Syllabus

UNIT – I

Introduction: Uses of computer networks

Transmission Modes: Serial and Parallel - Synchronous, Asynchronous and Isochronous - Simplex, Half duplex and full duplex

Data communication Components: Representation of data and its flow, Various Connection Topology, Protocols and Standards, OSI model, Transmission Media

LAN: Wired LAN, Wireless LAN, Virtual LAN

Techniques for Bandwidth utilization: Multiplexing - Frequency division, Time division and Wave division, Concepts on spread spectrum.

Introduction

- *A* ***network*** *is a set of devices (often referred to as* ***nodes****) connected by communication* ***links*****.** *A node can be a computer, printer, or any other device capable of sending and/or receiving data generated by other nodes on the network. A link can be a cable, air, optical fiber, or any medium which can transport a signal carrying information.*

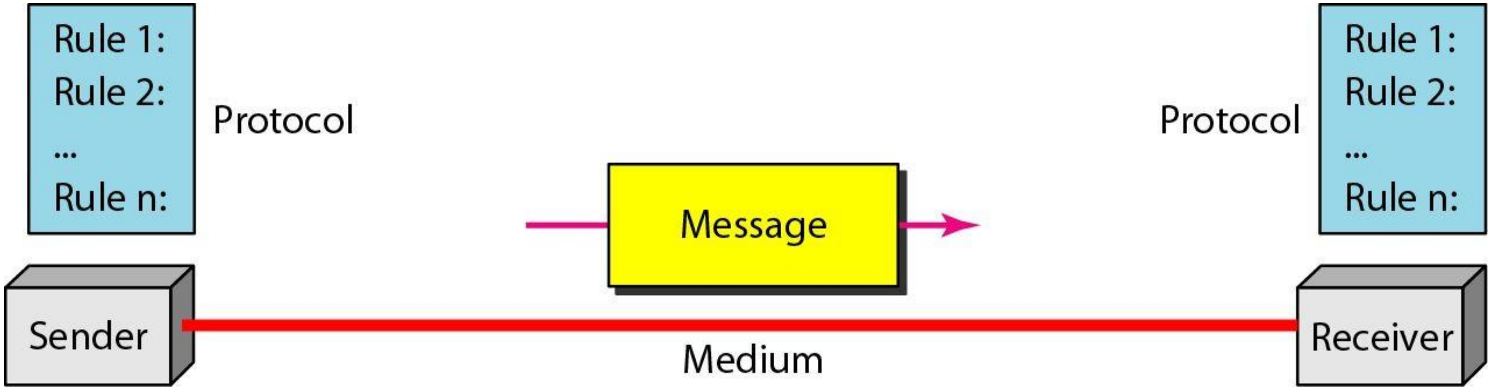


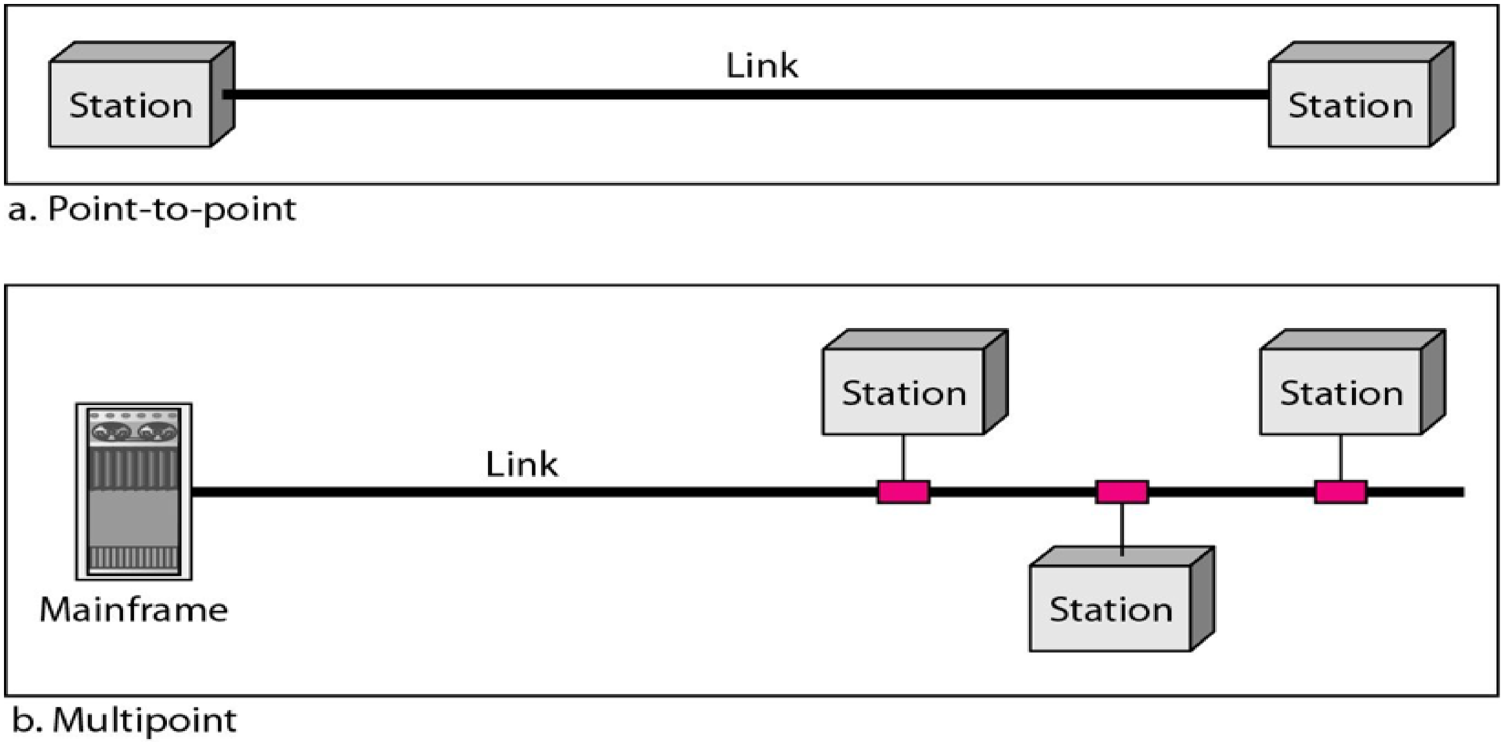
Figure 1.1 ***Components of a data communication system***

Network Criteria

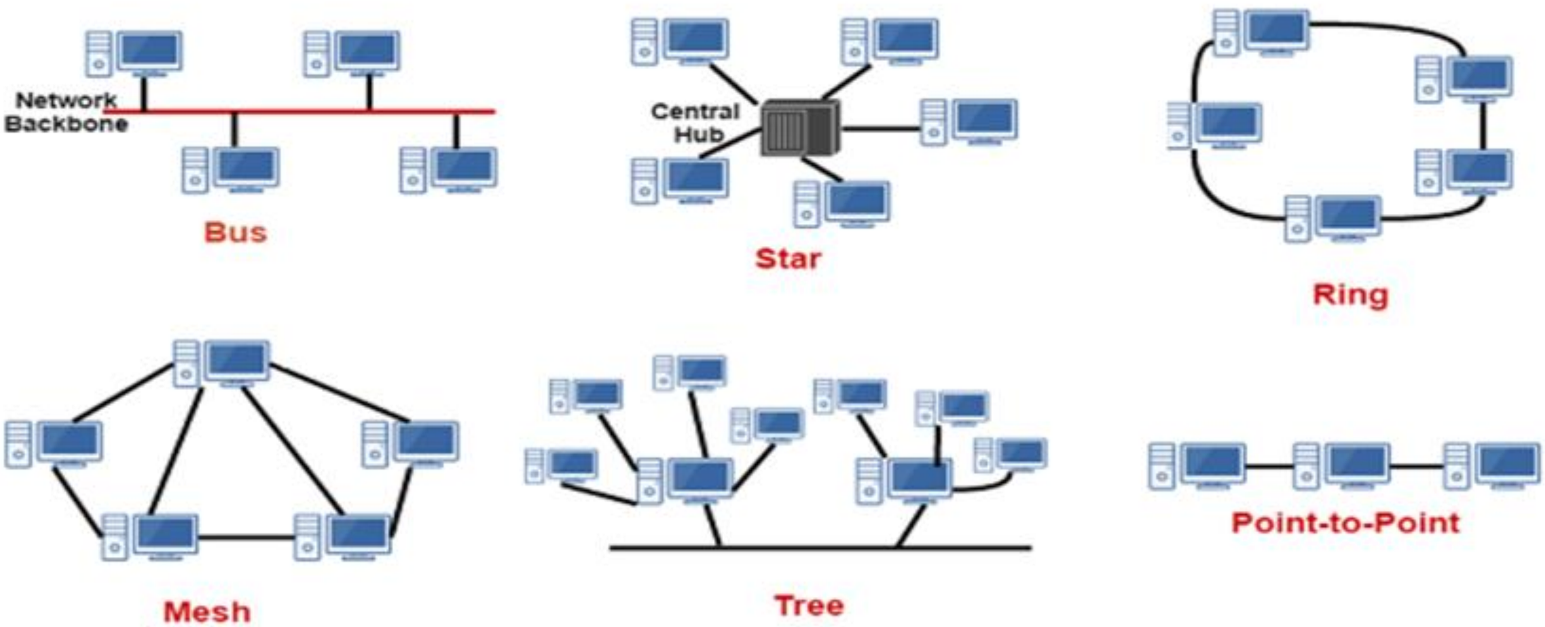
- **Performance**
  - ***Depends on Network Elements***
  - ***Measured in terms of Delay and Throughput***
- **Reliability**
  - ***Failure rate of network components***
  - ***Measured in terms of availability/robustness***
- **Security**
  - **Data protection against corruption/loss of data due to:**
    - ***Errors***
    - ***Malicious users***

Physical Structures

- **Type of Connection**
  - ***Point to Point - Single transmitter and receiver***
  - ***Multipoint - Multiple recipients of single transmission***



- **Physical Topology**
  - ***Connection of devices***
  - ***Type of transmission - Unicast, Mulitcast, Broadcast***



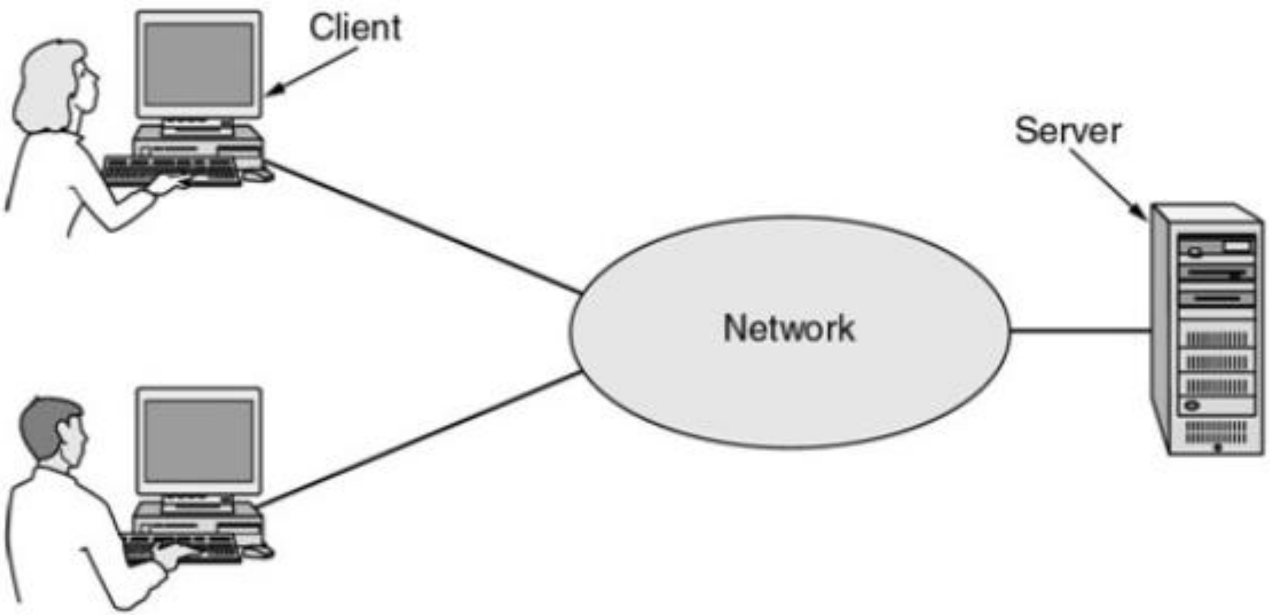
Uses of Computer Network

- Business Application
- Home Application
- Mobile Users
- Social Issues.

Uses of a computer Network

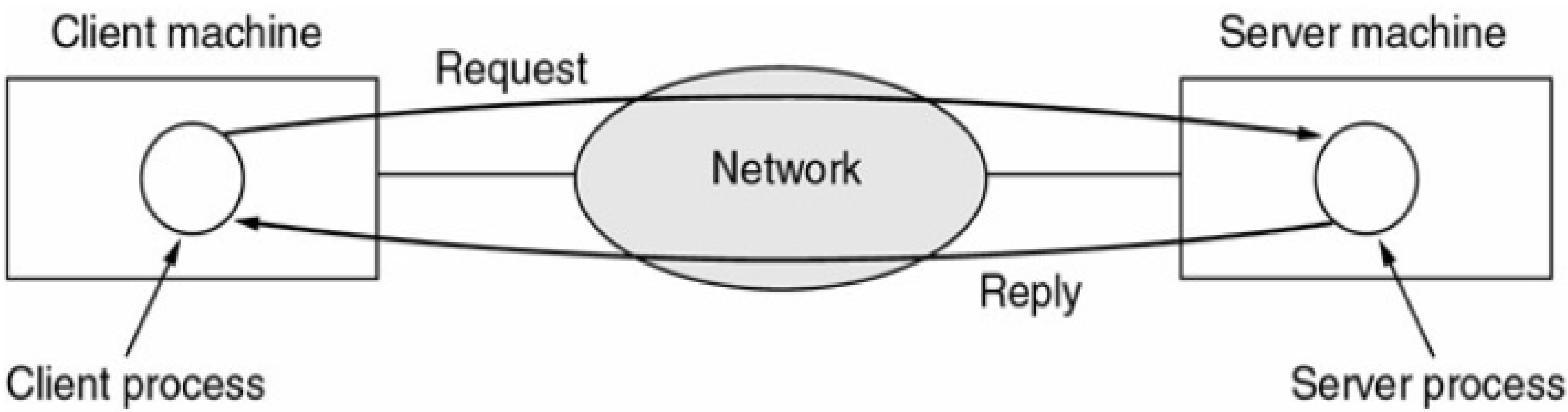
- File Sharing
- Software Cost & Management
- Text Communication
- Voice Communication
- Secure Data Access (Security)
- Resources Sharing such as
  - scanners, fax machines and printers etc.
- Workgroup Computing

Business Application Network



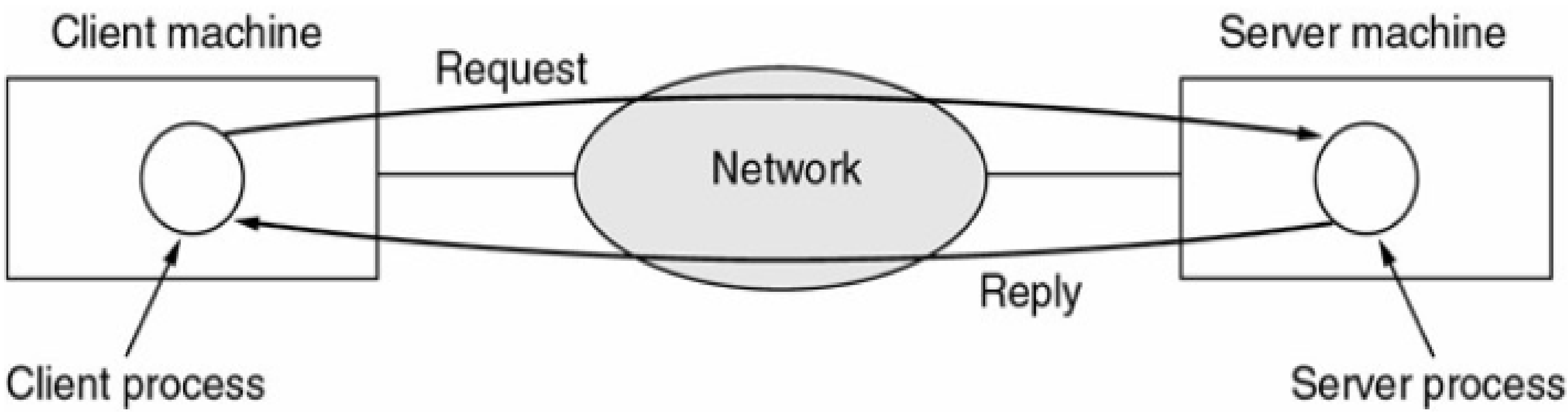
A network with two clients and one server.

