1) **Data Communication:** exchange of data between two devices via some form of transmission medium.
   a) **Four fundamentals:**
      i) **Delivery.** The system must deliver data to the correct destination. Data must be received by the intended device or user and only by that device or user.
      ii) **Accuracy.** The system must deliver the data accurately. Data that have been altered in transmission and left uncorrected are unusable.
      iii) **Timeliness.** The system must deliver data in a timely manner. Data delivered late is useless. In the case of video and audio, timely delivery means delivering data as they are produced, in the same order that they are produced, and without significant delay. This kind of delivery is called <u>real-time transmission</u>.
      iv) **Jitter**. Jitter refers to the variation in the packet arrival time. It is the uneven delay in the delivery of audio or video packets.
   b) **Components:**
      i) **Message**. The message is the information (data) to be communicated. Popular forms of information include text, numbers, pictures, audio, and video.
      ii) **Sender**. The sender is the device that sends the data message. It can be a computer, workstation, telephone handset, video camera, and so on.
      iii) **Receiver**. The receiver is the device that receives the message. It can be a computer, workstation, telephone handset, television, and so on.
      iv) **Transmission medium**. The transmission medium is the physical path by which a message travels from sender to receiver. Some examples of transmission media include twisted-pair wire, coaxial cable, fiber-optic cable, and radio waves.
      v) **Protocol**. A protocol is a set of rules that govern data communications. It represents an agreement between the communicating devices.
   c) **Transmission modes:**
      i) **Simplex:** unidirectional communication like keyboard, mouse
      ii) **Half Duplex:** can both transmit and receive, but not at the same time like walkie talkies.
      iii) **Full duplex:** Can transmit and receive simultaneously like telephone.
   d) **Network Types:**
      i) LAN
      ii) WAN
         (1) P2P WAN
         (2) Switched WAN
         (3) Internetwork: When two or more networks are connected, they make an internetwork, or internet.
      iii) Switched Network: a switch connects at least two links together.

(1) **Circuit - switched:** a dedicated connection, called a circuit, is always available between the two end systems; the switch can only make it active or inactive.
(2) **Packet - switched:** the communication between the two ends is done in blocks of data called packets. Switches function for both storing and forwarding because a packet is an independent entity that can be stored and sent later.

iv) The Internet

e) **Transmission Impairment:**

i) **Attenuation:** due to loss of energy(that's why Amplifiers are used)

Example 3.26

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

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

A loss of 3 dB (–3 dB) is equivalent to losing one-half the power.

ii) **Distortion:** due to change in form/shape of signal(can happen due to change in phase or due to Jitter)

iii) **Noise:** Corruption of signal(thermal/induced/impulse/cross-talk)

(1) Signal to Noise Ratio $\text{SNR} = \frac{\text{average signal power}}{\text{average noise power}}$

f) **Signal Types:**

i) Periodic

ii) Non-periodic

(1) **Bit length** is the distance one bit occupies on the transmission medium. **propagation speed × bit duration**

Example 3.20

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

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

iii) Composite: made of multiple periodic waves.

(1) Bandwidth: Range of frequencies contained in that signal.
(2) No. of bits per level

Example 3.16

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.

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

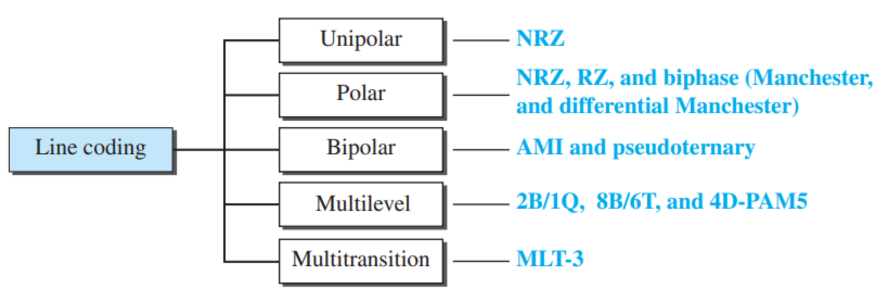
g) Representation of digital data by using digital signals:

