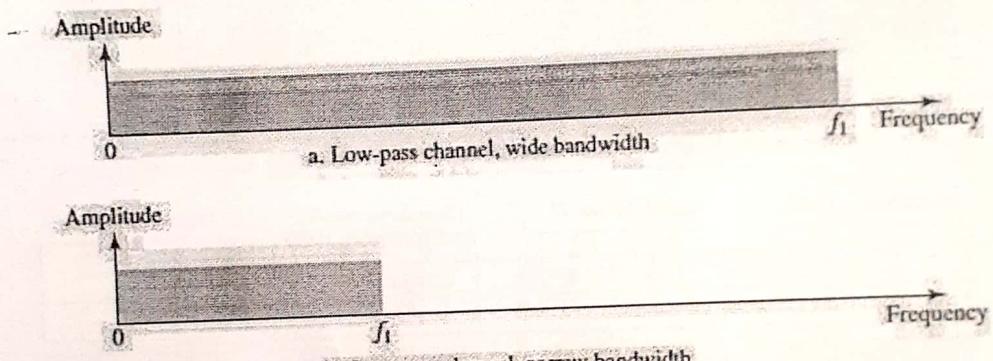


Figure 3.20 Bandwidths of two low-pass channels

- Two cases of a baseband communication:

Case 1: Low-pass channel with a wide bandwidth (Figure 3.20a)

Case 2: Low-pass channel with a limited bandwidth (Figure 3.20b)

Case 1: Low-Pass Channel with Wide Bandwidth

- To preserve the shape of a digital signal, we need to send the entire spectrum i.e. the continuous range of frequencies between zero and infinity.
- This is possible if we have a dedicated medium with an infinite bandwidth between the sender and receiver.
- If we have a medium with a very wide bandwidth, 2 stations can communicate by using digital signals with very good accuracy (Figure 3.21).
- Although the output signal is not an exact replica of the original signal, the data can still be deduced from the received signal.

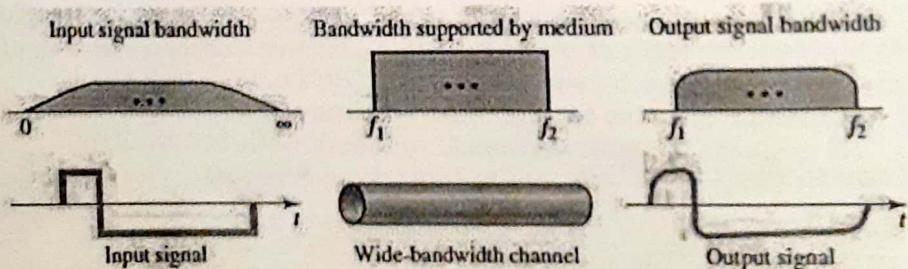
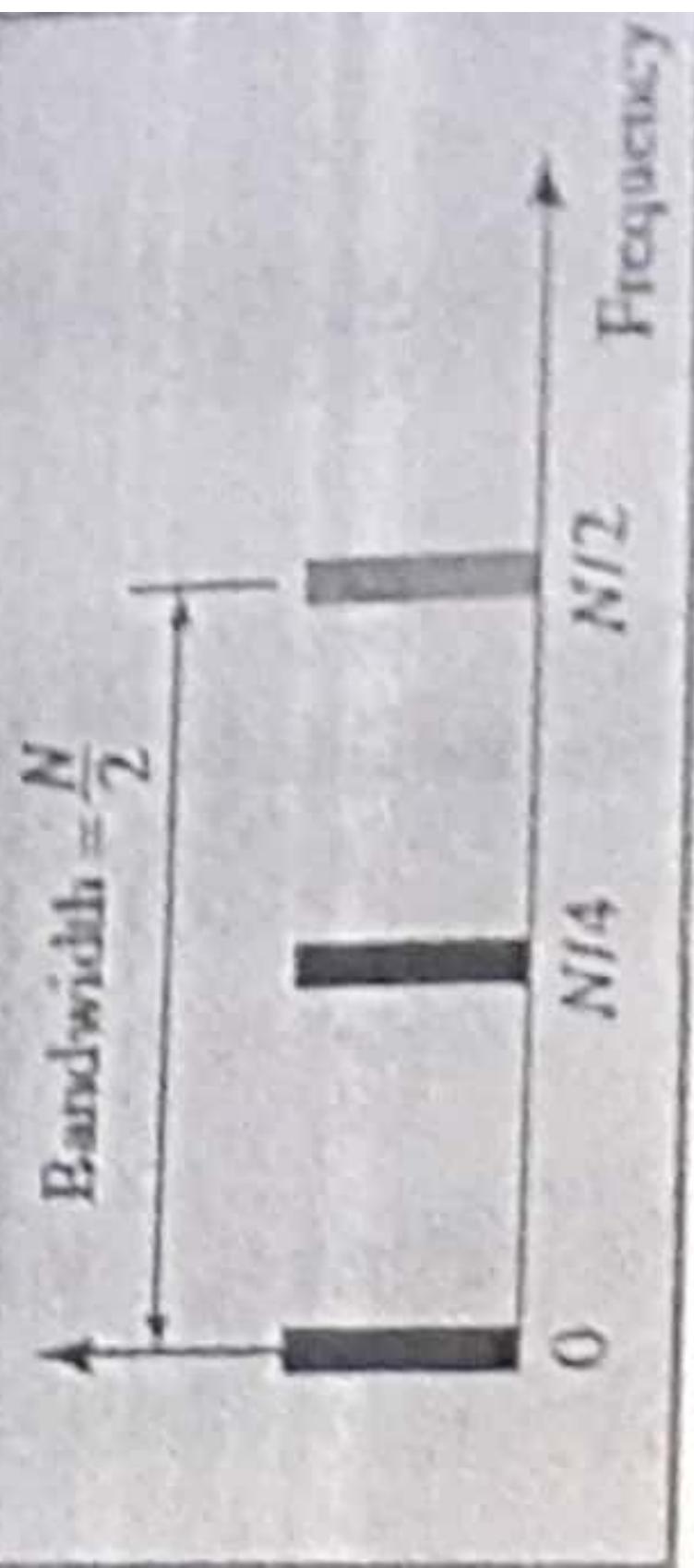
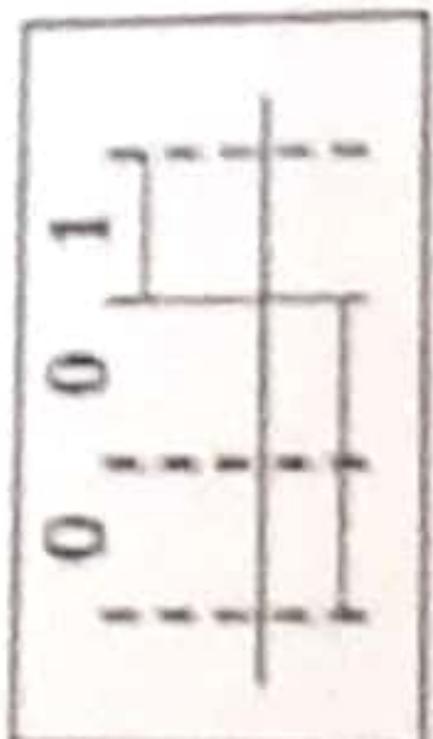