Business Application Network



The client-server model involves requests and replies.

Business Application Network

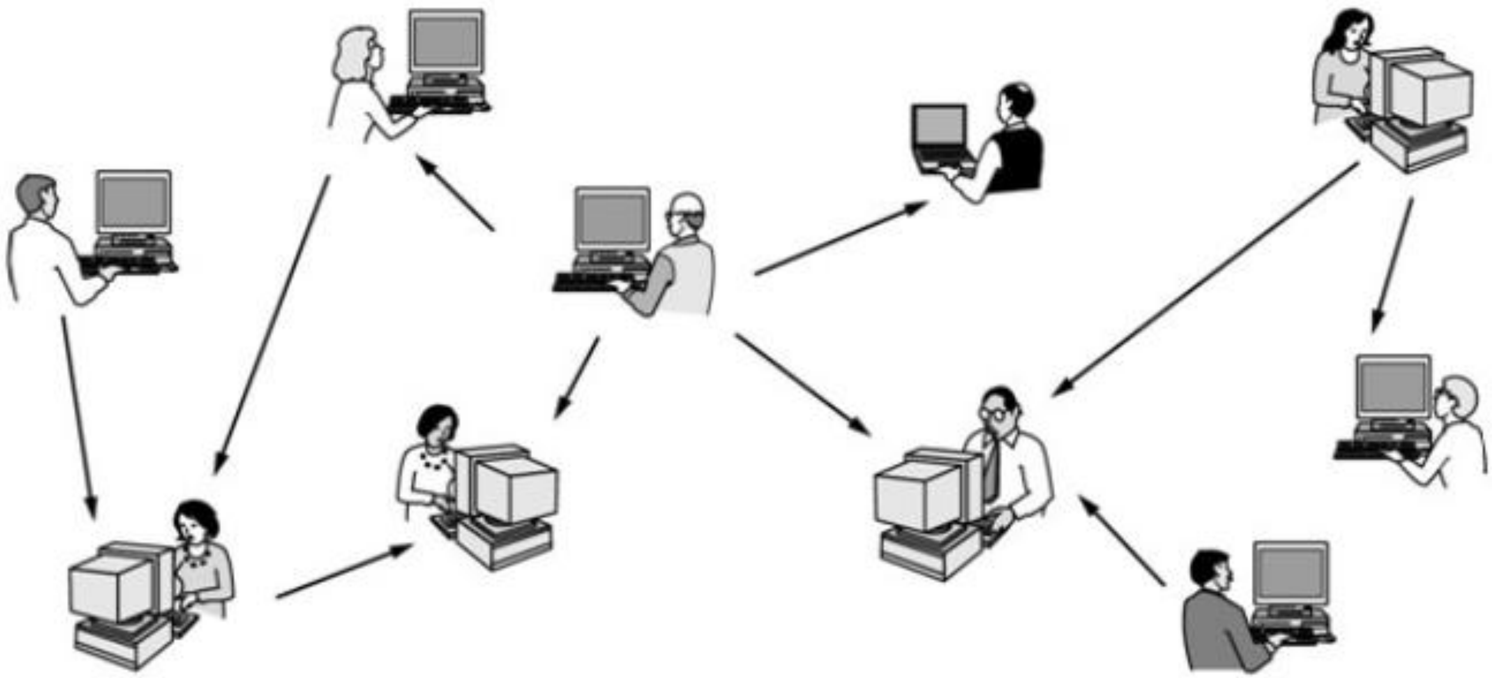


The client-server model involves requests and replies.

Home Network Application

- Access to Remote information.
- Person – to – Person Communication.
- Interactive Entertainment.
- Electronic Commerce.

Home Network Application



In peer-to-peer system there are no fixed clients and servers.

Home Network Application

Tag	Full name	Example
B2C	Business-to-consumer	Ordering books on-line
B2B	Business-to-business	Car manufacturer ordering tires from supplier
G2C	Government-to-consumer	Government distributing tax forms electronically
C2C	Consumer-to-consumer	Auctioning second-hand products on-line
P2P	Peer-to-peer	File sharing

Some forms of e-commerce.

Mobile Network Users

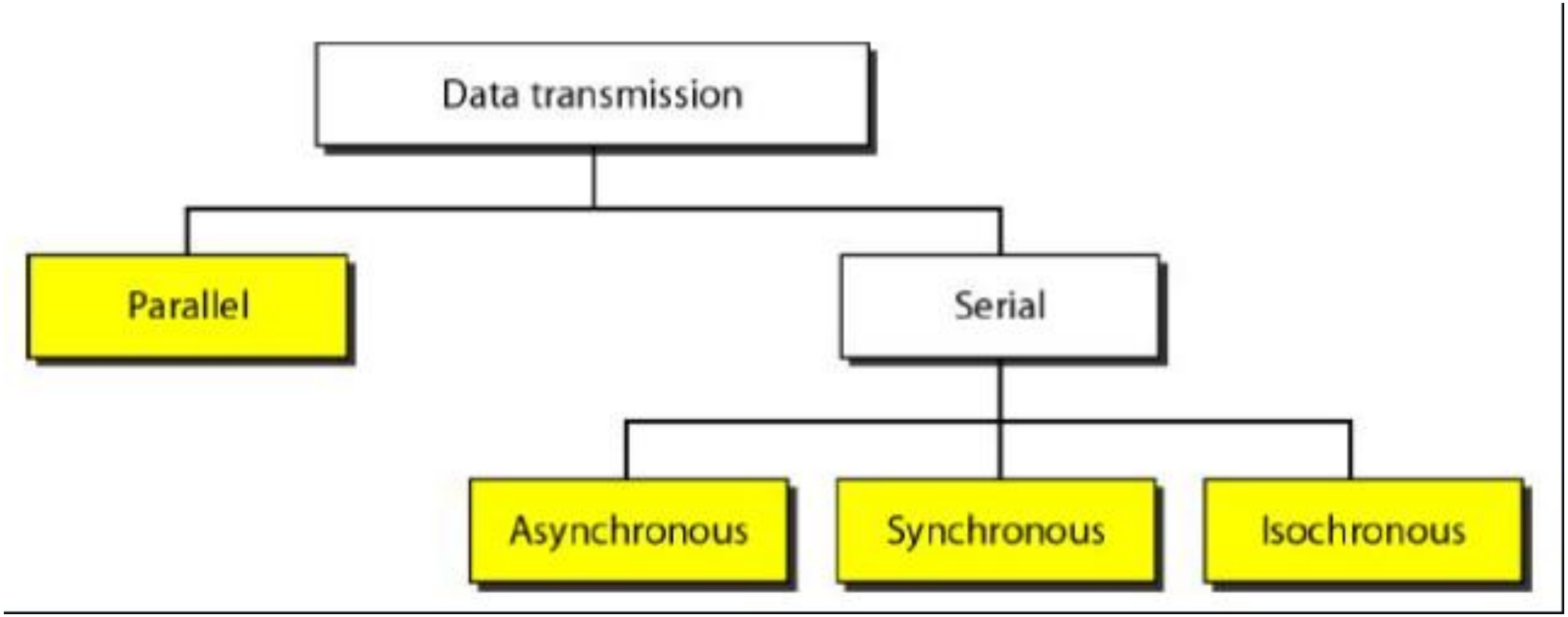
Wireless	Mobile	Applications
No	No	Desktop computers in offices
No	Yes	A notebook computer used in a hotel room
Yes	No	Networks in older, unwired buildings
Yes	Yes	Portable office; PDA for store inventory

Combinations of wireless networks and mobile computing.

DATA COMMUNICATIONS

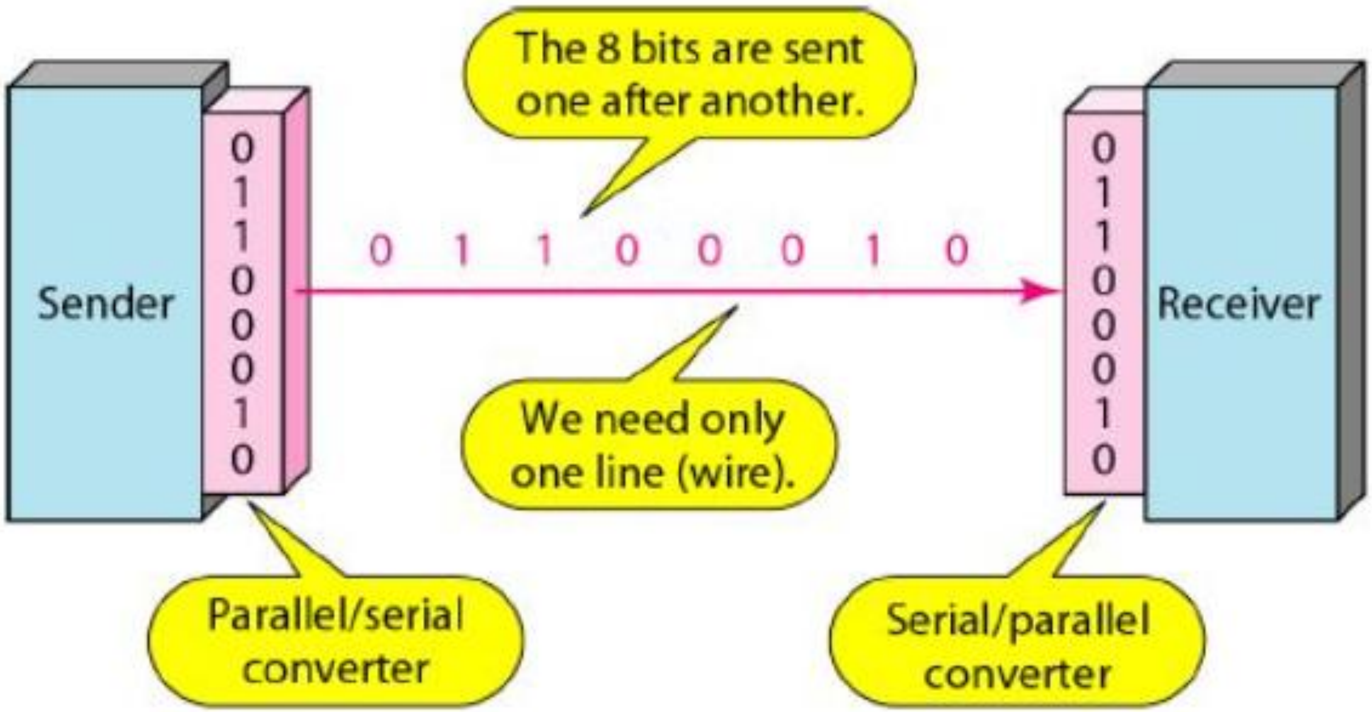
- *The term* ***telecommunication*** *means communication at a distance.*
- *The word* ***data*** *refers to information presented in whatever form is agreed upon by the parties creating and using the data.*
- ***Data communications*** *are the exchange of data between two devices via some form of transmission medium such as a wire cable.*
- **Serial** transmission is sending one bit at a time
- **Parallel** transmission is sending multiple bits at the same time over separate media

DATA COMMUNICATIONS



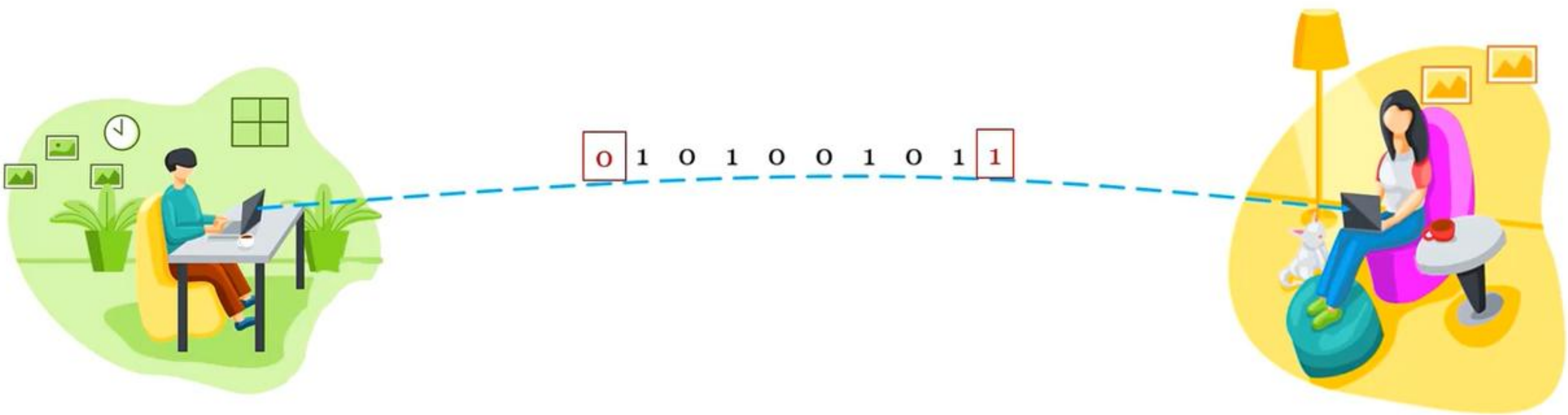
DATA COMMUNICATIONS

Serial Transmission:



Serial Transmission

Data is sent bit by bit and 8 bits are transferred at a time.



Serial Transmission

Data is sent bit by bit and 8 bits are transferred at a time.

Asynchronous and Synchronous Serial Transmission.

Asynchronous transmission has an extra bit added to each byte so that the receiver is alert about the arrival of new data.

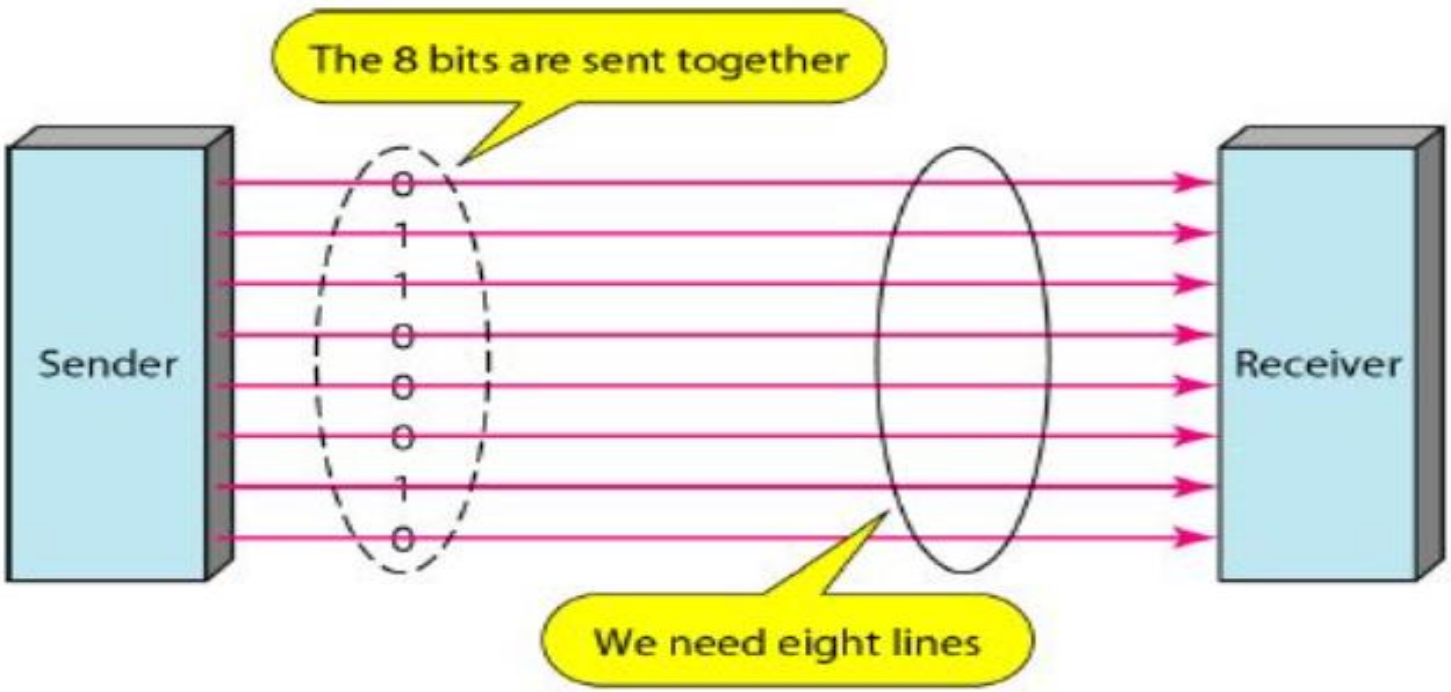
Synchronous transmission transfers data in the form of frames.