- **i)** Basic Characteristics:
  - **(1)** **Data element** is the smallest entity that can represent a piece of information: this is the bit.
  - **(2)** **Signal element** is the shortest unit (timewise) of a digital signal.
  - **(3)** **Data-rate/Bit-rate(N)** defines the number of data elements (bits) sent per second. Unit is bps.
    - **(a)** **Types:**
      - **(i)** Nyquist(Noiseless-> theoretical)

        $$\text{BitRate} = 2 \times \text{bandwidth} \times \log_2 L$$
      - **(ii)** Shannon(Noisy-> practical)

        $$\text{Capacity} = \text{bandwidth} \times \log_2(1 + \text{SNR})$$
  - **(4)** **Signal-rate/Pulse-rateModulation_rate/Baud-rate(S)** is the number of signal elements sent in 1s. Unit is Baud

    relationship between
  - **(5)** $S = N/r$ "r" is the number of data elements carried by each signal element.
- **ii)** Line coding: to convert digital data to digital signals, always needed.
  - **(1)** Schemes:
    - **(a)** Polar
    - **(b)** Unipolar -> NRZ(non return to zero) -> signal doesn't return to zero at the middle of the bit. But very costly(double of polar)



- **iii)** Block coding
- **iv)** Scrambling

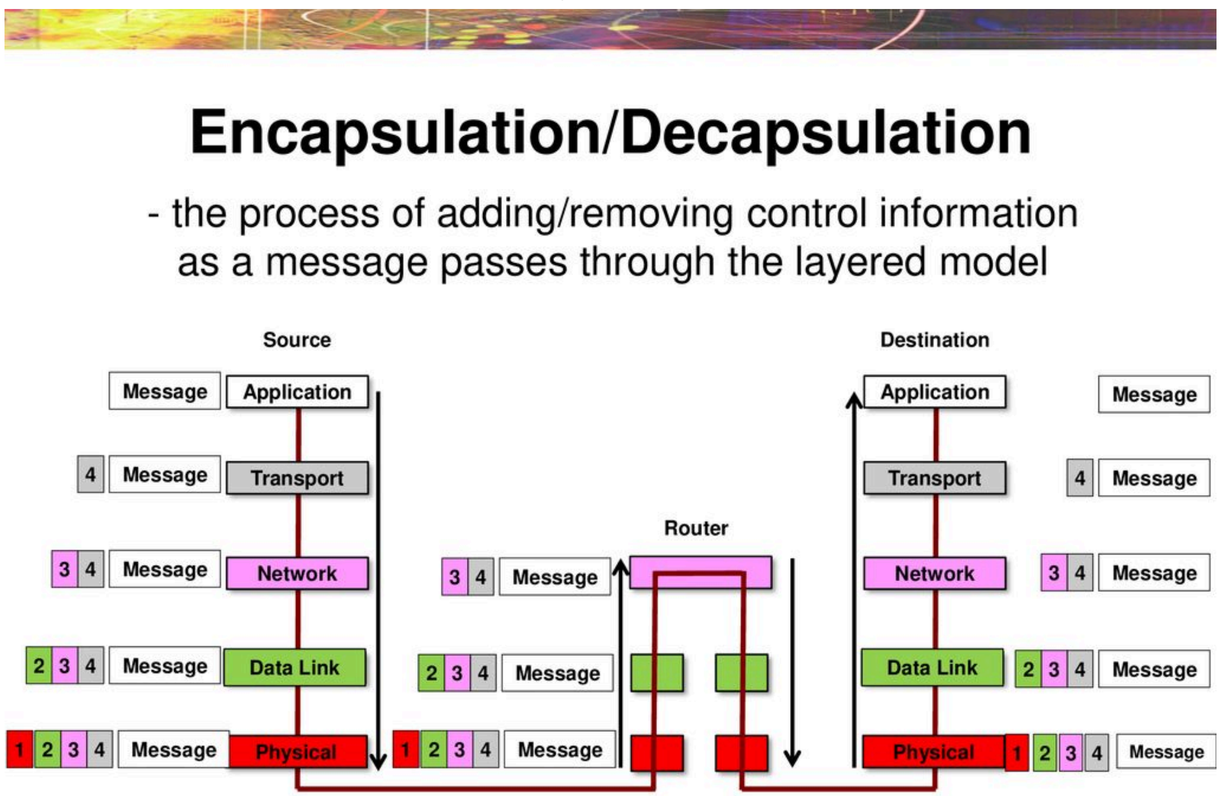
h) **Protocol Layering:** Complex communications are handled by dividing the task between different layers, a protocol at each layer, Thus, protocol layering.