Figure 3.21 Baseband transmission using a dedicated medium

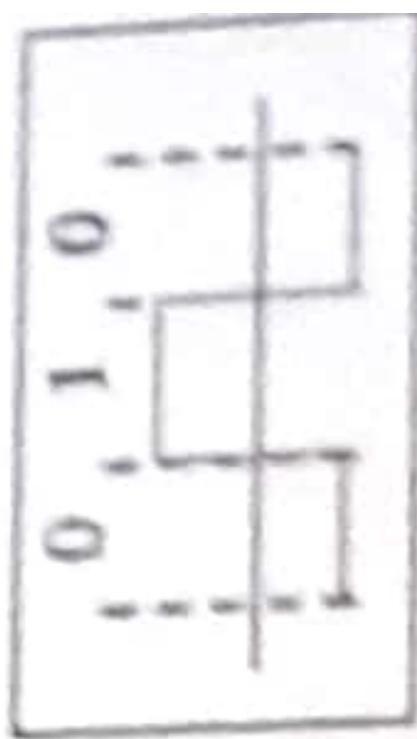
Amplitude

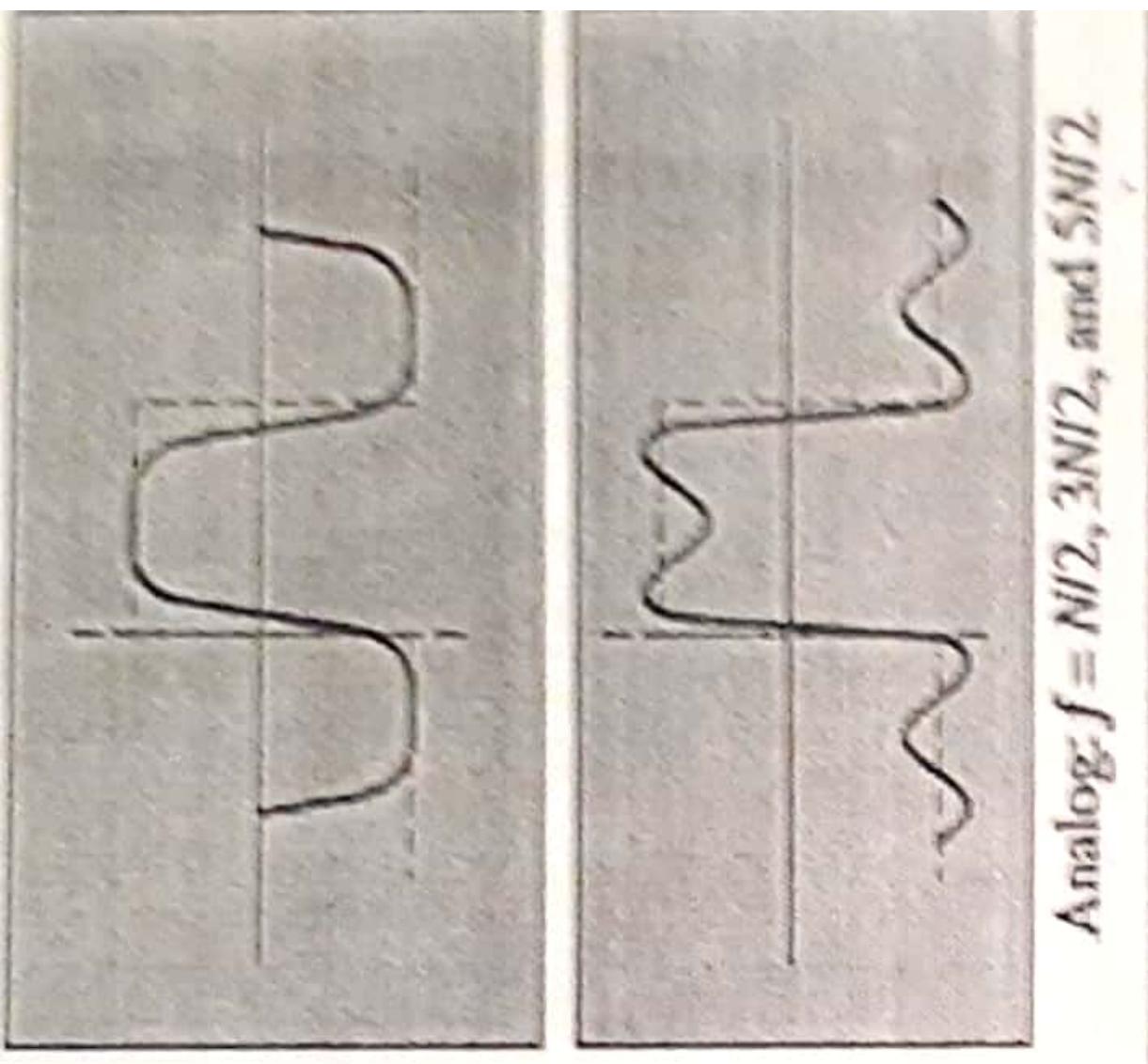


Digital; bit rate N



Digital; bit rate N





Analog: $f = N/2, 3N/2$, and $5N/2$

it signal with first three harmonics

1.9.4.2 Broadband Transmission (Using Modulation)

- Broadband transmission or modulation means changing the digital signal to an analog signal for transmission.
- Modulation allows us to use a bandpass channel (Figure 3.24).
- Bandpass channel means a channel with a bandwidth that does not start from zero.
- Bandpass channel means a channel with a bandwidth that does not start from zero.
- This type of channel is more available than a low-pass channel.

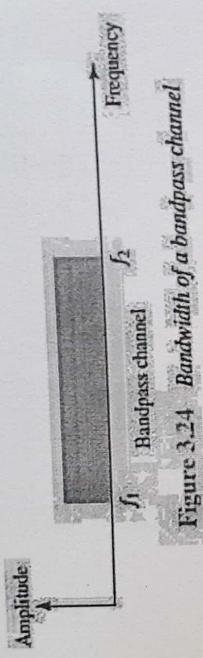


Figure 3.24 Bandwidth of a bandpass channel

- If the available channel is a bandpass channel;

We cannot send the digital signal directly to the channel;
We need to convert the digital signal to an analog signal before transmission (Figure 3.25).

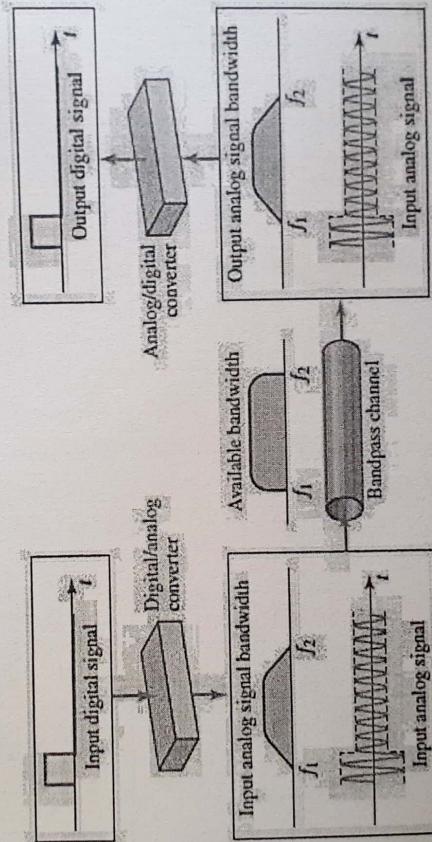


Figure 3.25 Modulation of a digital signal for transmission on a bandpass channel

1.10 TRANSMISSION IMPAIRMENT

- Signals travel through transmission media, which are not perfect.
- The imperfection causes signal-impairment.
- This means that signal at beginning of the medium is not the same as the signal at end of medium.
- What is sent is not what is received.
- Three causes of impairment are (Figure 3.26):
 - 1) Attenuation
 - 2) Distortion &
 - 3) Noise.