Used for long distance communication.

DATA COMMUNICATIONS

- **Parallel transmission:**

The idea of parallel transmission: send 8 bits at exactly the same time, over 8 separate wires. Besides the 8 data lines there are one or more control lines - wires to be used by sender and receiver to coordinate.



Parallel Transmission

Multiple data bits are sent together in a single clock pulse.

It is the fastest way of transmitting the data.

The communicating devices like computer uses parallel circuitry internally.

Parallel Transmission

Multiple data bits are sent together in a single clock pulse.

It is the fastest way of transmitting the data.

The communicating devices like computer uses parallel circuitry internally.

Parallel Transmission uses a 25 pin port having 17 signal lines and 8 ground lines.

Parallel Transmission is mainly used for short distance communication.

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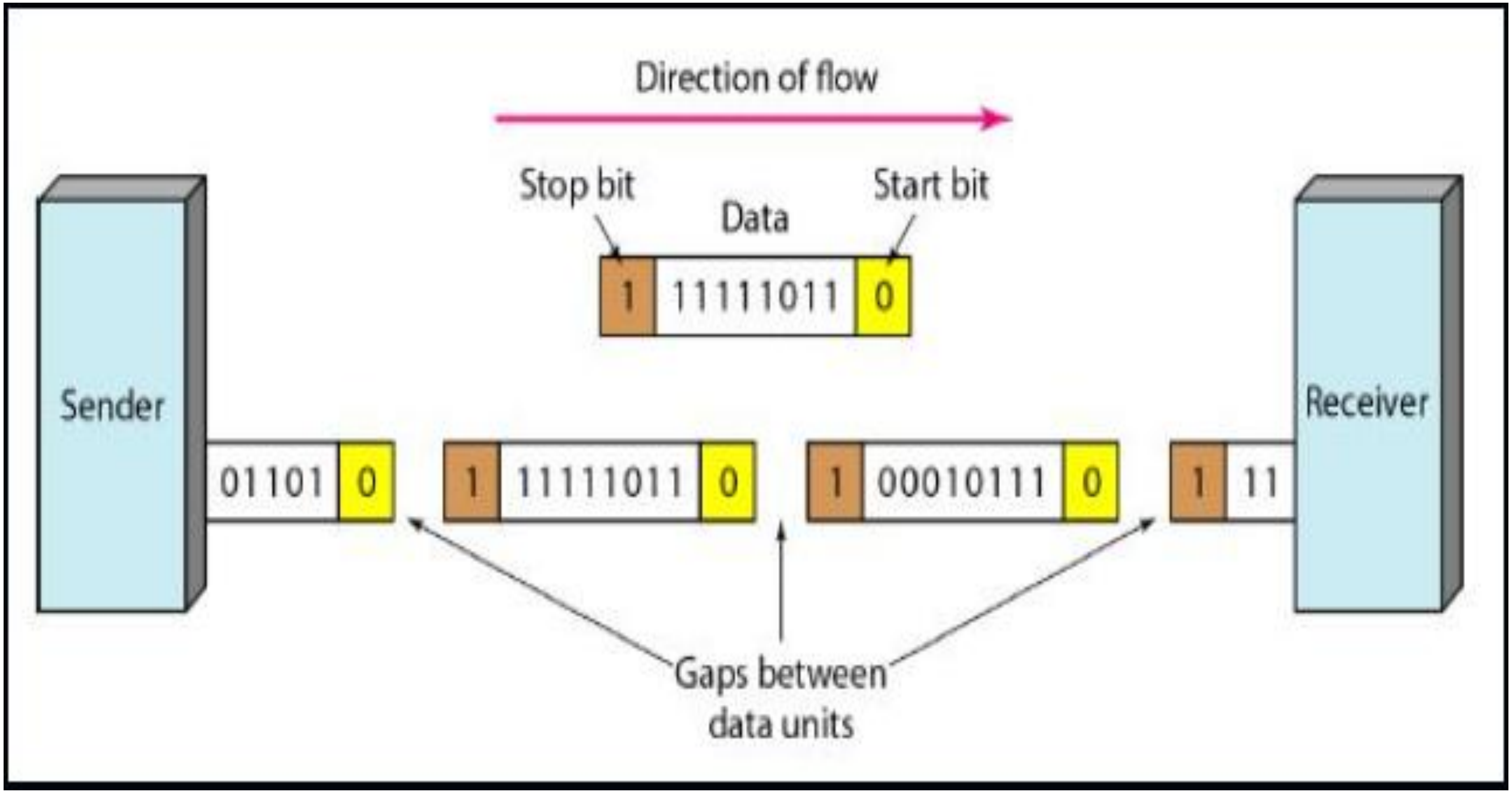
Serial Transmission	Vs	Parallel Transmission
Bit by Bit transmission & each bit requires one clock cycle .	Transmission	Multiple bits are transmitted in one clock cycle.
Economical	Cost	Expensive
1 bit in one clock cycle.	Rate	8 bits in one clock cycle.
Slow	Speed	Fast

Serial Transmission	Vs	Parallel Transmission
Used for long distance communication	Distance	Used for short distance communication
Only one communication channel required	Channel	N number of communication channel required
Conversion required at the device	Conversion	Conversion not required
Communication between the computers in remote areas	Example	Communication between computer and printer.

Feature	Parallel Port	Serial Port
Data Transmission	Transmits multiple bits of data simultaneously (in parallel).	Transmits one bit of data at a time (in serial).
Speed	Faster for short distances due to parallel transmission.	Slower compared to parallel ports for the same clock speed.
Number of Wires	Requires multiple data lines (one for each bit) plus control and ground lines.	Requires fewer wires (typically 3–9 for data, control, and ground).
Cable Length	Limited to short distances (usually up to 10 feet) due to signal interference and crosstalk.	Can be used over longer distances (up to 50 feet or more).
Applications	Used for devices like printers, scanners, and parallel port-based peripherals.	Used for modems, mice, and other serial communication devices.
Connector Types	Typically uses a DB-25 connector.	Uses DB-9 or DB-25 connectors.
Data Transfer Method	Transfers data in chunks (e.g., 8 bits at a time).	Transfers data sequentially (bit by bit).
Complexity of Hardware	More complex due to multiple data lines.	Simpler hardware requirements.
Usage Today	Rarely used; replaced by USB and other modern interfaces.	Still used in some niche applications like embedded systems.
Example Standards	IEEE 1284 (for printers).	RS-232, RS-422, RS-485.

Timing of Serial Transmission

Asynchronous Transmission:



Asynchronous Transmission:

- Data is sent in small packets, or "frames," with each frame containing start and stop bits to signal the beginning and end of the data.

Key Characteristics:

- No need for a shared clock between sender and receiver.
- Each frame is independent and self-synchronized using start and stop bits.
- Slower transmission compared to synchronous due to the additional overhead of start and stop bits.
- Simple and cost-effective for systems where transmission speed is not critical.

Applications:

- Email communication.
- Text messaging services.
- Serial communication protocols (e.g., RS-232, USB).
- Keyboard and mouse inputs to computers.

Advantages:

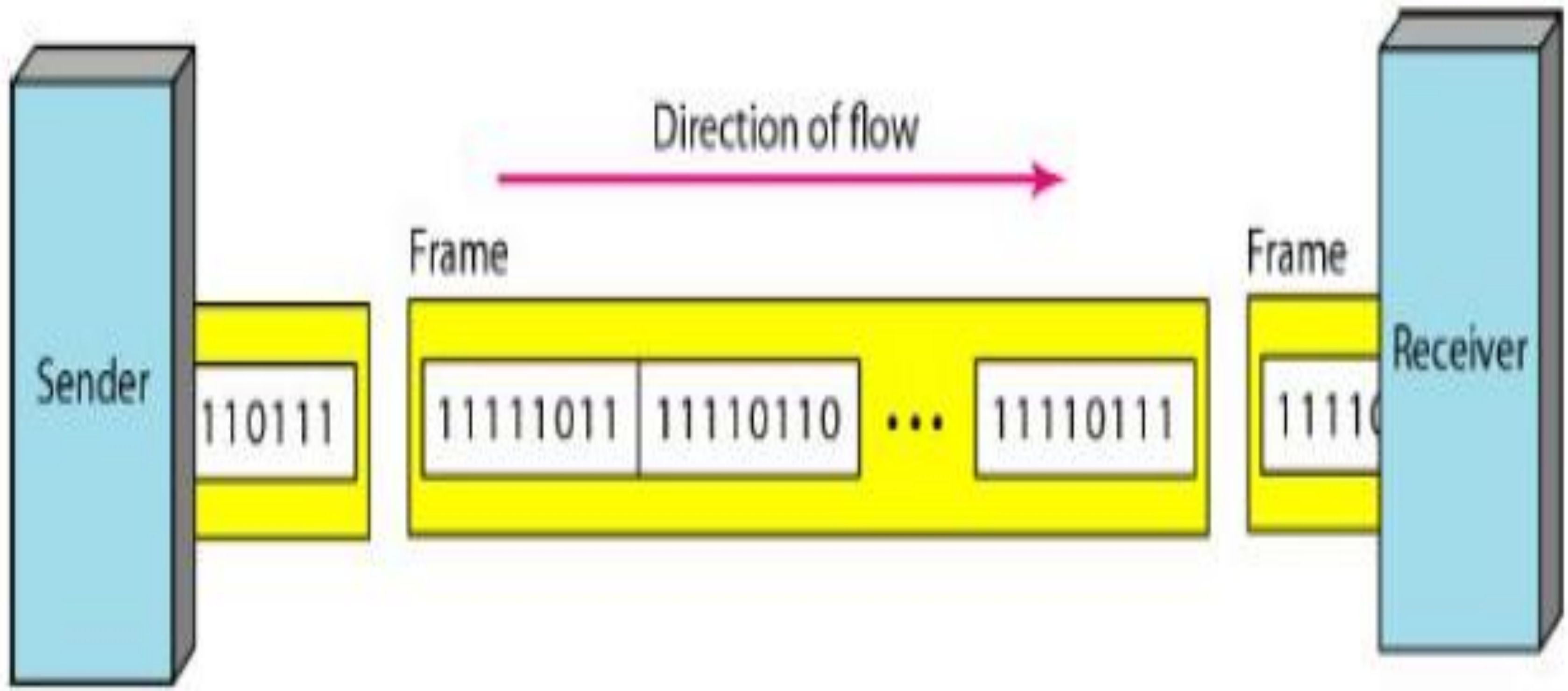
- Simple implementation.
- No need for continuous synchronization.

Disadvantages:

- Slower due to the overhead of start and stop bits.
- Suitable for low-speed communication.

Timing of Serial Transmission

Synchronous Transmission:



Synchronous Transmission

- Data is sent as a continuous stream of bits or bytes, synchronized with a clock signal. Both the sender and receiver share the same clock, which ensures proper timing for data transfer.

Key Characteristics:

- Continuous flow of data.
- No start or stop bits are used.
- Synchronization is maintained via a shared clock or specific synchronization mechanisms (e.g., preambles).
- Higher transmission speed and efficiency compared to asynchronous transmission.

Applications:

- High-speed networks (e.g., Ethernet, SONET/SDH).
- Video and audio streaming where data must remain synchronized.
- Real-time gaming applications.
- Telecommunication systems requiring precise timing (e.g., TDM systems).

Advantages:

- High data transfer rates.
- Suitable for high-speed networks.

Disadvantages:

- Requires complex hardware/software for synchronization.

Isochronous Transmission:

Data is sent at regular, consistent intervals, ensuring that the data arrives at the receiver at the same pace it was sent. This mode guarantees a specific time relationship between data units.

Key Characteristics:

- Real-time data transfer.
- Consistent timing intervals, reducing jitter.
- No retransmission of data in case of errors (as timing is critical).

Applications:

- Voice over IP (VoIP).
- Video conferencing.
- Multimedia streaming (e.g., IPTV).
- USB for time-sensitive applications like audio interfaces.
- Industrial control systems with strict timing requirements.

Advantages:

- Ideal for multimedia and real-time communication.

Disadvantages:

- No error correction or retransmission as timing is critical.

Comparison Table

Feature	Synchronous	Asynchronous	Isochronous
Synchronization	Shared clock	Start and stop bits	Regular time intervals
Efficiency	High	Low	Moderate to high
Overhead	Low (no start/stop bits)	High (start/stop bits)	Medium
Error Handling	Can include error-checking mechanisms	Handled per frame	No retransmission (timing critical)
Applications	High-speed networks, streaming	Text messaging, serial comm.	VoIP, video conferencing

Transmission Mode

- In data communication, transmission modes define the direction and flow of data between devices in a network.
- They describe how data is sent, whether it's in one direction, two directions alternately, or simultaneously.

Types of Transmission Modes:

1. Simplex Mode
2. Half-Duplex Mode
3. Full-Duplex Mode

Transmission Mode

1. Simplex mode:

Data flows in **only one direction.** There is no provision for the receiver to send data back to the sender.

Key Characteristics:

- Unidirectional communication.
- No feedback or acknowledgment from the receiver.
- Simple and cost-effective.

Applications:

- Television broadcasting.
- Radio broadcasting.
- Keyboard-to-monitor data transmission.

Transmission Mode

2. Half-Duplex Mode

Data flows in **both directions**, but only **one direction at a time.** The sender and receiver take turns transmitting data.

Key Characteristics:

- Bi-directional communication, but not simultaneous.
- Efficient use of the communication channel.
- Requires coordination to avoid collisions.

Applications:

- Walkie-talkies.
- Two-way radio communication.
- CSMA/CD in Ethernet.

Transmission Mode

3. Full-Duplex Mode

Data flows in **both directions simultaneously**. Both sender and receiver can transmit and receive data at the same time.

Key Characteristics:

- Bi-directional and simultaneous communication.
- Higher efficiency and faster communication.
- Requires separate channels or advanced protocols to avoid interference.

Applications:

- Telephone networks.
- Video conferencing.
- High-speed internet connections (e.g., fiber-optic communication).