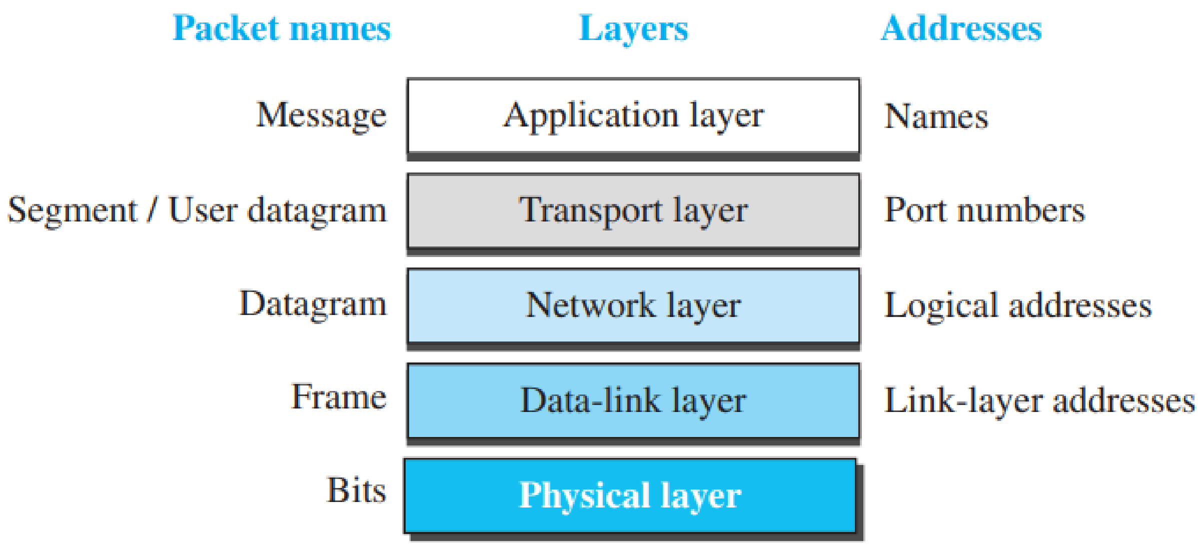
- **i)** **Principles:**

(1) For <u>bidirectional</u> communication, each layer must be able to perform two <u>opposite</u> tasks, one in each direction.
(2) Two objects under each layer at both sites should be <u>identical</u>.

ii) **Encapsulation and Decapsulation:**

(1) **Encapsulation:** process of concatenating layer-specific headers or trailers to a message for transmitting information over computer networks.
(2) **Decapsulation:** exact reverse process of encapsulation, additional info added on the sender's side gets removed when it travels on the receiver's side from the Physical layer to the Application layer.





2) **Multiplexing & Demultiplexing**
   - **a)** Used to share a physical transmission medium (like a cable or a wireless channel) among multiple signals
   - **b)** Common types:
     - **i)** **Frequency Division Multiplexing (FDM)(Analog):** divides the available bandwidth of the medium into smaller frequency ranges. Each data stream is modulated onto a different carrier frequency within the overall bandwidth. Example: radio & tv.
       - **(1)** Simplistic
       - **(2)** Easy to implement
       - **(3)** **Cross-talk:** Signals in adjacent frequency bands can interfere with each other, causing data corruption. Careful allocation of frequencies and maintaining sufficient guard bands between channels is crucial to minimize this issue.
       - **(4)** Limited-capacity
       - **(5)** Channel-wastage
     - **ii)** **Time Division Multiplexing (TDM)(Digital):** Here, the available time on the medium is divided into time slots. Each data stream is allocated specific time slots within a repeating cycle to transmit its data.
       - **(1)** Inefficient Bandwidth Use
       - **(2)** Guaranteed Bandwidth
       - **(3)** Can Delay
       - **(4)** **Two types:**
         - **(a)** Synchronous
         - **(b)** Asynchronous
     - **iii)** **Wavelength Division Multiplexing (WDM)(Analog):** Primarily used in fiber optic communication. It utilizes different wavelengths of light to carry separate data streams on the same fiber optic cable. Think of it like