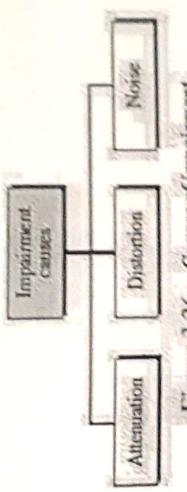


Figure 3.26 Causes of impairment

1.10.1 Attenuation

- As signal travels through the medium, its strength decreases as distance increases. This is called attenuation (Figure 3.27).
- As the distance increases, attenuation also increases.
- For example:
Voice-data becomes weak over the distance & loses its contents beyond a certain distance.
- To compensate for this loss, amplifiers are used to amplify the signal.

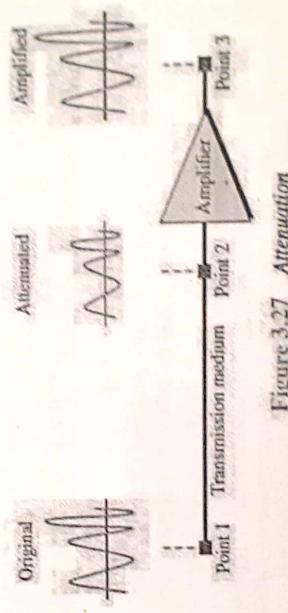


Figure 3.27 Attenuation

1.10.1.1 Decibel

- The decibel (dB) measures the relative strengths of
 - 2 signals or
 - one signal at 2 different points.
- The decibel is negative if a signal is attenuated.
- The decibel is positive if a signal is amplified.

$$dB = 10 \log_{10} \frac{P_2}{P_1}$$

- Variables P_1 and P_2 are the powers of a signal at points 1 and 2, respectively.
- To show that a signal has lost or gained strength, engineers use the unit of decibel.

Example 1.7

Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that $P_2 = \frac{1}{2} P_1$. In this case, the attenuation (loss of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5 P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

Example 1.8
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

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} 10 = 10(1) = 10 \text{ dB}$$

Example 1.9
Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dB_m and is calculated as $\text{dB}_m = 10 \log_{10} P_m$, where P_m is the power in milliwatts. Calculate the power of a signal if its $\text{dB}_m = -30$.

Solution

We can calculate the power in the signal as

$$\text{dB}_m = 10 \log_{10} \rightarrow \text{dB}_m = -30 \rightarrow \log_{10} P_m = -3 \rightarrow P_m = 10^{-3} \text{ mW}$$

Example 1.10

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

The loss in the cable in decibels is $5 \times (-0.3) = -1.5 \text{ dB}$. We can calculate the power as

$$\begin{aligned} \text{dB} &= 10 \log_{10} (P_2/P_1) = -1.5 \rightarrow (P_2/P_1) = 10^{-0.15} = 0.71 \\ P_2 &= 0.71P_1 = 0.7 \times 2 \text{ mW} = 1.4 \text{ mW} \end{aligned}$$

1.10.2 Distortion

- Distortion means that the signal changes its form or shape (Figure 3.29).
- Distortion can occur in a composite signal made of different frequencies.
- Different signal-components
 - have different propagation speed through a medium.
 - have different delays in arriving at the final destination.
- Differences in delay create a difference in phase if delay is not same as the period-duration.
- Signal-components at the receiver have phases different from what they had at the sender.
- The shape of the composite signal is therefore not the same.

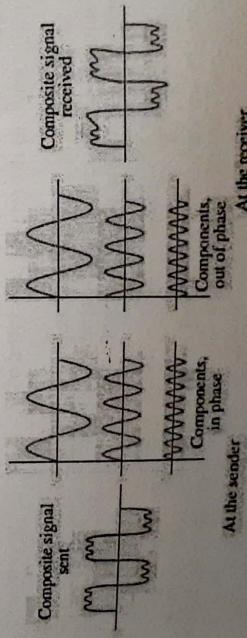


Figure 3.29 Distortion

1.10.3 Noise

- Noise is defined as an unwanted data (Figure 3.30).
- In other words, noise is the external energy that corrupts a signal.
- Due to noise, it is difficult to retrieve the original data/information.
- Four types of noise:

i) Thermal Noise

- It is random motion of electrons in wire which creates extra signal not originally sent by transmitter.

ii) Induced Noise

- Induced noise comes from sources such as motors & appliances.

- These devices act as a sending-antenna.

iii) Crosstalk

- Crosstalk is the effect of one wire on the other.

- One wire acts as a sending-antenna and the other as the receiving-antenna.

- The transmission-medium acts as the receiving-antenna.

iv) Impulse Noise

- Impulse Noise is a spike that comes from power-lines, lightning, and so on.

- Impulse Noise is a spike that comes from power-lines, lightning, and so on.

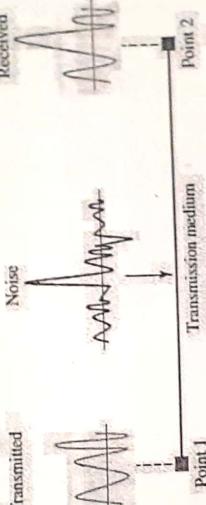


Figure 3.30 Noise

1.10.3.1 Signal-to-Noise Ratio (SNR)

- SNR is used to find the theoretical bit-rate limit.
- SNR is defined as
- SNR = $\frac{\text{average signal power}}{\text{average noise power}}$
- SNR is actually the ratio of what is wanted (signal) to what is not wanted (noise).
- A high-SNR means the signal is less corrupted by noise.
- A low-SNR means the signal is more corrupted by noise.
- Because SNR is the ratio of 2 powers, it is often described in decibel units, SNR_{dB} , defined as

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

Example 1.11

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:

$$\text{SNR} = (10,000 \mu\text{W}) / (1 \mu\text{W}) = 10,000 \quad \text{SNR}_{\text{dB}} = 10 \log_{10} 10,000 = 10 \log_{10} 10^4 \approx 40$$

1.1.1 DATA RATE LIMITS

- Data-rate depends on 3 factors:
 - 1) Bandwidth available
 - 2) Level of the signals
 - 3) Quality of channel (the level of noise)
- Two theoretical formulas can be used to calculate the data-rate:
 - 1) Nyquist for a noiseless channel
 - 2) Shannon for a noisy channel.