Transmission Mode

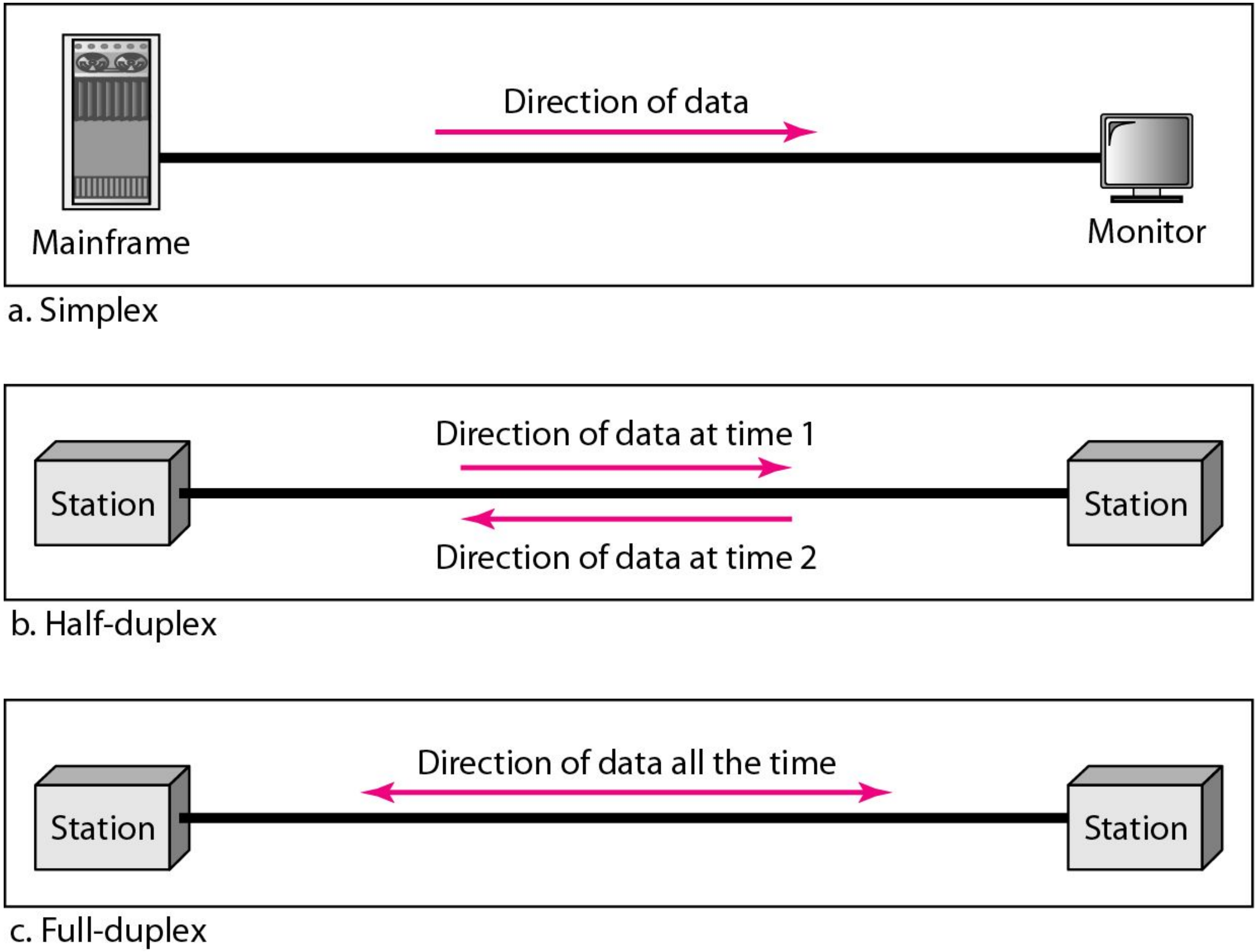


Figure. *Data flow (simplex, half-duplex, and full-duplex)*

Comparison Table

Feature	Simplex	Half-Duplex	Full-Duplex
Direction	One-way	Two-way (one at a time)	Two-way (simultaneous)
Efficiency	Low	Medium	High
Data Flow	Unidirectional	Alternating	Simultaneous
Applications	Broadcasting systems	Walkie-talkies	Telephone networks

Data
Communication Components

- **Components:**

There are five main components of data communication and they are explained below.

- *Message*
- *Sender*
- *Receiver*
- *Transmission Medium*
- *Protocol*

Data Communication Components

Message:

•The message actually refers to data that is to be shared or a piece of information. A message is in any form, like a text file, an audio file, a video file, and so on.

Sender:

• Someone who can play the role of a source must be there to pass messages from source to destination. The sender plays a part of the data communication device root. The node can be a computer, mobile device, telephone, laptop, video camera, workstation, etc.

Data Communication Components

Receiver:

It is the destination where messages sent by the source have finally arrived. It is a message-receiving system. The receiver is in the form of a computer, cell phone, workstation, etc., identical to the sender.

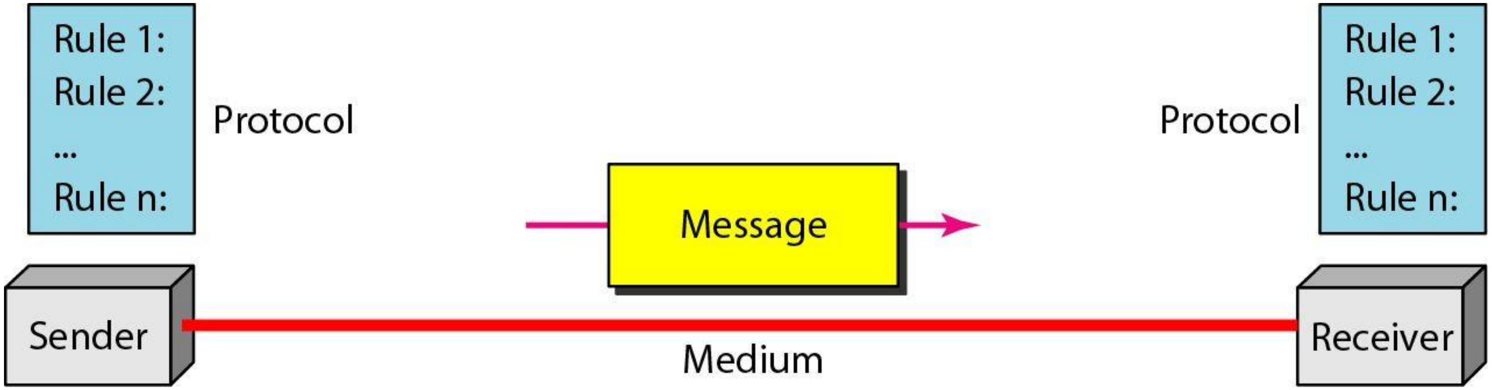
Transmission Medium:

- There must be something in the entire data communication process that could act as a bridge between sender and receiver. The transmission is the physical path from the sender to the recipient where the information or message passes.
- **The examples of transmission medium** are twisted pair cable, fibre optic cable, radio waves, microwaves, etc. The transmission medium could be guided (with wires) or unguided (without wires).

Data Communication Components

Protocol:

- Different sets of rules have already been designed by the designers of communication systems to control data communication, reflecting a sort of agreement between communicating devices.

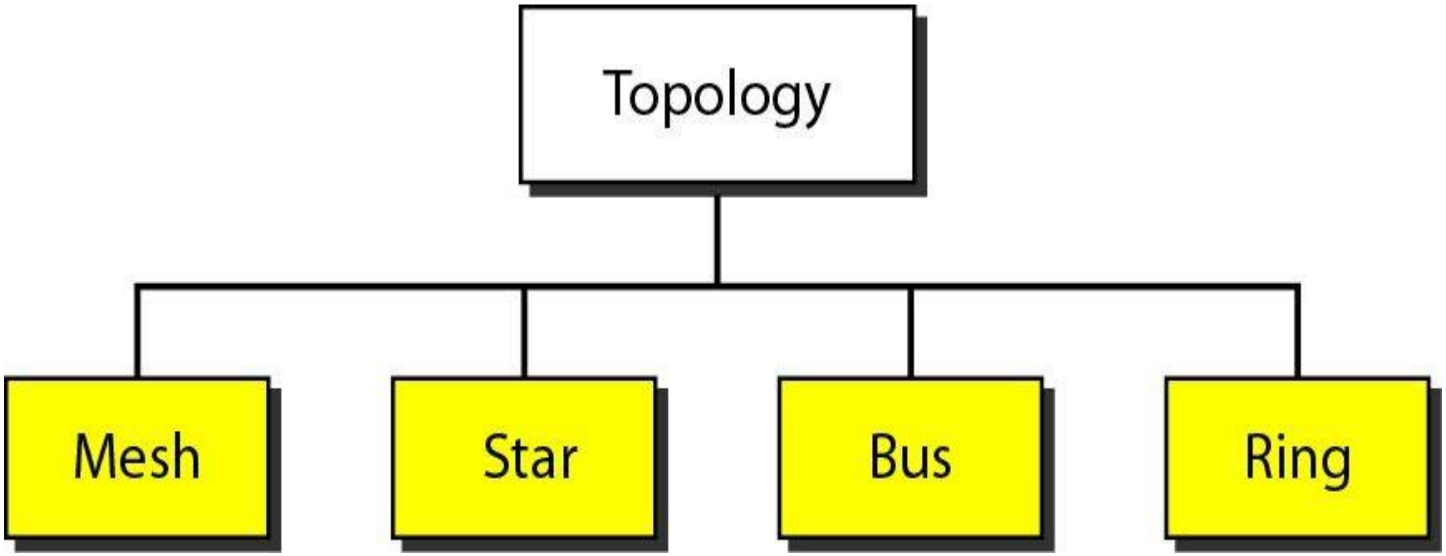


Components of a data communication system

Topology

- A network topology is the physical and logical arrangement of nodes and connections in a network. Nodes usually include devices such as switches, routers and software with switch and router features. Network topologies are often represented as a graph.
- Network topologies describe the arrangement of networks and the relative location of traffic flows. Administrators can use network topology diagrams to determine the best placements for each node and the optimal path for traffic flow.

Topology



Categories of topology

Mesh Topology

•**Description**: Every device is connected to every other device in the network, either fully (full mesh) or partially (partial mesh).

•**Advantages**:

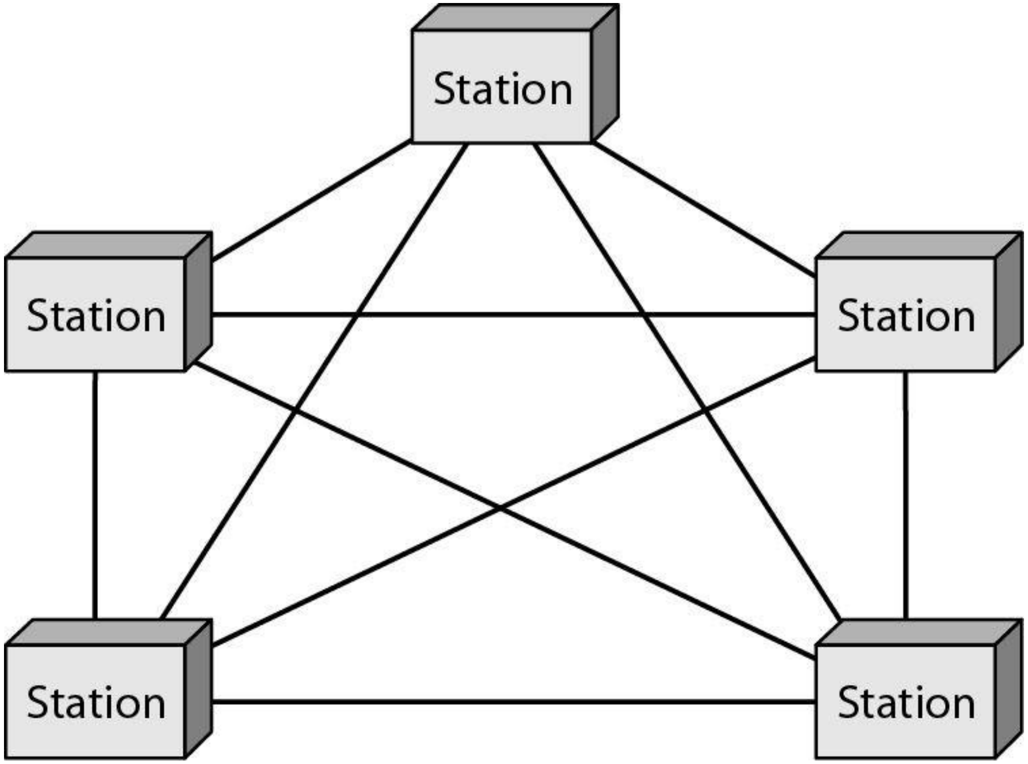
- High fault tolerance as there are multiple paths for data.
- Excellent performance for high traffic.

•**Disadvantages**:

- Expensive and complex to set up due to the large number of connections.
- Requires significant cabling and hardware.

•**Use Case**: WANs, mission-critical networks, and military applications.

Mesh Topology



A fully connected mesh topology (five devices)

Mesh Topology

Mesh Topology:

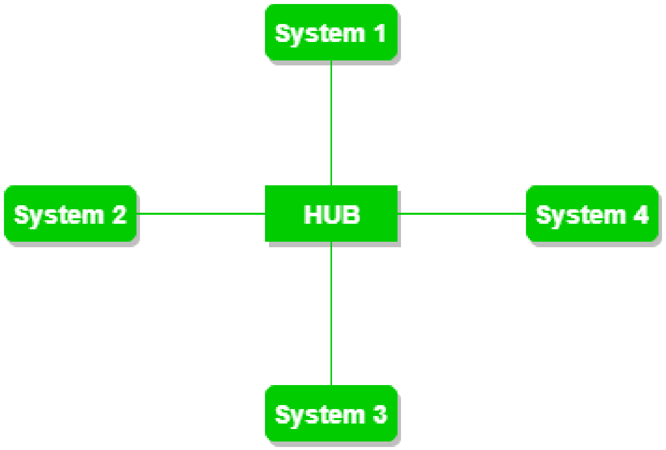
•Mesh topology is mainly used for wireless networks.

•Mesh topology can be formed by using the formula:

Number of cables/links = (n*(n-1))/2;

Star Topology

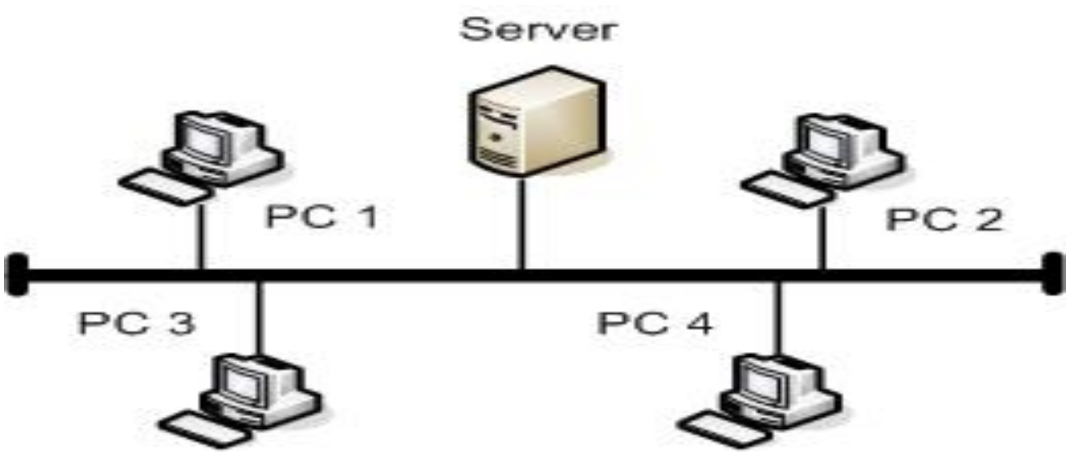
- **Description**: All devices are connected to a central device like a hub, switch, or router.
- **Advantages**:
  - Easy to manage and troubleshoot.
  - Failure of one device does not affect the rest of the network.
  - Scalable and supports high data speeds.
- **Disadvantages**:
  - If the central device fails, the entire network is disrupted.
  - Requires more cabling than bus topology.
- **Use Case**: Most modern LANs use star topology.



Star Topology

Bus Topology

- **Description**: All devices are connected to a single central cable (backbone).
- **Advantages**:
  - Easy to install and cost-effective for small networks.
  - Requires less cable than other topologies.
- **Disadvantages**:
  - Difficult to troubleshoot.
  - If the backbone fails, the entire network goes down.
  - Limited scalability and performance degrades with heavy traffic.
- **Use Case**: Small office or home networks.