sending multiple colors of light through the same fiber, each color carrying its own information.

- **(1)** High-Cost
- **(2)** High Bandwidth Capacity
- **(3)** Lower interference chances -> clearer & reliable
- **(4)** **Dispersion Effect:** Signal gets distorted as light traverses over longer distances.
- **(5)** **Two types:**
  - **(a)** Dense: used when large no. of optical signals to a single fiber(~80 channels with 0.8nm spacing)
  - **(b)** Coarse: ~18 channels with 20 nm spacing

Example 6.2

Five channels, each with a 100-kHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10 kHz between the channels to prevent interference?

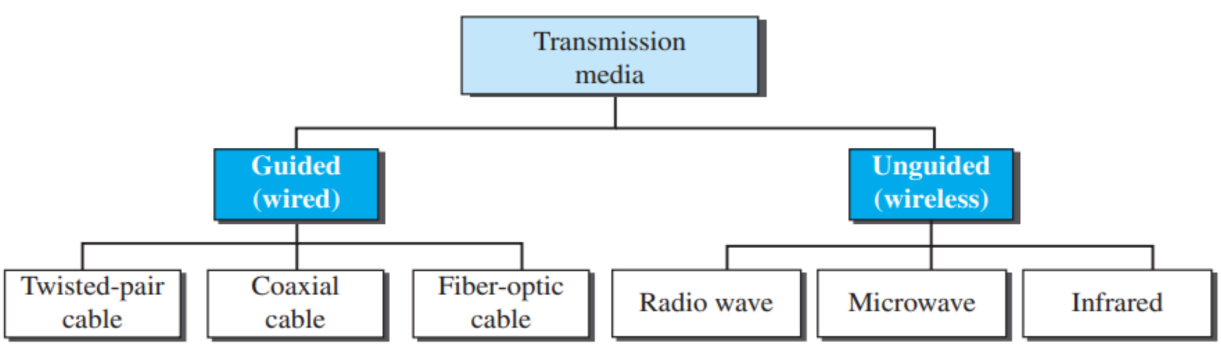
Solution

For five channels, we need at least four guard bands. This means that the required bandwidth is at least $5 \times 100 + 4 \times 10 = 540$ kHz, as shown in Figure 6.7.

c) **Benefits of Multiplexing:**

- i) **Increased Efficiency:** better utilization of expensive communication resources like cables and bandwidth.
- ii) **Cost-Effective:** By sharing a single medium, multiplexing reduces the need for separate infrastructure for each data stream, leading to cost savings.
- iii) **Scalability:** It allows for adding more data streams to the existing infrastructure.

3) **Transmission Media:**



a) **Guided/Wired Media**

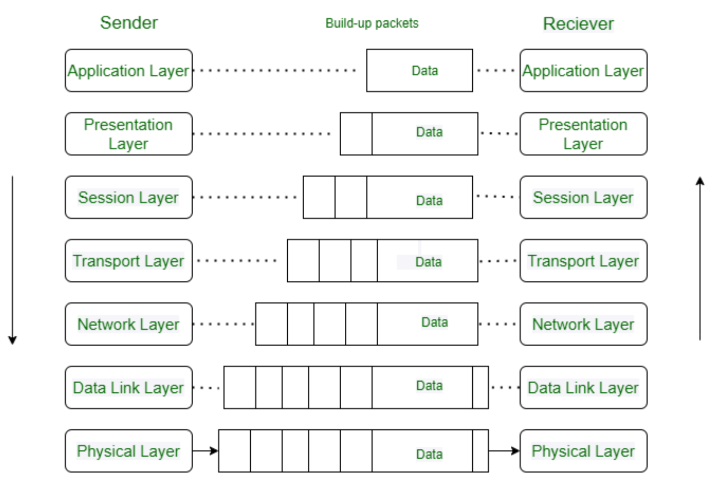
- i) **Optical fibers:** A glass or plastic core is surrounded by a <u>cladding</u> of less dense glass or plastic. This difference in density allows reflection off the cladding instead of being refracted into it.
  - **(1)** Higher bandwidth