1.1.1.1 Noiseless Channel: Nyquist Bit Rate

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

$$\text{BitRate} = 2 \times \text{Bandwidth} \times \log_2 L$$

where bandwidth = bandwidth of the channel

$$L = \text{number of signal-levels used to represent data}$$

$$\text{BitRate} = \text{bitrate of channel in bps}$$

- According to the formula,
 - By increasing number of signal-levels, we can increase the bit-rate.
 - Although the idea is theoretically correct, practically there is a limit.
 - When we increase the number of signal-levels, we impose a burden on the receiver.
 - If no. of levels in a signal is 2, the receiver can easily distinguish b/w 0 and 1.
 - If no. of levels is 64, the receiver must be very sophisticated to distinguish b/w 64 different levels.
 - In other words, increasing the levels of a signal reduces the reliability of the system.

Example 1.12

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

$$\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

Example 1.13

Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate can be calculated as

$$\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12,000 \text{ bps}$$

Example 1.14

We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

Solution

We can use the Nyquist formula as shown:

$$265,000 = 2 \times 20,000 \times \log_2 L \rightarrow \log_2 L = 6.625 \rightarrow L = 2^{6.625} = 98.7 \text{ levels}$$

1.11.2 Noisy Channel: Shannon Capacity

- In reality, we cannot have a noiseless channel; the channel is always noisy.
- For a noisy channel, the Shannon capacity formula defines the theoretical maximum bit-rate.
$$\text{Capacity} = \text{bandwidth} \times \log_2(1 + \text{SNR})$$
where bandwidth = bandwidth of channel in bps.

- This formula does not consider the no. of levels of signals being transmitted (as done in the Nyquist bit rate).
This means that no matter how many levels we have, we cannot achieve a data-rate higher than the capacity of the channel.
- In other words, the formula defines a characteristic of the channel, not the method of transmission.

Example 1.15

We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000 Hz (300 to 3300 Hz) assigned for data communications. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as:

$$C = B \log_2(1 + \text{SNR}) = 3000 \log_2(1 + 3162) = 3000 \times 11.62 = 34,860 \text{ bps}$$

Example 1.16

The signal-to-noise ratio is often given in decibels. Assume that $\text{SNR}_{\text{dB}} = 36$ and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as:

$$\begin{aligned}\text{SNR}_{\text{dB}} &= 10 \log_{10} \text{SNR} \rightarrow \text{SNR} = 10^{\frac{\text{SNR}_{\text{dB}}}{10}} \rightarrow \text{SNR} = 10^{3.6} = 3981 \\ C &= B \log_2(1 + \text{SNR}) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}\end{aligned}$$

Example 1.17

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:

$$C = B \log_2(1 + \text{SNR}) = 10^6 \log_2(1 + 63) = 10^6 \log_2 64 = 6 \text{ Mbps}$$

The Shannon formula gives us 6 Mbps, the upper limit. For better performance we choose something lower, 4 Mbps, for example. Then we use the Nyquist formula to find the number of signal levels.

$$4 \text{ Mbps} = 2 \times 1 \text{ MHz} \times \log_2 L \rightarrow L = 4$$

1.12 PERFORMANCE

1.12.1 Bandwidth

- One characteristic that measures network-performance is bandwidth.
- Bandwidth of analog and digital signals is calculated in separate ways:

(1) Bandwidth of an Analog Signal (in hz)

- Bandwidth of an analog signal is expressed in terms of its frequencies.
- Bandwidth is defined as the range of frequencies that the channel can carry.
- It is calculated by the difference b/w the maximum frequency and the minimum frequency.

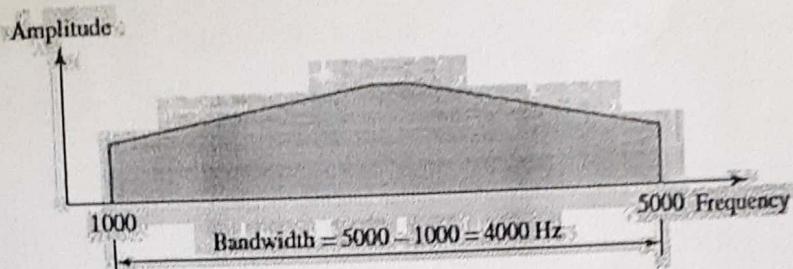


Figure 3.13 The bandwidth of signals

In figure 3.13, the signal has a minimum frequency of $F_1 = 1000\text{Hz}$ and maximum frequency of $F_2 = 5000\text{Hz}$.

$$\text{Hence, the bandwidth is given by } F_2 - F_1 = 5000 - 1000 = 4000 \text{ Hz}$$

(2) Bandwidth of a Digital Signal (in bps)

- Bandwidth refers to the number of bits transmitted in one second in a channel (or link).
- For example:
The bandwidth of a Fast Ethernet is a maximum of 100 Mbps. (This means that this network can send 100 Mbps).

Relationship between (1) and (2)

- There is an explicit relationship between the bandwidth in hertz and bandwidth in bits per seconds.
- Basically, an increase in bandwidth in hertz means an increase in bandwidth in bits per second.
- The relationship depends on
 - baseband transmission or
 - transmission with modulation.

1.12.2 Throughput

- The throughput is a measure of how fast we can actually send data through a network.
- Although, bandwidth in bits per second and throughput seem the same, they are actually different.
- A link may have a bandwidth of B bps, but we can only send T bps through this link with T always less than B.

• In other words,

- 1) The bandwidth is a potential measurement of a link.
- 2) The throughput is an actual measurement of how fast we can send data.

For example:

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

Example 1.18

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

$$\text{Throughput} = (12,000 \times 10,000) / 60 = 2 \text{ Mbps}$$

1.12.3 Latency (Delay)

- The latency 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.

$$\text{Latency} = \text{propagation time} + \text{transmission time} + \text{queuing time} + \text{processing delay}$$

1) Propagation Time

- Propagation time is defined as the time required for a bit to travel from source to destination.

- Propagation time is given by

$$\text{Propagation time} = \text{Distance} / (\text{Propagation Speed})$$

- Propagation speed of electromagnetic signals depends on
 - medium and
 - frequency of the signal.

Example 1.19

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

$$\text{Propagation time} = (12,000 \times 10,000) / (2.4 \times 10^8) = 50 \text{ ms}$$

b

2) Transmission Time

- The time required for transmission of a message depends on

- size of the message and
- bandwidth of the channel.

- The transmission time is given by

$$\text{Transmission time} = (\text{Message size}) / \text{Bandwidth}$$

Example 1.20

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

Solution

We can calculate the propagation and transmission time as

$$\text{Propagation time} = (12,000 \times 1000) / (2.4 \times 10^8) = 50 \text{ ms}$$

$$\text{Transmission time} = (2500 \times 8) / 10^9 = 0.020 \text{ ms}$$

c

Example 1.21

What are the propagation time and the transmission time for a 5-MB (megabyte) message (an image) 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

We can calculate the propagation and transmission times as

$$\text{Propagation time} = (12,000 \times 1000) / (2.4 \times 10^8) = 50 \text{ ms}$$

$$\text{Transmission time} = (5,000,000 \times 8) / 10^6 = 40 \text{ s}$$

3) Queuing Time

➤ Queuing-time is the time needed for each intermediate-device to hold the message before it can be processed.

(Intermediate device may be a router or a switch)

➤ The queuing-time is not a fixed factor. This is because

i) Queuing-time changes with the load imposed on the network.

ii) When there is heavy traffic on the network, the queuing-time increases.