Ring Topology

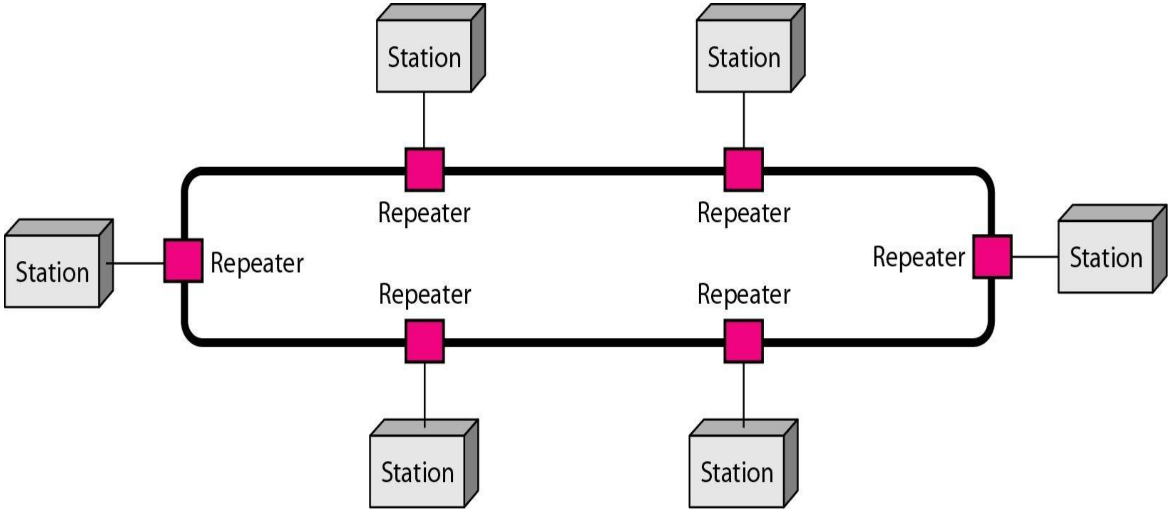
SASTRA
ENGINEERING · MANAGEMENT · LAW · SCIENCES · HUMANITIES · EDUCATION
DEEMED TO BE UNIVERSITY
(U/S 3 OF THE UGC ACT, 1956)
THINK MERIT | THINK TRANSPARENCY | THINK SASTRA

•**Description**: Each device is connected to two other devices, forming a circular pathway for data to travel.

•**Advantages**:
- Data flows in a single direction, reducing collisions.
- Suitable for token-passing protocols.

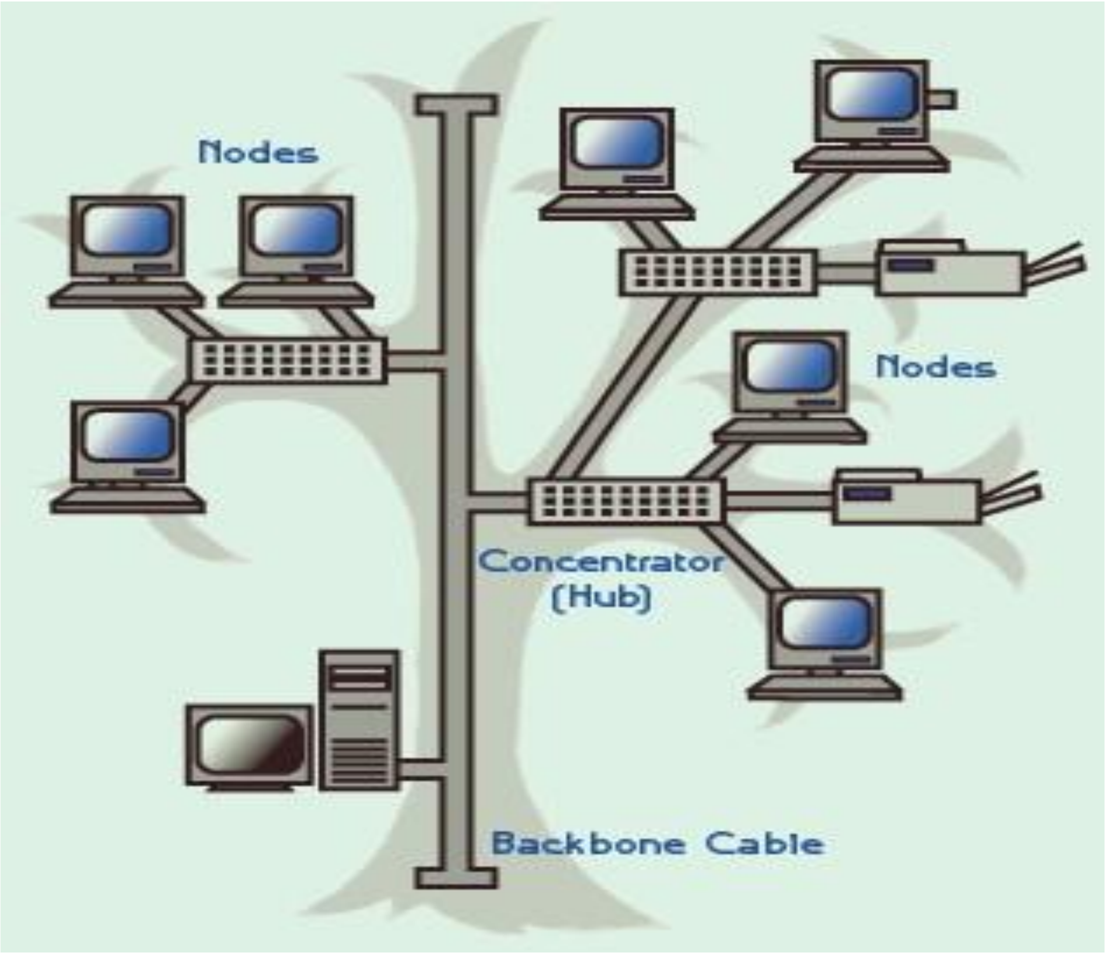
•**Disadvantages**:
- Failure of one device can disrupt the entire network.
- Troubleshooting is complex.

•**Use Case**: Legacy networks and some MANs.



Tree Topology

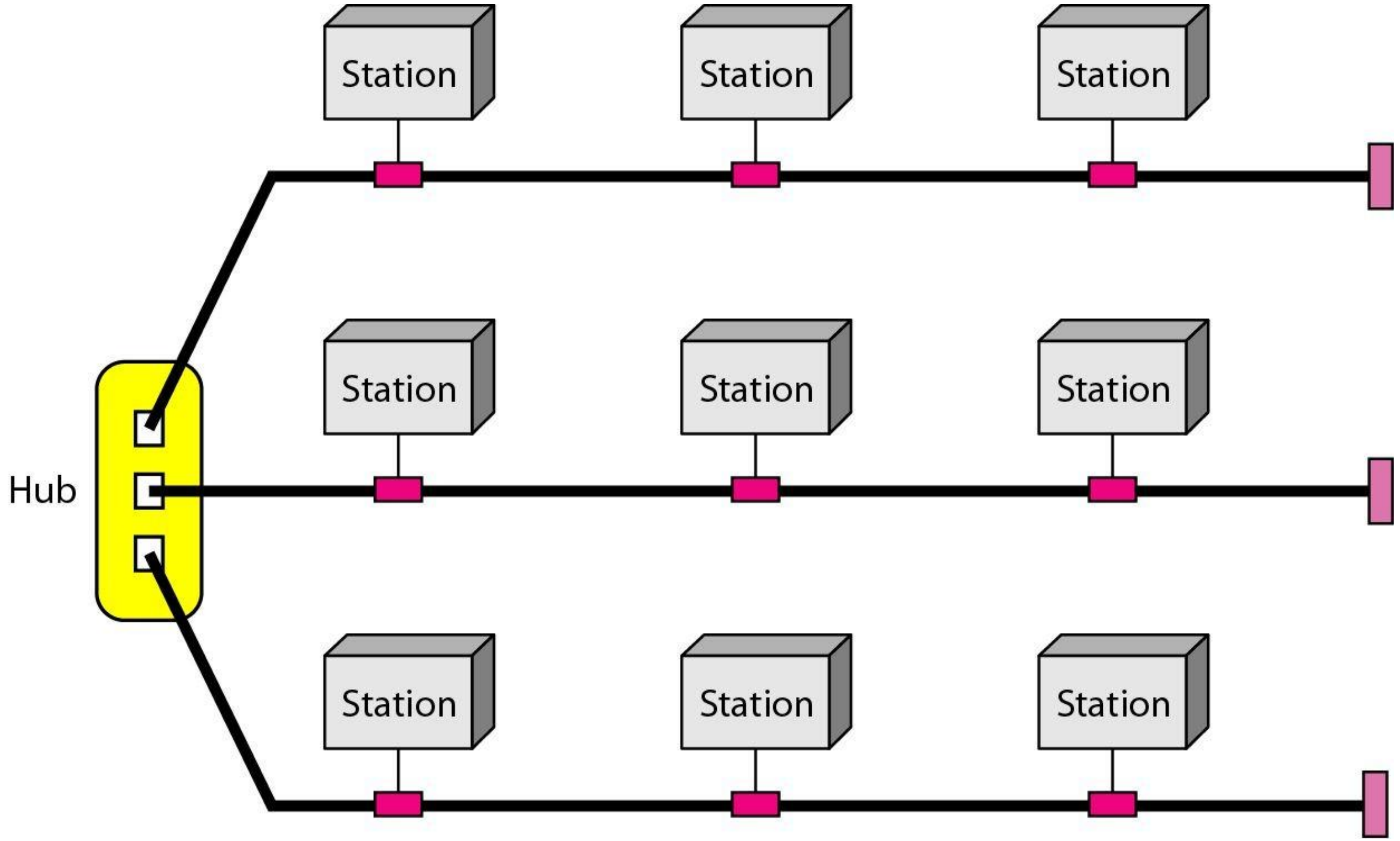
- **Description**: A hierarchical topology combining star and bus topologies, where groups of devices are connected to a central node, forming a tree structure.
- **Advantages**:
  - Scalable and suitable for large networks.
  - Easy to manage and maintain.
- **Disadvantages**:
  - A failure at the root node can affect the entire network.
  - Requires significant cabling.
- **Use Case**: Corporate networks.


Nodes
Nodes
Concentrator
(Hub)
Backbone Cable

Hybrid Topology

- **Description**: A combination of two or more different topologies.
- **Advantages**:
  - Flexible and adaptable to diverse needs.
  - Combines the strengths of multiple topologies.
- **Disadvantages**:
  - Expensive and complex to implement.
  - Troubleshooting can be challenging.
- **Use Case**: Large organizations and enterprises.

Hybrid Topology



A hybrid topology: a star backbone with three bus networks

Logical Topologies

- **Point-to-Point**: Direct communication between two devices.
- **Broadcast**: Data is sent to all devices in the network.
- **Token Passing**: Data passes sequentially between devices (e.g., token ring networks).

Choosing the Right Topology

The selection of a topology depends on factors like:

- Network size and scale.
- Cost and budget constraints.
- Performance and fault tolerance requirements.
- Nature of the application (e.g., real-time communication or data sharing).
- Each topology has its unique strengths and weaknesses, making them suitable for different network scenarios.

- **Problem**: A bus topology connects 10 devices. Each device has one interface to connect to the bus. How many cables and ports are required?

Solution:

- A single central cable (backbone) is used.
- Each device connects to the backbone with one interface.

Answer:

- **Cables required**: 1 (the backbone).
- **Ports per device**: 1.
- Total: 10 ports (1 per device).

- **Problem**: A star topology network connects 8 devices to a central hub. How many cables and ports are required?

Solution:

- Each device requires a dedicated cable to connect to the hub.
- Each device and the hub need one port per connection.

Answer:

- **Cables required**: 8 (one per device).
- **Ports required**:
    - 8 at the hub.
    - 8 at the devices.
    - Total = **16 ports**.

- **Problem**: A ring topology has 6 devices. How many links (connections) are required?

Solution:

- In a ring topology, each device connects to two other devices to form a closed loop.

Answer:

- **Links required**: Equal to the number of devices (6).

- **Problem**: A full mesh network has 5 devices. How many links are required?

- **Solution**:
- In a full mesh topology, every device is directly connected to every other device.
- The number of links is calculated using the formula for combinations:
- Links required $= n(n-1)/2$
- Links required $= 5(5-1)/2 = 5 \cdot 4/2 = 10$
- **Links required**: 10.

- **Problem**: A tree topology has a root node connected to 3 intermediate nodes, each of which connects to 4 leaf nodes. How many total devices and links are there?

- **Solution**:
- **Devices**:
  - Root node: 1.
  - Intermediate nodes: 3.
  - Leaf nodes: $3 \cdot 4 = 12$
  - Total devices = $1+3+12=16$.
- **Links**:
  - Links between the root and intermediate nodes: 3.
  - Links between intermediate nodes and leaf nodes: $3 \cdot 4 = 12$
  - Total links = $3+12=15$.
- **Answer**:
- **Devices**: 16.
- **Links**: 15.

PROTOCOLS

- *A protocol is synonymous with rule.*
- *It consists of a set of rules that govern data communications.*
- *It determines what is communicated, how it is communicated and when it is communicated.*
- *The key elements of a protocol are*
    - **Syntax**
    - **Semantics**
    - **Timing**

Elements of a Protocol:

1. Syntax

•Refers to the structure or format of the data,

•Includes specifications like:

- **Data formats** (e.g., XML, JSON)
- **Message structure** (e.g., header, payload, footer)
- **Encoding rules** for data representation.

2. Semantics

•Defines the meaning of each section of bits or data in the protocol.

•Explains the actions to be taken upon receiving a particular message or signal.

•Ensures that the sender and receiver interpret the data in the same way.

3. Timing

•Specifies:

- **When** data should be sent (e.g., intervals, synchronizations).
- **How fast** data should be sent and processed (e.g., data rate, flow control).

•Addresses issues like synchronization and latency, ensuring proper coordination between sender and receiver.

STANDARD

• Standards are the set of rules for data communication that are needed for exchange of information among devices.

•It is important to follow Standards which are created by various Standard Organization like IEEE , ISO , ANSI etc.

Types of Standards

1. De Facto Standard
2. De Jure Standard

De Facto Standard

- A de facto standard refers to a practice, product, or protocol that has gained widespread acceptance and usage in an industry or domain, despite not being officially approved or recognized by formal standardization bodies.

Examples:

- Microsoft Word
- PDF (Portable Document Format)
- TCP/IP
- QWERTY Keyboard Layout

De Jure Standard

- A **de jure standard** refers to a standard that has been formally established, approved, and adopted by an official standardization body or regulatory authority.