(2) Less attenuation
(3) Light weight
(4) Resistive to corrosion
(5) High maintenance and costly
(6) Only unidirectional

b) **Unguided/Wireless Media:** Uses EM waves

Feature	Radio	Infrared	Microwave	Satellite
Frequency Range	3 kHz to 300 GHz	300 GHz to 400 THz	1 GHz to 100 GHz	1 GHz to 40 GHz
Transmission Range	Few meters to several kilometers	Short range (a few meters)	1 km to 100 km	Up to 36,000 km (geostationary)
Bandwidth	Low to high (varies with frequency)	Low (narrow bandwidth)	High	Moderate to high
Latency	Low to moderate	Very low	Low	High
Line of Sight	Not required	Required	Required	Required
Interference	Moderate to high (affected by obstacles, weather, etc.)	Low (affected by obstructions)	Moderate (affected by obstacles)	High (weather, space debris)
Application	WiFi, mobile communications, broadcasting	Remote controls, short-range communications	Long-distance telecommunication, radar	Global communications, TV broadcasting, GPS
Advantages	Wide coverage, good penetration	High security, low interference	High capacity, long distance	Global coverage, reliable in remote areas
Disadvantages	Prone to interference, limited bandwidth	Short range, requires direct line of sight	Requires line of sight, can be expensive	High latency, expensive infrastructure

4) **OSI**: Open System Interconnection provides a standardized way to view how data is transmitted between different computer systems over a network.



a)

b) **Benefits of the OSI Model:**
   i) Provides a common language for discussing network communication.
   ii) Helps in identifying and troubleshooting network issues by isolating problems within specific layers.
   iii) Standardizes the development of network protocols and devices.

c) **Disadvantages Compared to TCP/IP:**
   i) The OSI model is less efficient. The TCP/IP model has a more practical structure with fewer layers (4 layers) and a clearer mapping to real-world protocols.

d) **Layers:**
   i) **Physical layer:** physical transmission of data bits(eg: cable, network card)
      (1) Data Types:
         (a) Analog (continuous)
         (b) Digital (discrete)
      (2) Example: Mesh, Star, Ring & Bus topologies
   ii) **Data Link Layer:** transmission of data frames between physically connected network devices.
      (1) Encapsulates network layer Packets, adds physical addressing (using MAC addresses), error detection & handling and flow control
      (2) **Examples:** Ethernet, Wi-Fi (IEEE 802.11), Packet switching.
   iii) **Network Layer:** logical addressing and routing of data packets. It decides the route to be taken by the packets.
      (1) The source and destination addresses are added to the data packets inside the network layer.
      (2)

Routing	Forwarding
Routing is the process of moving data from one device to another device.	Forwarding is simply defined as the action applied by each router when a packet arrives at one of its interfaces.
Operates on the Network Layer.	Operates on the Network Layer.
Work is based on Forwarding Table.	Checks the forwarding table and work according to that.
Works on protocols like Routing Information Protocol (RIP) for Routing.	Works on protocols like UDP Encapsulating Security Payloads

      (3) Other services expected from network layer:
         (a) **Error Control**
         (b) **Flow Control**
      (4) **Virtual circuit**
      (5) **Datagram**
      (6) **Subnetting**
      (7) Examples: IP (Internet Protocol), ICMP (Internet Control Message Protocol), Routing protocols.
   iv) **Transport Layer:** takes services from the Application layer and provides services to the Network layer.