➤ An intermediate-device

→ queues the arrived messages and

→ processes the messages one by one.

➤ If there are many messages, each message will have to wait.

4) Processing Delay

➤ Processing delay is the time taken by the routers to process the packet header.

1.12.4 Bandwidth Delay Product

- Two performance-metrics of a link are 1) Bandwidth and 2) Delay
- The bandwidth-delay product is very important in data-communications.
- Let us elaborate on this issue, using 2 hypothetical cases as examples.

Case 1: The following figure shows case 1 (Figure 3.32).

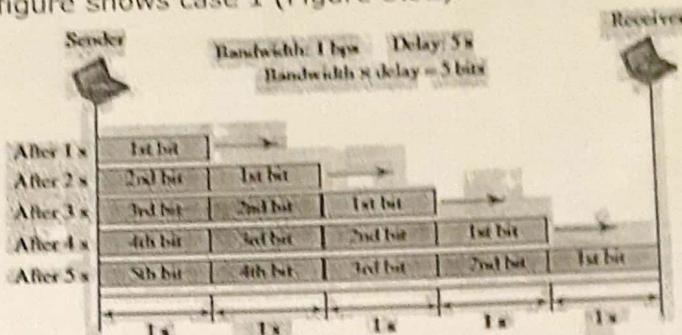


Figure 3.32 Filling the link with bits for case 1.

Let us assume,

Bandwidth of the link = 1 bps

Delay of the link = 5s.

From the figure 3.32, bandwidth-delay product is $1 \times 5 = 5$. Thus, there can be maximum 5 bits on the line.

There can be no more than 5 bits at any time on the link.

Case 2: The following figure shows case 2 (Figure 3.33).

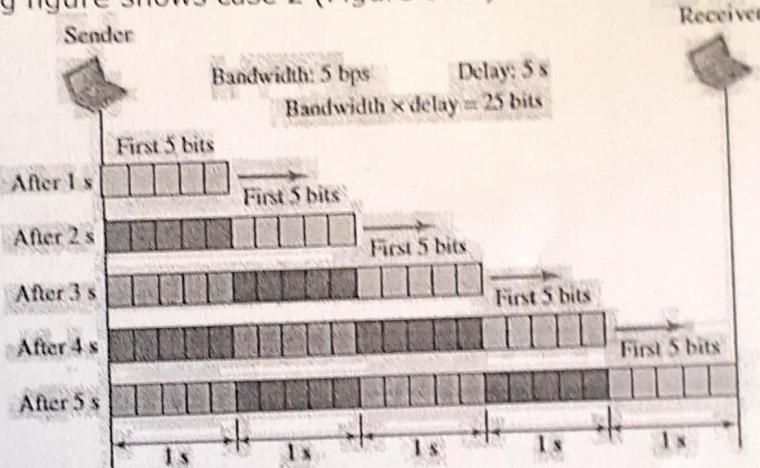


Figure 3.33 Filling the link with bits in case 2.

Let us assume,

Bandwidth of the link = 4 bps

Delay of the link = 5s.

From the figure 3.33, bandwidth-delay product is $5 \times 5 = 25$. Thus, there can be maximum 25 bits on the line.

At each second, there are 5 bits on the line, thus the duration of each bit is 0.20s.

- The above 2 cases show that the (bandwidth X delay) is the number of bits that can fill the link.
- This measurement is important if we need to
 - send data in bursts and
 - wait for the acknowledgment of each burst.
- To use the maximum capability of the link
 - We need to make the burst-size as $(2 \times \text{bandwidth} \times \text{delay})$.
 - We need to fill up the full-duplex channel (two directions).
- Amount $(2 \times \text{bandwidth} \times \text{delay})$ is the number of bits that can be in transition at any time (Fig 3.34).



Figure 3.34 Concept of bandwidth-delay product

1.12.5 Jitter

- Another performance issue that is related to delay is jitter.
- We can say that jitter is a problem
 - if different packets of data encounter different delays and
 - if the application using the data at the receiver site is time-sensitive (for ex: audio/video).
- For example:
 - If the delay for the first packet is 20 ms
 - the delay for the second is 45 ms and
 - the delay for the third is 40 ms
 - then the real-time application that uses the packets suffers from jitter.

MODULE 1(CONT.): DIGITAL TRANSMISSION

1.13 DIGITAL TO DIGITAL CONVERSION

- Data can be analog or digital, so can be the signal that represents it.
- Signal encoding is the conversion from analog/digital data to analog/digital signal.
- The possible encodings are:
 - 1) Digital data to digital signal
 - 2) Digital data to analog signal
 - 3) Analog data to digital signal
 - 4) Analog data to analog signal

1.13.1 LINE CODING

- Line-coding is the process of converting digital-data to digital-signals (Figure 4.1).
- The data may be in the form of text, numbers, graphical images, audio, or video
- The data are stored in computer memory as sequences of bits (0s or 1s).
- Line-coding converts a sequence of bits to a digital-signal.
- At the sender, digital-data is encoded into a digital-signal.

At the receiver, digital-signal is decoded into a digital-data.

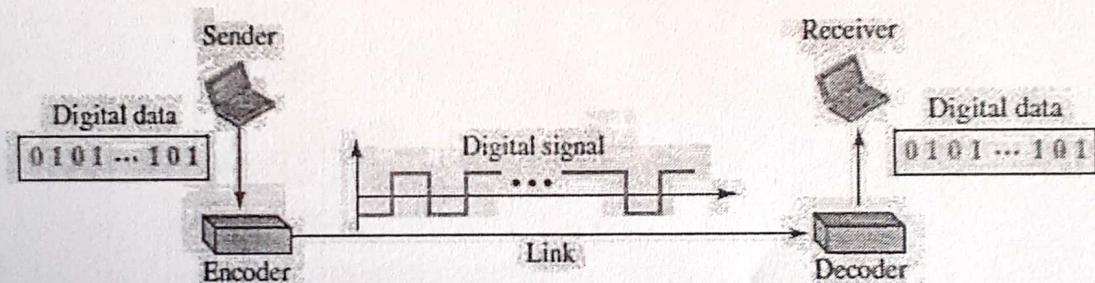


Figure 4.1 *Line coding and decoding*

1.13.1.1 Characteristics

- Different characteristics of digital signal are
 - Signal Element Vs Data Element
 - Data Rate Vs Signal Rate
 - Bandwidth
 - Baseline Wandering
 - DC Components
 - Built-in Error Detection
 - Self-synchronization
 - Immunity to Noise and Interference
 - Complexity

1) Data Element vs. Signal Element

Data Element	Signal Element
A data-element is the smallest entity that can represent a piece of information (Figure 4.2).	A signal-element is shortest unit (timewise) of a digital-signal.
A data-element is the bit.	A signal-element carries data-elements.
Data-elements are being carried.	Signal-elements are the carriers.

➤ Ratio r is defined as number of data-elements carried by each signal-element.