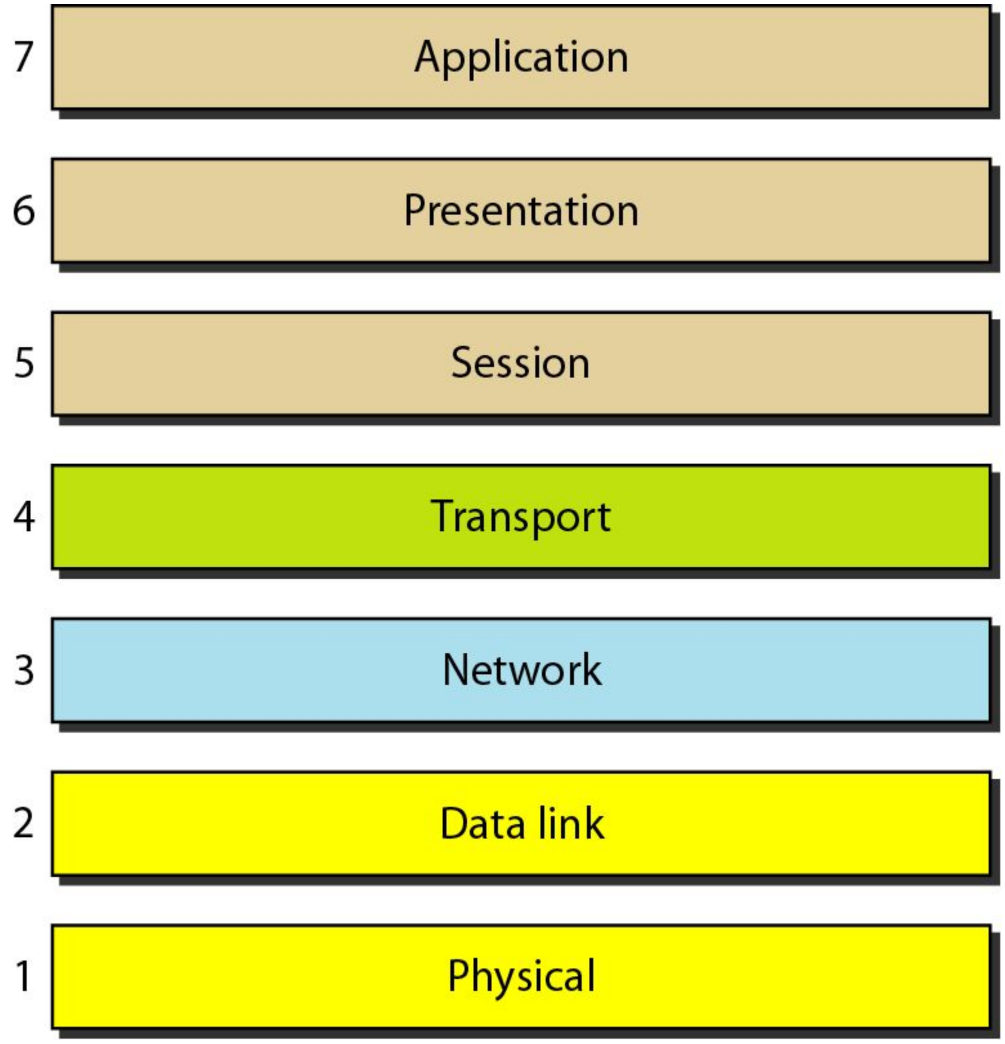
Examples:

1. ISO/IEC 27001
2. IEEE 802.11
3. HTML5
4. USB (Universal Serial Bus)

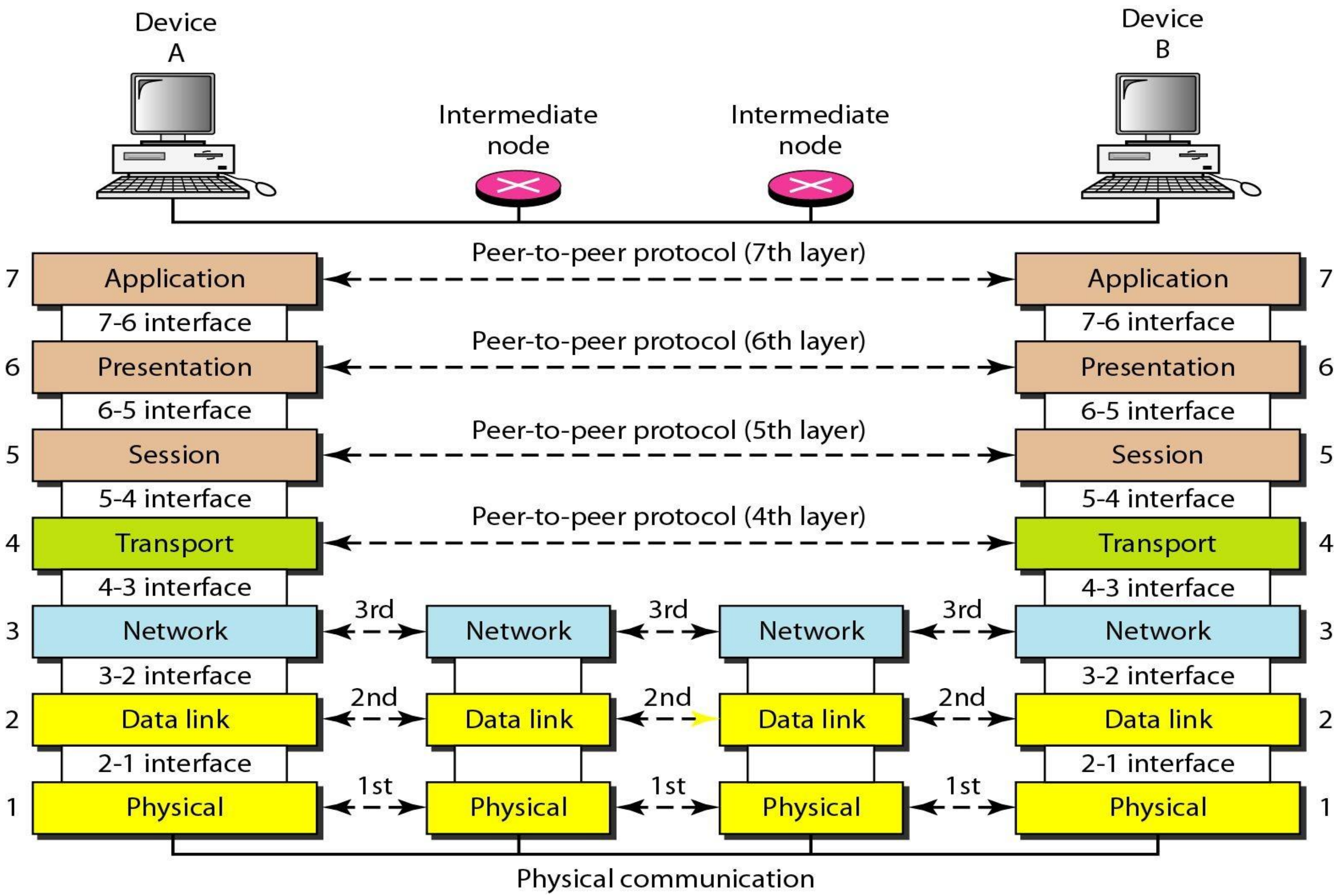
THE OSI MODEL

- Established in 1947, the International Standards Organization (ISO) is a multinational body dedicated to worldwide agreement on international standards.
- An ISO standard that covers all aspects of network communications is the Open Systems Interconnection (OSI) model.
- It was first introduced in the late 1970s.

THE OSI MODEL

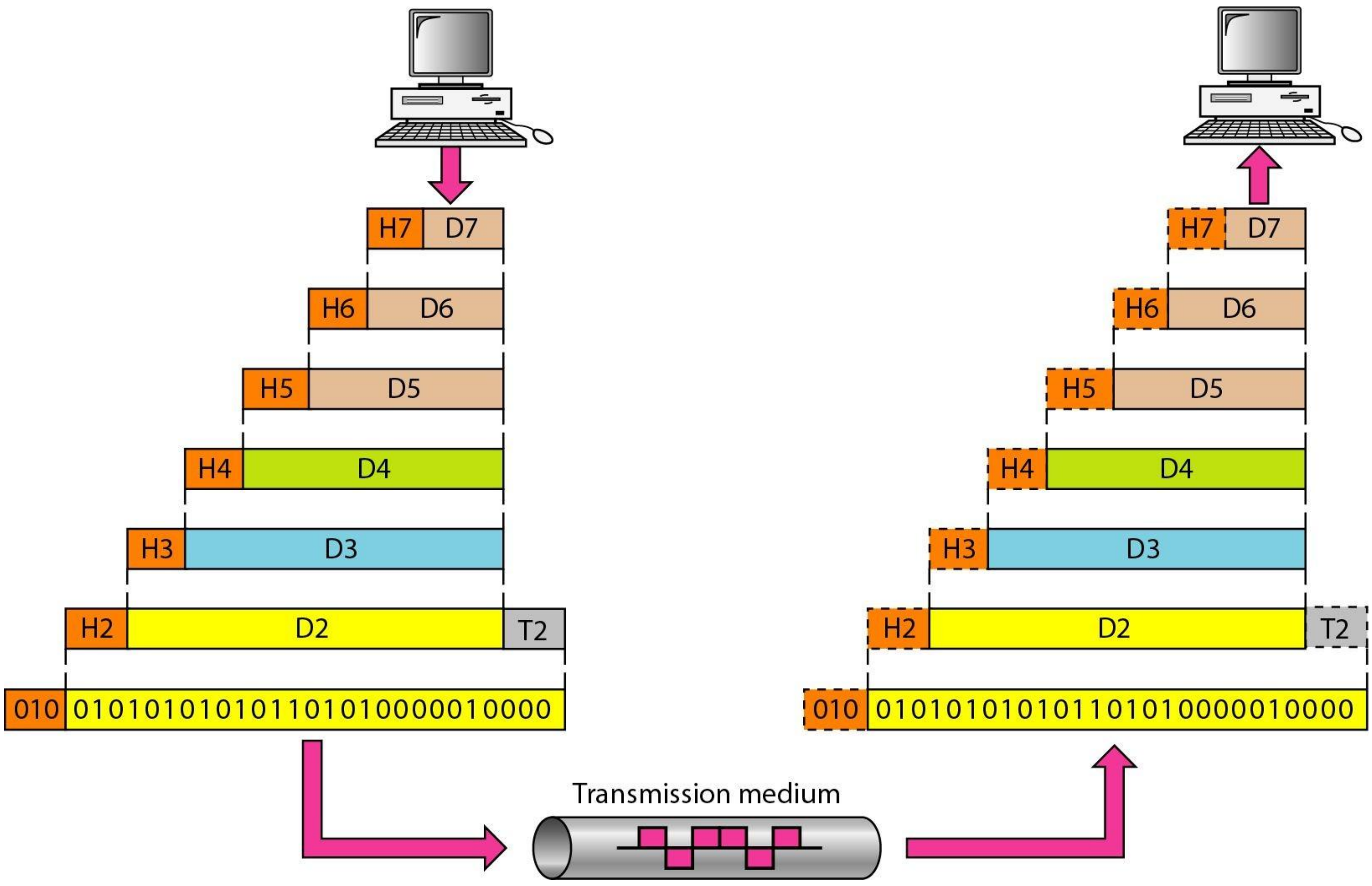


THE OSI MODEL



The interaction between layers in the OSI model

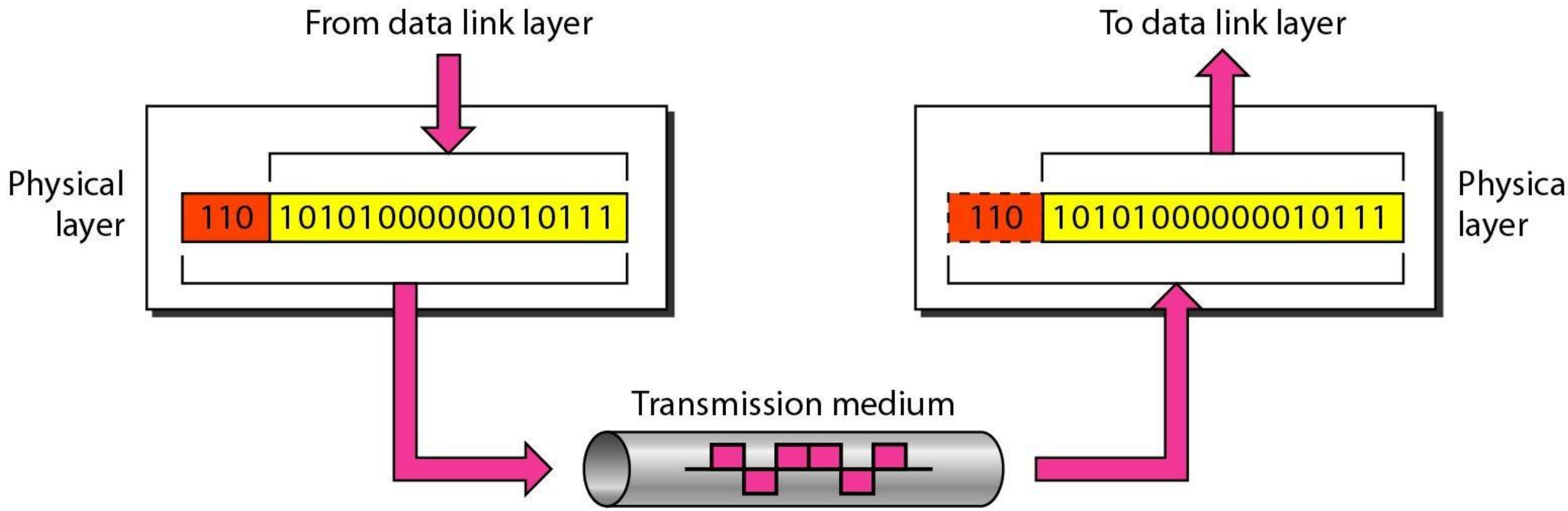
THE OSI MODEL



An exchange using the OSI model

LAYERS IN THE OSI MODEL

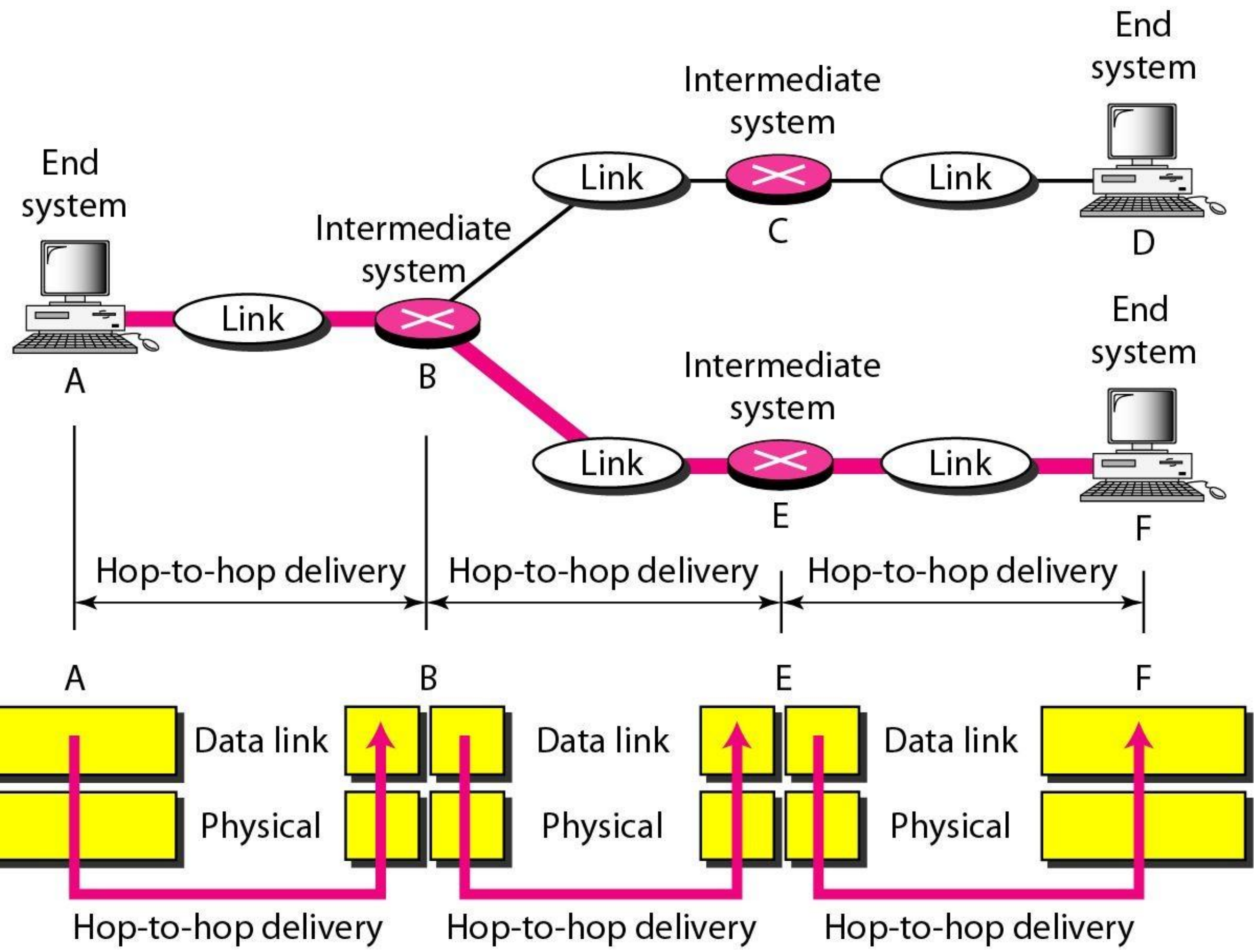
Physical layer



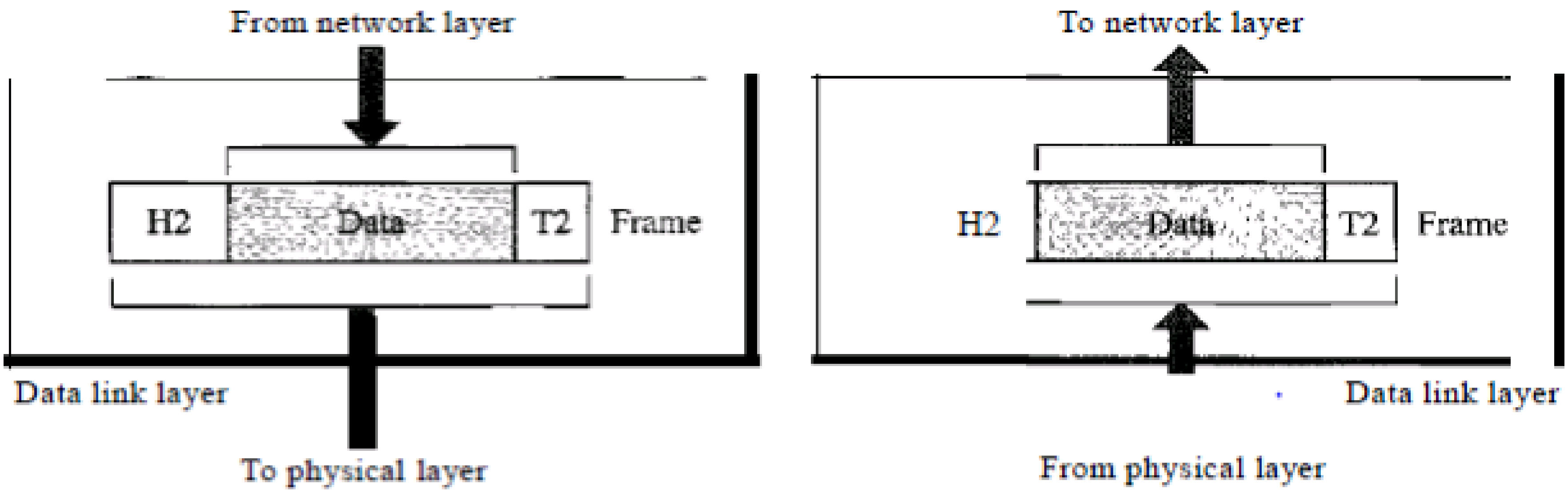
The physical layer is responsible for movements of individual bits from one hop (node) to the next.