(1) Establishes connections, Multiplexing & demultiplexing, flow control, error checking, and retransmission of lost data.
(2) Client server paradigm
(3) Connectionless service
(4) Connection oriented service
(5) Flow control:
(6) Examples: TCP (Transmission Control Protocol), UDP (User Datagram Protocol).

v) **Session Layer:** Establishes, manages, and terminates sessions between communicating applications.
(1) Provides mechanisms for data synchronization, dialog control (allowing half-duplex or full-duplex communication), and session termination.
(2) Examples: RPC (Remote Procedure Call), SSH (Secure Shell), Named Pipes.

vi) **Presentation Layer:** Deals with data formatting and presentation for the application layer.
(1) data encryption/decryption, compression/decompression, and character set conversion to ensure compatibility
(2) Examples: ASCII, EBCDIC, JPEG, MPEG, SSL/TLS.

vii) **Application Layer:** Provides network services directly to user applications.
(1) Examples: HTTP (web browsing), FTP (file transfer), SMTP (email), DNS (domain name resolution).

5) IP ADDRESS

a) unique numerical label assigned to each device connected to a network that uses the Internet Protocol for communication. Used by routers to determine the path data packets should take to reach their destination across networks.
b) Find Range, Network Id, Host, Broadcast address
c) **Types:**

i) **IPV4** -> 187.156.156.69
~4 billion devices can be assigned unique id with ipv4
(1) **Loopback address:** distinct reserved ip address starting from 127.0.0.0 to 127.255.255.255 used to transmit and receive data packets.
(2) **Localhost:** 127.0.0.1
(3)

IP Class	Address Range	Default Subnet Mask
A	1.0.0.0 - 126.255.255.255	255.0.0.0
B	128.0.0.0 - 191.255.255.255	255.255.0.0
C	192.0.0.0 - 223.255.255.255	255.255.255.0
D (Multicast)	224.0.0.0 - 239.255.255.255	Not Applicable
E (Reserved)	240.0.0.0 - 255.255.255.255	Not Applicable

(4) Subnetting in Classful Addressing
(5) **CIDR: Classless inter domain routing** allows users to create variable length subnet mask
    (a) **Denoted by:** “/X” eg: a subnet of 255.255.255.0 would be denoted by /24
    (b) Lec-50: Subnetting in CIDR Addressing | Classless I…
    (c) **Example: 255.255.255.0**
        (i) Convert each octet to binary and count number of 1’s
        (ii) In our example, in total there are 24 binary 1's, so the subnet mask is /24.

ii) IPV6 -> 2001:db8:0:1234:0:567:8:1
    (1) 128 bit IP address to include and identify more devices

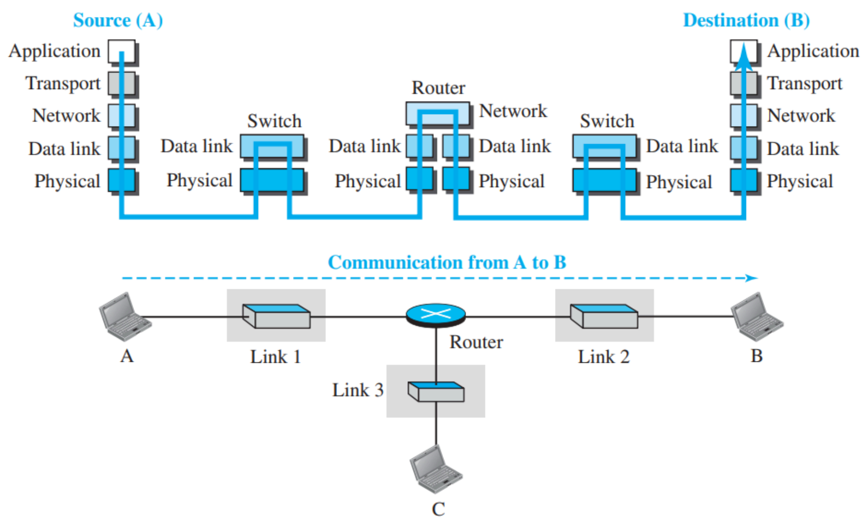
d) Classification:
   i) Public: Available publicly which is provided by your network provider to your router that further divides it to connected devices
      (1) Dynamic: ISP provides an IP address to your connected device from a range of available IP addresses and this instance keeps on changing every time you reconnect with your router i.e Dynamic.
      (2) Static: Generally used by DNS servers to track traffic which is why it’s less secure.
   ii) Private: Used for devices reserved for internal communication within a network and do not have a direct connection to the broader internet. Common ranges start from 10.0.0.0 or 192.168.0.0 or 172.16.0.0 etc.