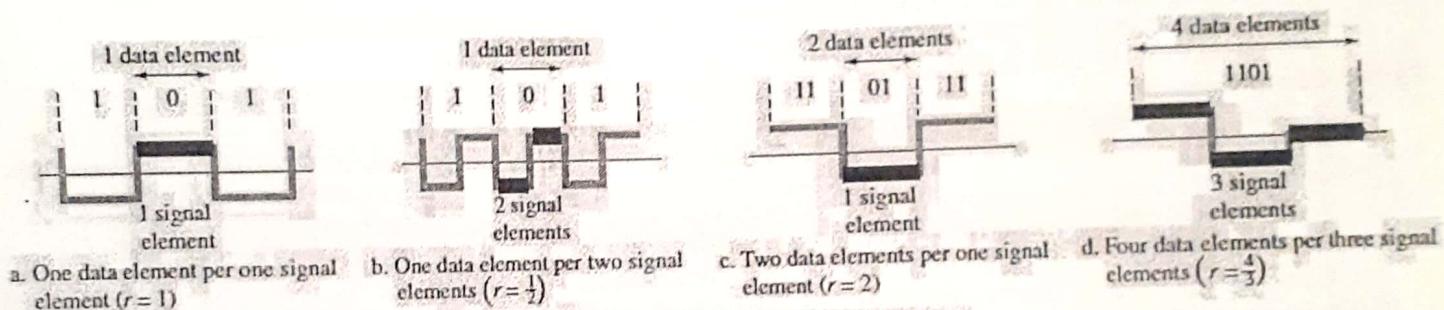


Figure 4.2 Signal element versus data element

2) Data Rate vs. Signal Rate

Data Rate	Signal Rate
The data-rate defines the number of data-elements (bits) sent in 1 sec.	The signal-rate is the number of signal-elements sent in 1 sec.
The unit is bits per second (bps).	The unit is the baud.
The data-rate is sometimes called the bit-rate.	The signal-rate is sometimes called the pulse rate, the modulation rate, or the baud rate
Goal in data-communications: increase the data-rate.	Goal in data-communications: decrease the signal-rate.
Increasing the data-rate increases the speed of transmission.	Decreasing the signal-rate decreases the bandwidth requirement.

➤ The relationship between data-rate and signal-rate is given by

$$S_{\text{ave}} = c \times N \times (1/r) \quad \text{baud}$$

where N = data-rate (in bps)

c = case factor, which varies for each case

S = number of signal-elements and

r = previously defined factor.

➤ This relationship depends on

→ value of r .

→ data pattern.

(If we have a data pattern of all 1s or all 0s, the signal-rate may be different from a data pattern of alternating 0s and 1s).

3) Bandwidth

- Digital signal that carries information is non-periodic.
- The bandwidth of a non-periodic signal is continuous with an infinite range.
- However, most digital-signals we encounter in real life have a bandwidth with finite values.
- The effective bandwidth is finite.
- The baud rate, not the bit-rate, determines the required bandwidth for a digital-signal.
- More changes in the signal mean injecting more frequencies into the signal.
(Frequency means change and change means frequency.)
- The bandwidth refers to range of frequencies used for transmitting a signal.
- Relationship b/w baud rate (signal-rate) and the bandwidth (range of frequencies) is given as

$$B_{\min} = c \times N \times (1/r)$$

where N = data-rate (in bps)

c = case factor, which varies for each case

r = previously defined factor

B_{\min} = minimum bandwidth

4) Baseline Wandering

- While decoding, the receiver calculates a running-average of the received signal-power. This average is called the baseline.
- The incoming signal-power is estimated against this baseline to determine the value of the data-element.
- A long string of 0s or 1s can cause a drift in the baseline (baseline wandering).
Thus, make it difficult for the receiver to decode correctly.
- A good line-coding scheme needs to prevent baseline wandering.

5) DC Components

- When the voltage-level in a digital-signal is constant for a while, the spectrum creates very low frequencies.
- These frequencies around zero are called DC (direct-current) components.
- DC components present problems for a system that cannot pass low frequencies.
- For example: Telephone line cannot pass frequencies below 200 Hz.
- For Telephone systems, we need a scheme with no DC component.

6) Built-in Error Detection

- Built-in error-detecting capability has to be provided to detect the errors that occurred during transmission.

7) Self Synchronization

- To correctly interpret the signals received from the sender, the receiver's bit intervals must correspond exactly to the sender's bit intervals.
- If the receiver clock is faster or slower, the bit intervals are not matched and the receiver might misinterpret the signals.

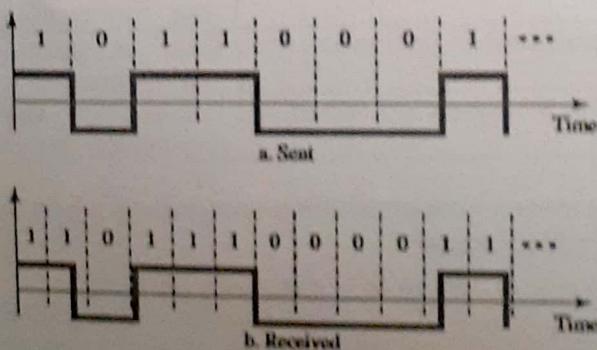


Figure 4.3 Effect of lack of synchronization

- As shown in figure 4.3, we have a situation where the receiver has shorter bit duration.
- The sender sends 10110001, while the receiver receives 110111000011.
- A self-synchronizing digital-signal includes timing-information in the data being transmitted.
 - This can be achieved if there are transitions in the signal that alert the receiver to the beginning, middle, or end of the pulse.
- If the receiver's clock is out-of-synchronization, these points can reset the clock.

8) Immunity to Noise & Interference

➤ The code should be immune to noise and other interferences.

9) Complexity

➤ A complex scheme is more costly to implement than a simple one.

➤ For ex: A scheme that uses 4 signal-levels is more difficult to interpret than one that uses only 2 levels.

Example 1.22

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

$$S = c \times N \times (1/r) = 1/2 \times 100,000 \times (1/1) = 50,000 = 50 \text{ kband}$$

Example 1.23

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.

$$1000 \text{ bits sent} \rightarrow 1001 \text{ bits received} \rightarrow 1 \text{ extra bps}$$

At 1 Mbps, the receiver receives 1,001,000 bps instead of 1,000,000 bps.

$$1,000,000 \text{ bits sent} \rightarrow 1,001,000 \text{ bits received} \rightarrow 1000 \text{ extra bps}$$

1.13.2 LINE CODING SCHEMES

- The Line Coding schemes are classified into 3 broad categories (Figure 4.4):

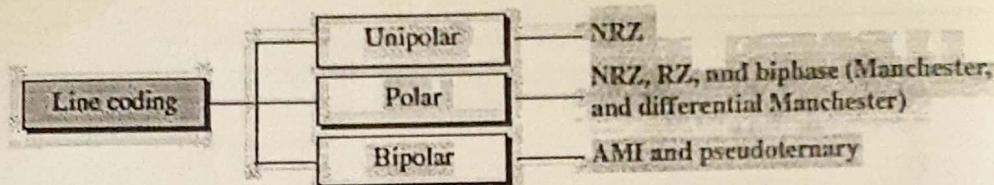


Figure 4.4 Line coding schemes

1.13.2.1 Unipolar Scheme

- All signal levels are either above or below the time axis.