LAYERS IN THE OSI MODEL

Hop-to-Hop delivery



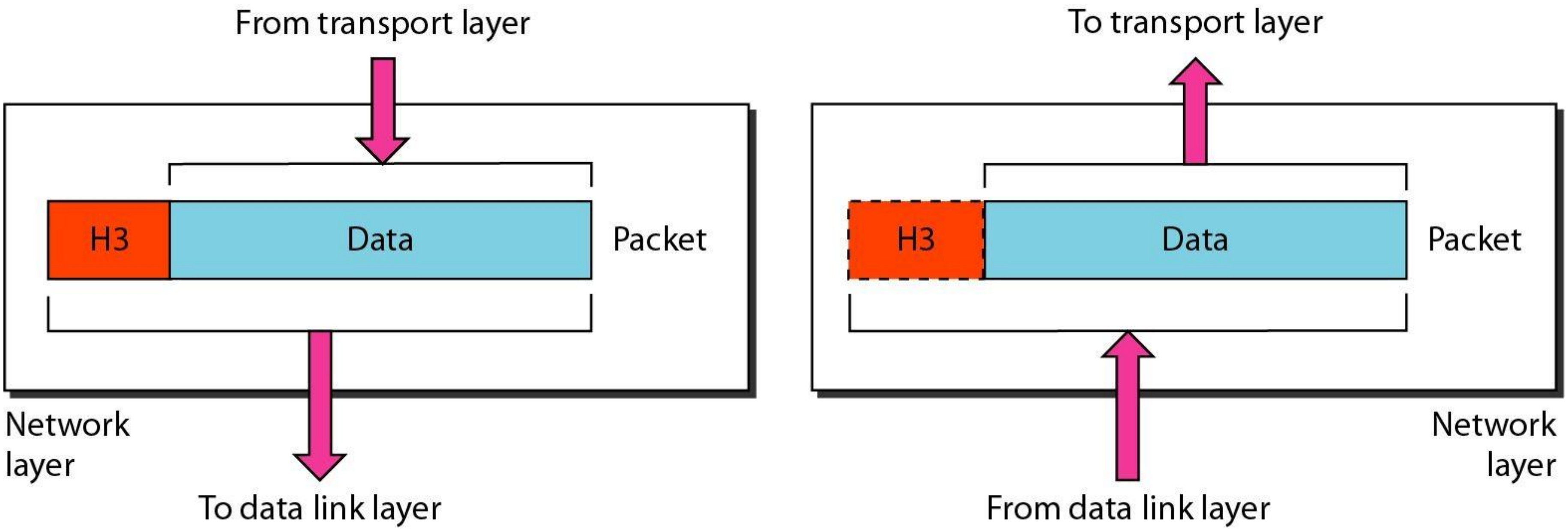
LAYERS IN THE OSI MODEL



Data link Layer

LAYERS IN THE OSI MODEL

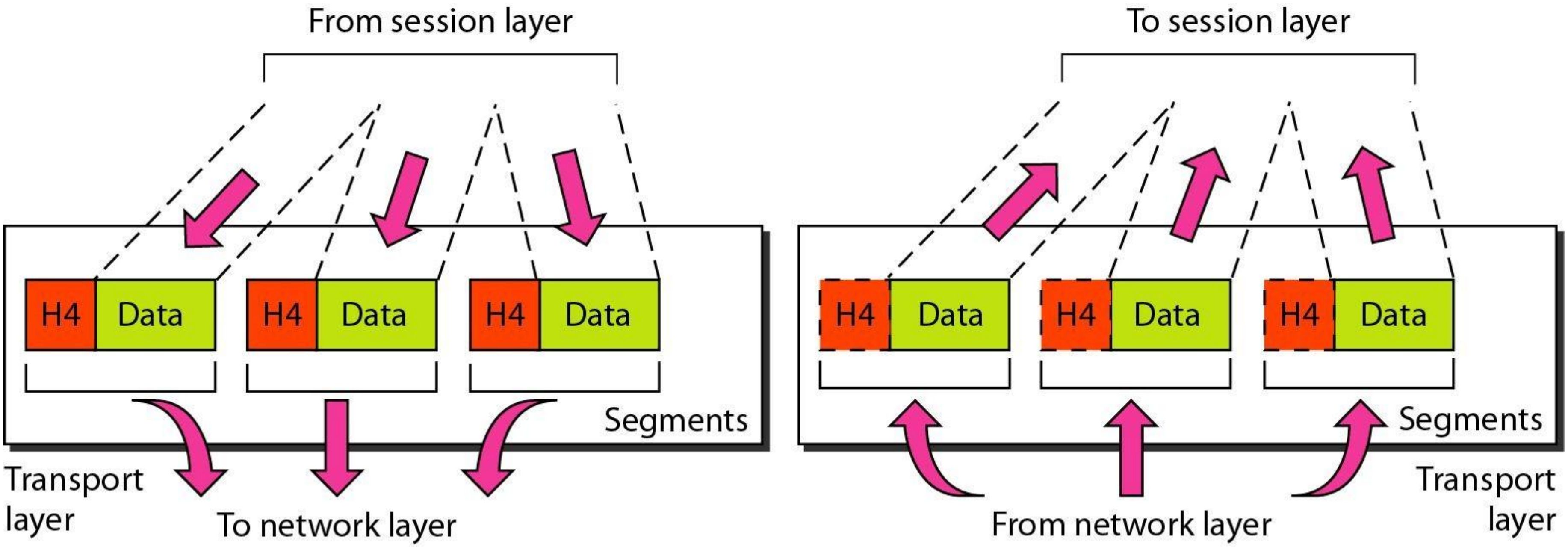
Network layer



The network layer is responsible for the delivery of individual packets from the source host to the destination host.

LAYERS IN THE OSI MODEL

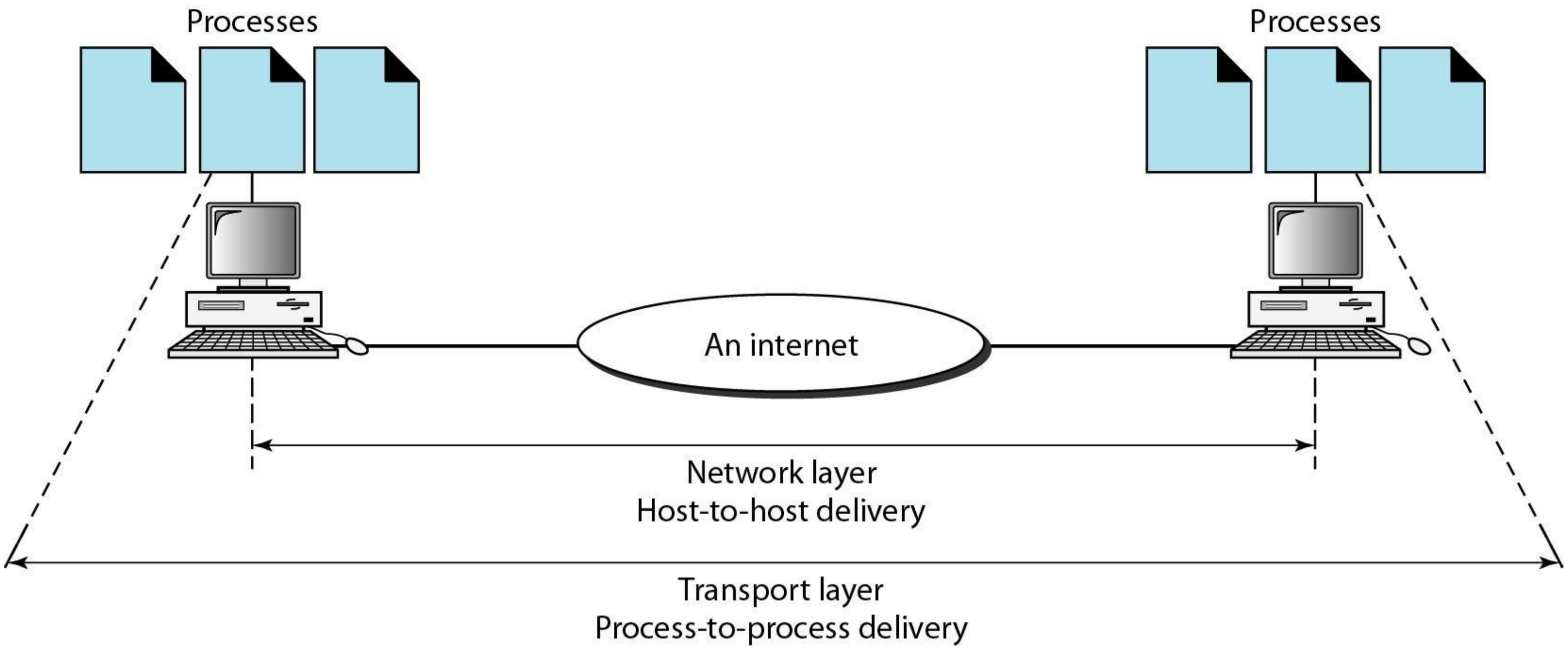
Transport layer



The transport layer is responsible for the delivery of a message from one process to another.

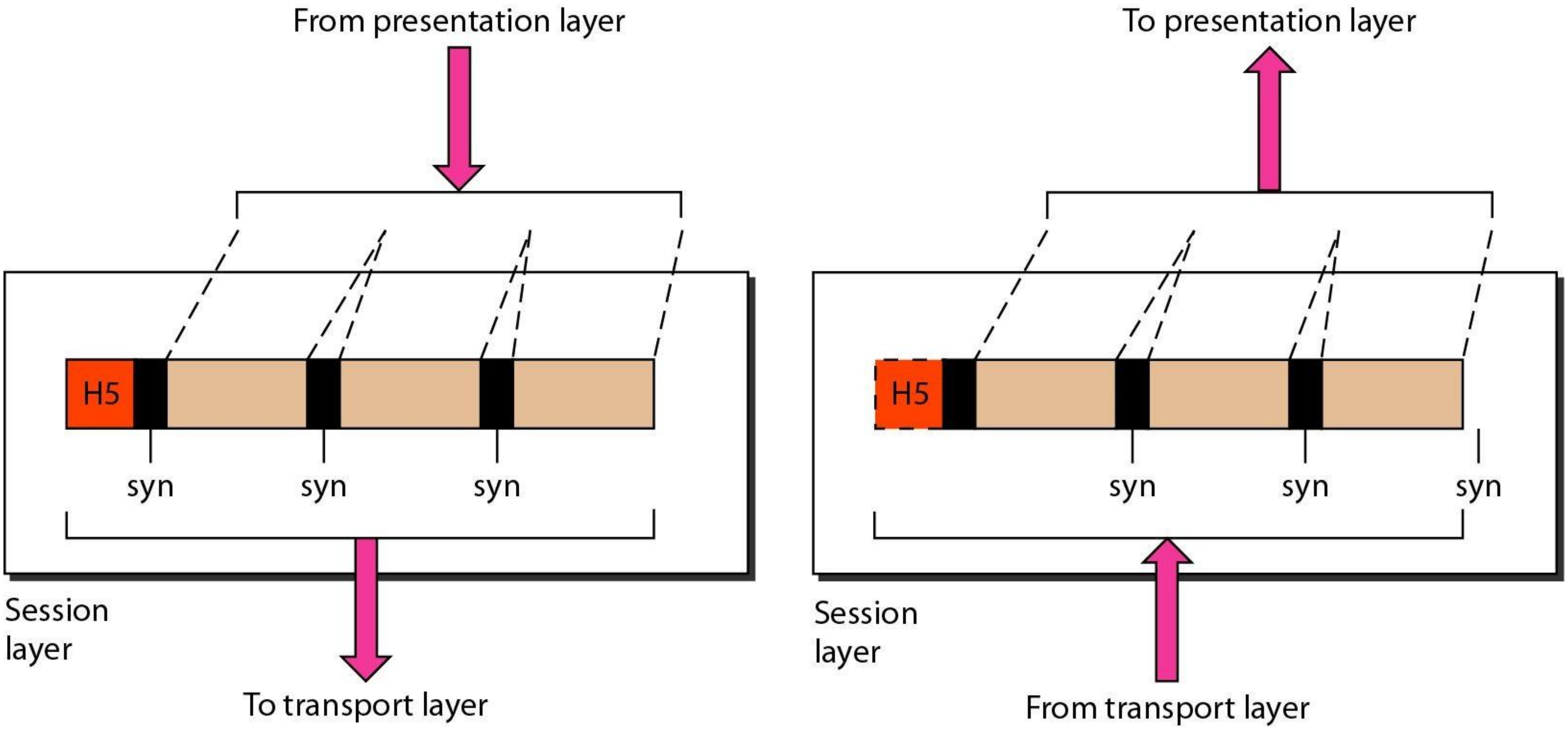
LAYERS IN THE OSI MODEL

Reliable process-to-process delivery of a message



LAYERS IN THE OSI MODEL

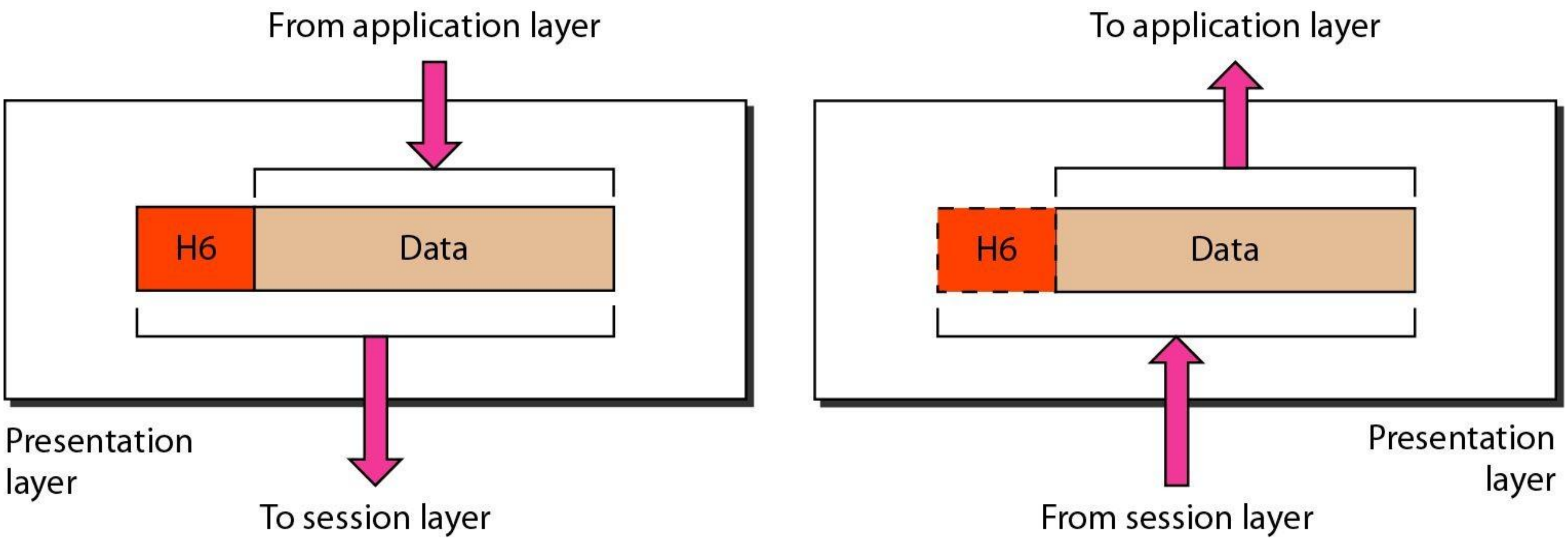
Session layer



The session layer is responsible for dialog control and synchronization.