6) MAC(Media access control) ADDRESS:
   a) MAC address is a hardware address associated with a network interface card, while an IP address is a logical address used for routing data packets in a network. MAC addresses are used at the Data Link Layer, and IP addresses are used at the Network Layer.
   b) Multiple access protocol:
   c) Collision detection:
   d) MAC addressing:
   e) Data-link layer switching:

7) NETWORK DEVICES
   a) Repeater: regenerates signal over the same network before the signal becomes too weak or corrupted or to extend the length to which the signal can be transmitted over the same network.
   b) Hub: Multi-port repeaters
      i) Hubs cannot filter data, so data packets are sent to all connected devices.
      ii) inefficient
   c) Bridge: operates at the data link layer [2 port device]
      i) Can filter content by reading the MAC addresses of the source and destination.

ii) used for interconnecting two LANs
d) **Switch:** Multi port bridge, data link layer device or layer 3.
   i) can perform error checking
   ii) forward good packets selectively to the correct port only.
e) **Router:** switch that routes data packets based on their IP addresses. Network Layer device
   i) connect LANs and WANs

8) **PROTOCOLS**
a) User datagram protocol**(UDP)**
b) Transfer Control Protocol**(TCP/IP)**



c) File Transfer Protocol**(FTP)**
d) Simple Mail Transfer Protocol**(SMTP)**
e) Remote Login Protocol**(TELNET)**
f) World Wide Web**(WWW)**
g) HyperText Transfer Protocol**(HTTP)**
h) Uniform Resource Locator**(URL)**
i) Automatic Repeat Protocol**(ARP)**
j) Internet Control Message Protocol**(ICMP)**

9) **DIJKSTRA ROUTING** L-4.10: Dijkstra's Algorithm - Single Source Shortest Path - …
a) To increase the efficiency in routing the data packets and decreasing the traffic, we find the shortest path using this algo.
b) mainly for building a graph or subnet containing routers as nodes and edges as communication lines connecting the nodes.

10) **DISTANCE VECTOR ROUTING** aka **BELLMAN FORD'S ALGO**
a) Slower than Dijkstra
b) Can be used in weighted and unweighted graphs or -ve edge weights
c) **Algo:** L-4.13: Bellman Ford Algorithm | Dijkstra's Vs Bellman Ford | Single …
   i) Initialize all vertices v in a distance array dist[] as INFINITY.
   ii) pick a random vertex as vertex 0 and assign dist[0] =0.

iii) Then iteratively update the minimum distance to each node (dist[v]) by comparing it with the sum of the distance from the source node (dist[u]) and the edge weight N-1 times.
iv) Example

11) ERROR DETECTION & CORRECTION TECHNIQUES

a) **Errors:**
   i) Single bit error
   ii) Burst error
   iii) Jitter: inconsistent arrival of the data packets at the receiver's end

b) **Detection:**
   i) Bit Parity ->
      Lec-28: Single Bit Parity along With Hamming Distance Concept | E…
   ii) Cyclic redundancy check CRC ->
      Lec-29: Cyclic Redundancy Check(CRC) for Error Detection and C…
   iii) Checksum->
   iv) Checksum in HINDI | Checksum Error Detection Example | Checks…
   v)

c) **Correction & Recovery:**
   i) Hamming code ->
      Lec-30: Hamming Code for Error Detection & Correction both with e…
   ii) ARQ ->
      Lec-25: Various Flow Control Protocols | Stop&Wait , GoBackN & S…

12)