NRZ (Non-Return-to-Zero)

- The positive voltage defines bit 1 and the zero voltage defines bit 0 (Figure 4.5).
- It is called NRZ because the signal does not return to 0 at the middle of the bit.

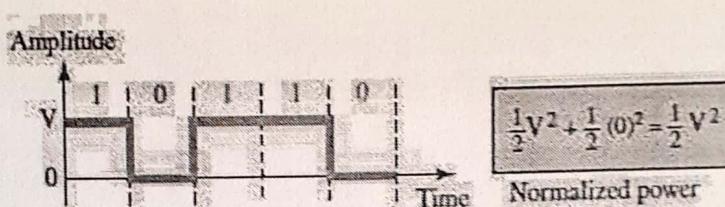


Figure 4.5 Unipolar NRZ scheme

➤ Disadvantages:

- Compared to polar scheme, this scheme is very costly.
- Also, the normalized power is double that for polar NRZ.
- Not suitable for transmission over channels with poor performance around zero frequency
(Normalized power → power needed to send 1 bit per unit line resistance)

1.13.2.2 Polar Schemes

- The voltages are on the both sides of the time axis.
- Polar NRZ scheme can be implemented with two voltages (V).

For example: $-V$ for bit 1

$+V$ for bit 0.

a) Non-Return-to-Zero (NRZ)

- We use 2 levels of voltage amplitude.
- Two versions of polar NRZ (Figure 4.6):

i) NRZ-L (NRZ-Level)

- The level of the voltage determines the value of the bit.
- For example: i) Voltage-level for 0 can be positive and ii) Voltage-level for 1 can be negative.

ii) NRZ-I (NRZ-Invert)

- The change or lack of change in the level of the voltage determines the value of the bit.
- If there is no change, the bit is 0;
- If there is a change, the bit is 1.

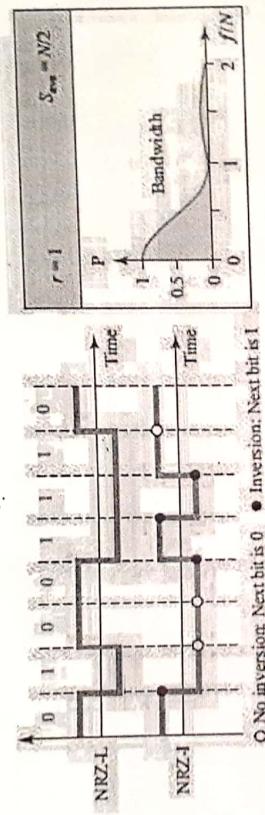


Figure 4.6 Polar NRZ-L and NRZ-I schemes

Disadvantages:

1) Baseline wandering is a problem for both variations (NRZ-L NRZ-I).

- In NRZ-L, if there is a long sequence of 0s or 1s, the average signal-power becomes skewed.

The receiver might have difficulty discerning the bit value.

- In NRZ-I, this problem occurs only for a long sequence of 0s.

If we eliminate the long sequence of 0s, we can avoid baseline wandering.

2) The synchronization problem also exists in both schemes.

→ A long sequence of 0s can cause a problem in both schemes.

→ A long sequence of 1s can cause a problem in only NRZ-L.

3) In NRZ-L, problem occurs when there is a sudden change of polarity in the system.

- For example:

In twisted-pair cable, a change in the polarity of the wire results in
→ all 0s interpreted as 1s and
→ all 1s interpreted as 0s.

NRZ-I does not have this problem.

Both schemes have an average signal-rate of $N/2$ Bd.

- NRZ-L and NRZ-I both have a DC component problem.

Example 1.24

A system is using NRZ-I to transfer 10-Mbps data. What are the average signal rate and minimum bandwidth?

Solution

The average signal rate is $S = N/2 = 500$ kbaud. The minimum bandwidth for this average baud rate is $B_{\min} = S = 500$ kHz.

b) Return-to-Zero (RZ)

- In NRZ encoding, problem occurs when the sender-clock and receiver-clock are not synchronized.
- Solution: Use return-to-zero (RZ) scheme (Figure 4.7).
- RZ scheme uses 3 voltages: positive, negative, and zero.
- There is always a transition at the middle of the bit. Either
 - from high to zero (for 1)
 - from low to zero (for 0)

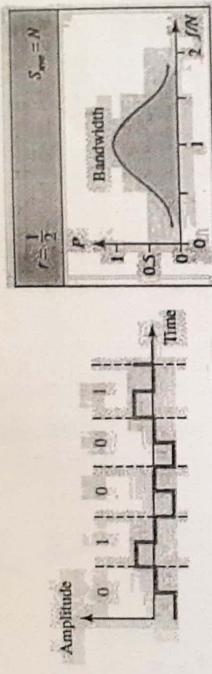
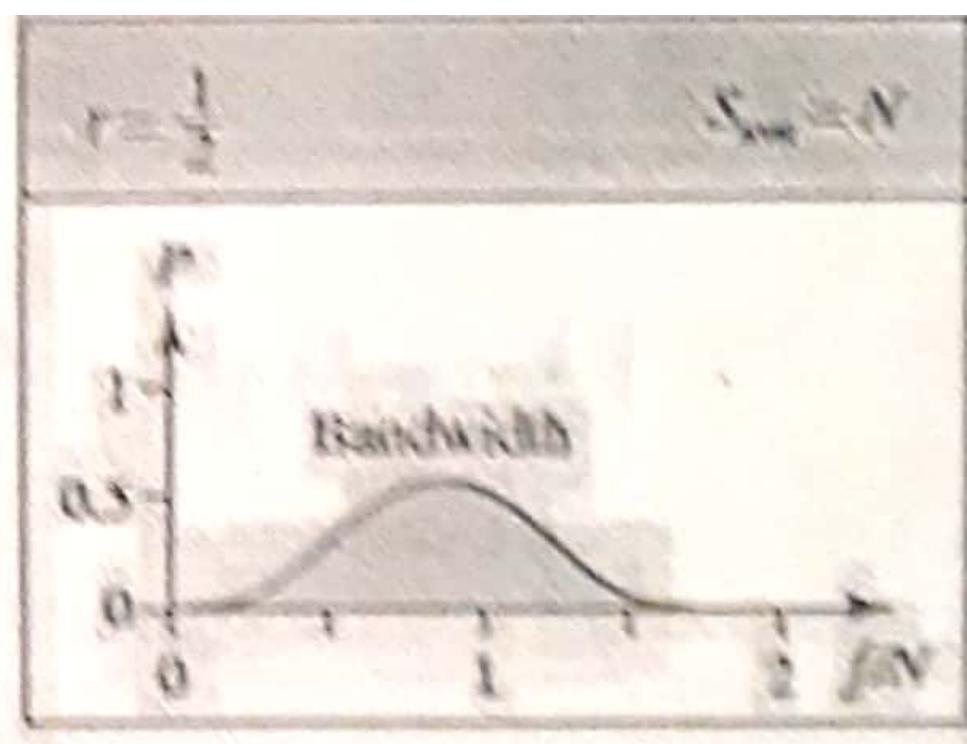
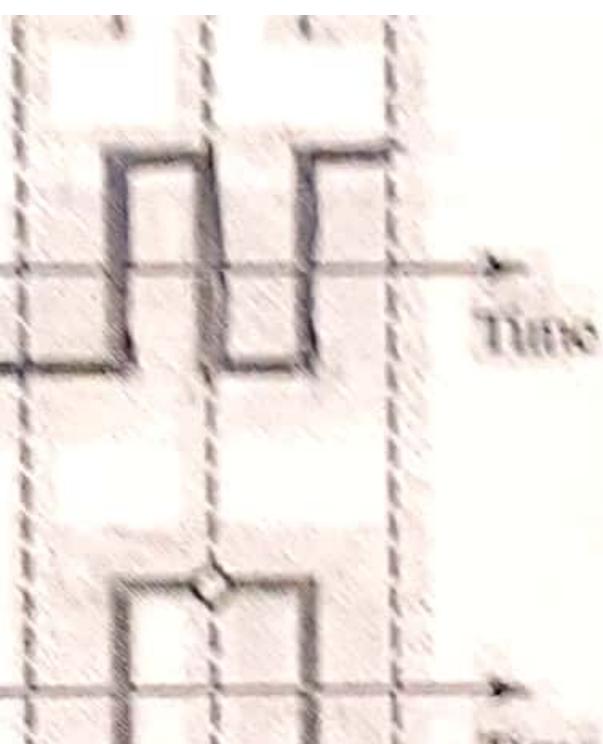


Figure 4.7 Polar RZ scheme

- Disadvantages:
 - 1) RZ encoding requires 2 signal-changes to encode a bit & . . . occupies greater bandwidth.
 - 2) Complexity: RZ uses 3 levels of voltage, which is more complex to create and detect.
 - 3) Problem occurs when there is a sudden change of polarity in the system. This result in
 - all 0s interpreted as 1s &
 - all 1s interpreted as 0s.



- This coding scheme uses 3 voltage levels (Figure 4.9):
 - positive
 - negative &
 - zero.

- Two variations of bipolar encoding:
 - AMI (Alternate Mark Inversion)
 - Pseudoternary

i) AMI

- Binary 0 is represented by a neutral 0 voltage (AMI \rightarrow Alternate 1 Inversion).
- Binary 1s are represented by alternating positive and negative voltages.

ii) Pseudoternary

- Binary 1 is represented by a neutral 0 voltage.
- Binary 0s are represented by alternating positive and negative voltages.

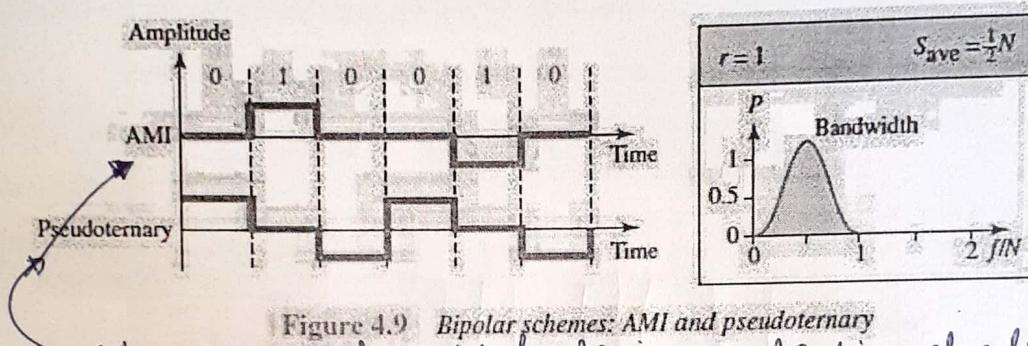


Figure 4.9 Bipolar schemes: AMI and pseudoternary

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Advantages:

- The bipolar scheme has the same signal-rate as NRZ.
- There is no DC component ' each bit has a positive & negative voltage contribution.
- The concentration of the energy is around frequency N/2.

Disadvantage:

- AMI has a synchronization problem when a long sequence of 0s is present in the data.

Table 4.1 Summary of line coding schemes

Category	Scheme	Bandwidth (average)	Characteristics
Unipolar	NRZ	$B = N/2$	Costly, no self-synchronization if long 0s or 1s, DC
Polar	NRZ-L	$B = N/2$	No self-synchronization if long 0s or 1s, DC
	NRZ-I	$B = N/2$	No self-synchronization for long 0s, DC
	Biphase	$B = N$	Self-synchronization, no DC, high bandwidth
Bipolar	AMI	$B = N/2$	No self-synchronization for long 0s, DC

MODULE-WISE QUESTIONS

MODULE 1: INTRODUCTION

- 1) Define data communications. Explain its 4 fundamental characteristics. (4*)
- 2) Explain different components of data communication system. (6*)
- 3) Explain different forms of information. (4)
- 4) Describe simplex, half-duplex and full duplex methods of data flow. (6*)
- 5) Explain the 3 criteria necessary for an effective and efficient network. (4*)
- 6) Explain point to point and multipoint connection. (4*)
- 7) Explain the following topologies:
 - i) Mesh
 - ii) Star
 - iii) Bus
 - iv) Ring(12*)
- 8) Explain in detail LAN & WAN. List the differences between LAN & WAN. (10*)
- 9) Explain circuit-switched and packet-switched networks. (6*)
- 10) Explain components of Internet. (4*)
- 11) Explain different method of accessing the Internet. (6*)
- 12) With respect to RFC, explain the following:
 - i) Maturity Levels
 - ii) Requirement Levels.(6)
- 13) What are internet standards? Explain the functions of standard organizations. (4*)

MODULE 1(CONT.): NETWORK MODELS

- 1) Explain TCP/IP architecture with a layer diagram. (4*)
- 2) List the 5 layers and its functionality in TCP/IP model. (8*)
- 3) With respect to in TCP/IP model, explain the following:
 - i) Encapsulation and decapsulation.
 - ii) Multiplexing and demultiplexing.(8)
- 4) Explain four levels of addressing employed in TCP/IP protocol. (6*)
- 5) What are the uses of a layered network model? Compare OSI and TCP/IP models. (4)

MODULE 1(CONT.): DATA AND SIGNALS

- 1) Compare the following:
 - i) Analog signal vs. Digital signal.
 - ii) Periodic signal vs. Non-periodic signal.(4)
- 2) Describe digital signal as a composite analog signal. (4)
- 3) Explain 2 methods for transmitting a digital signal (8*)
- 4) What do you mean by transmission impairment? Explain causes of transmission impairment? (6*)
- 5) What are the three factors data rate is dependent on? Explain the theoretical formula which was developed to calculate the data rate. (8*)
- 6) Explain 4 performance parameters of network. (8*)

MODULE 1(CONT.): DIGITAL TRANSMISSION

- 1) Explain in detail any 6 characteristics of digital signal. (6*)
- 2) Compare the following:
 - i) Data element vs. Signal element.
 - ii) Data rate vs. Signal rate.(4)
- 3) Explain following encoding schemes with example:
 - i) Unipolar Scheme
 - ii) Polar Schemes
 - iii) Bipolar Schemes(8*)
- 4) Represent the following sequences using different line coding schemes.
 - i) 101011100.
 - ii) 10110011.
 - iii) 00110101.(6*)
- 5) Define the following:
 - i) Network
 - ii) Internet
 - iii) Protocol
 - iv) Decibel
 - v) SNR
 - vi) Line coding(6*)