LAYERS IN THE OSI MODEL

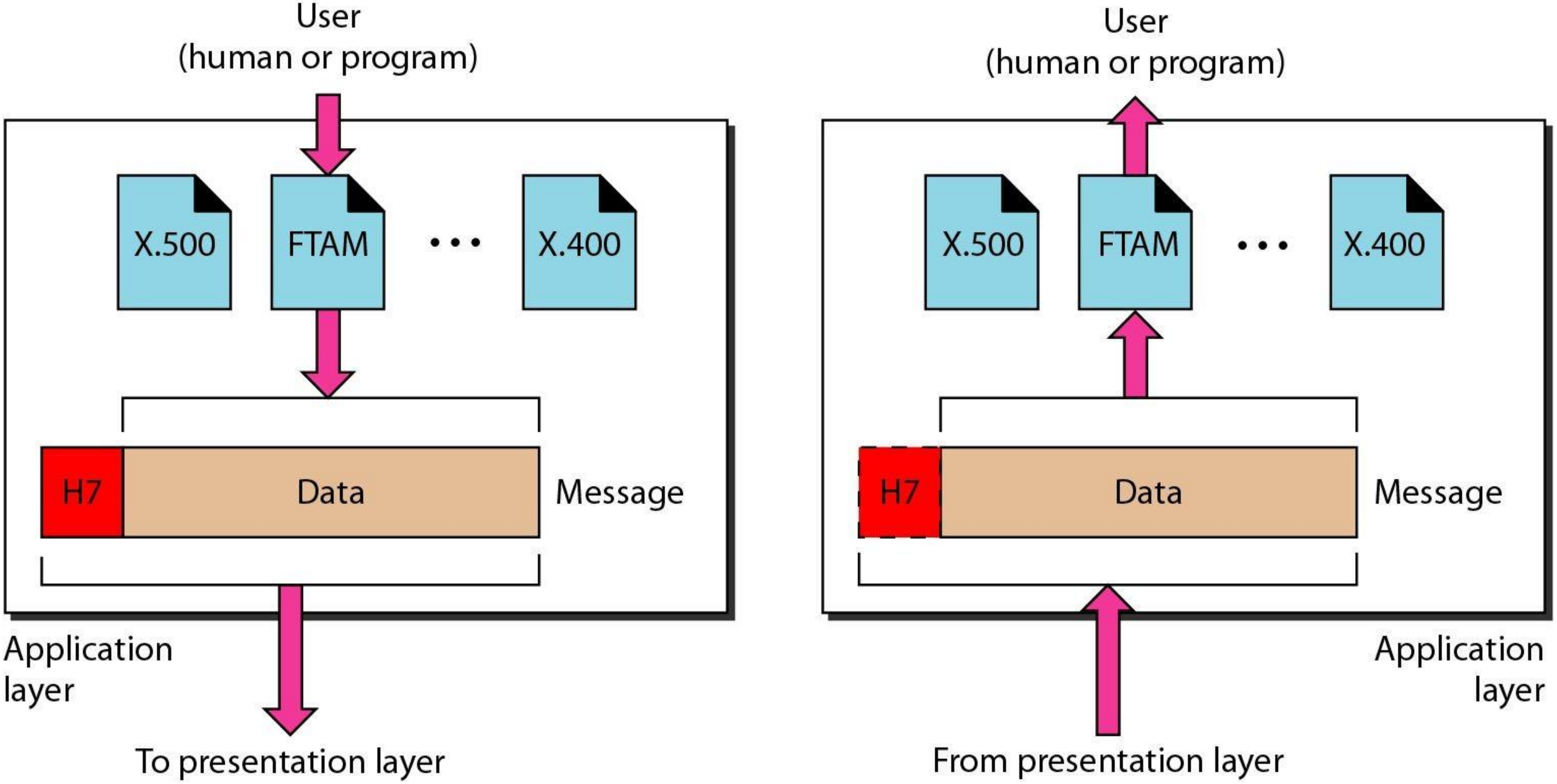
Presentation layer



The presentation layer is responsible for translation, compression, and encryption.

LAYERS IN THE OSI MODEL

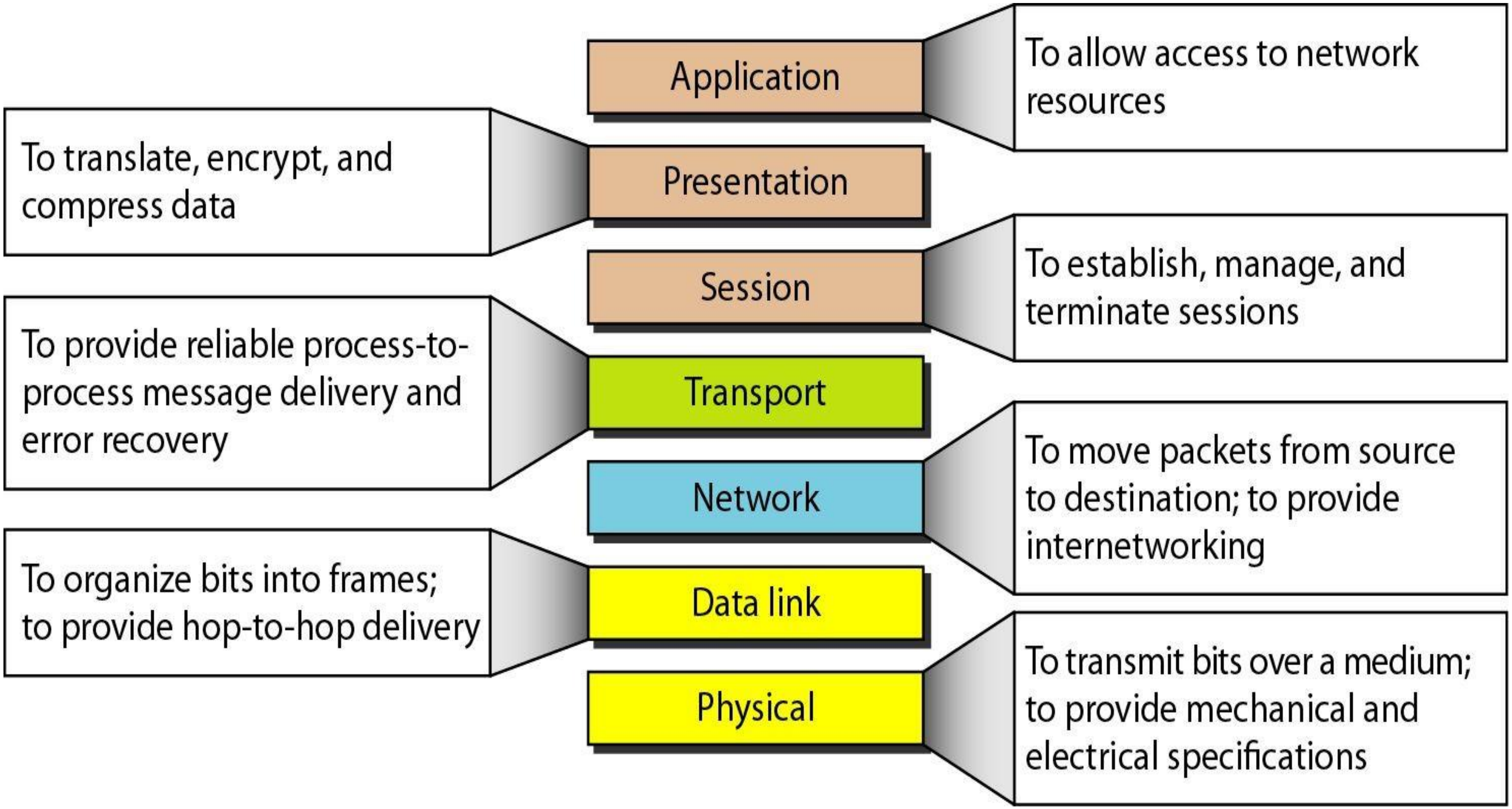
Application layer



The application layer is responsible for providing services to the user.

LAYERS IN THE OSI MODEL

Summary of layers



Syllabus

UNIT – I

Introduction: Uses of computer networks

Transmission Modes: Serial and Parallel - Synchronous, Asynchronous and Isochronous - Simplex, Half duplex and full duplex

Data communication Components: Representation of data and its flow, Various Connection Topology, Protocols and Standards, OSI model, Transmission Media

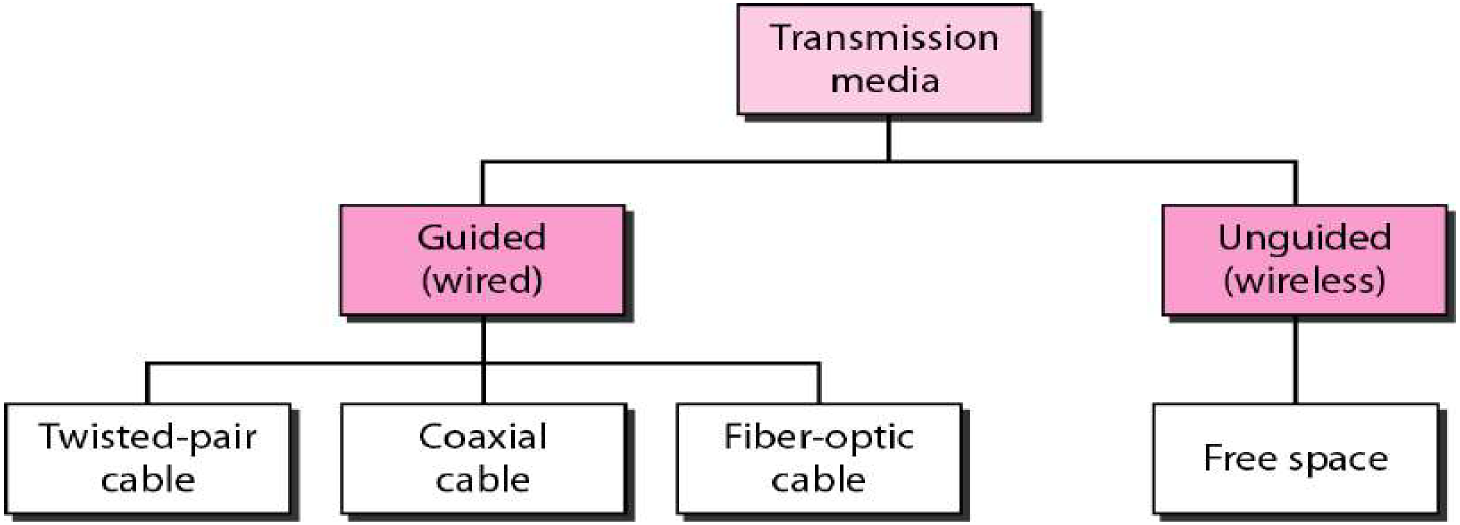
LAN: Wired LAN, Wireless LAN, Virtual LAN

Techniques for Bandwidth utilization: Multiplexing - Frequency division, Time division and Wave division, Concepts on spread spectrum.

Transmission Media

- A transmission **medium can be broadly defined as anything that can carry information from a** source to a destination. For example, the transmission medium for two people having a dinner conversation is the _________????

- For a written message, the transmission medium might be a mail carrier, a truck, or an airplane.



Physical Media

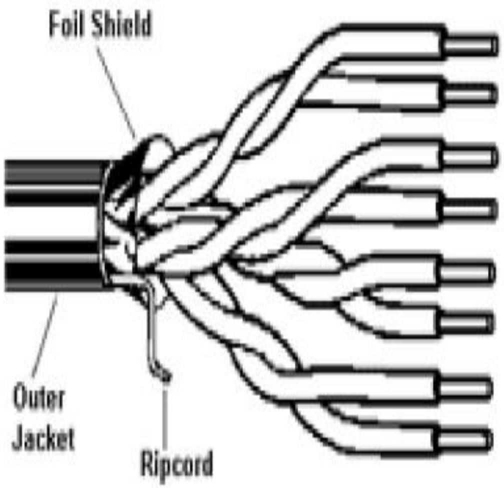
Things to Remember:

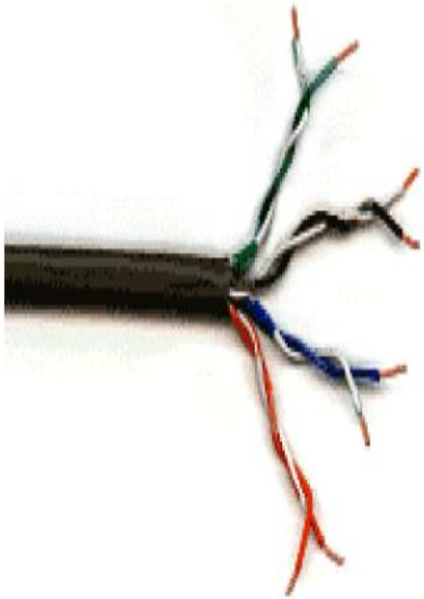
Physical Link: ransmitted data bit propagates across link

Guided Media: signals propagate in solid media: copper, fibre

Unguided Media: signals propagate freely. e.g., radio

Twisted-Pair Copper Wire



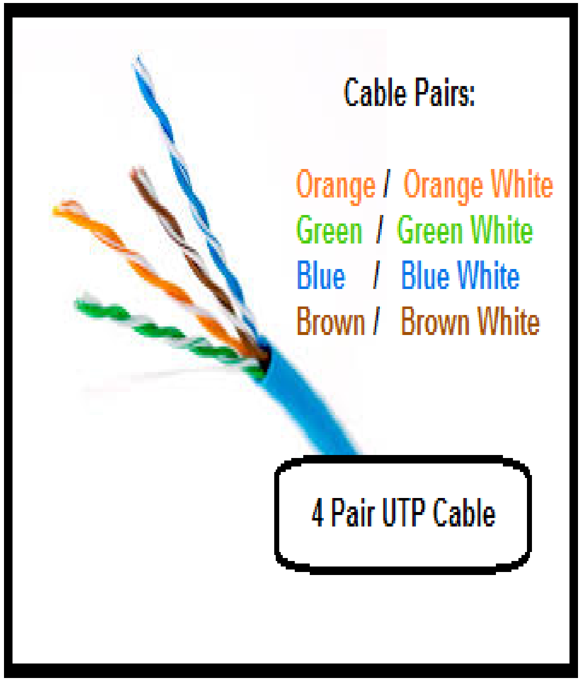


Why Twisted Pair?

- Least Expensive
- Most commonly used transmission medium
- **For over 100 years it has been used by telephone networks.**
- 99 % of the wired connections from the telephone handset to the local telephone switch use twisted-pair copper wire.
- Used in our homes and work environments.
- Twisted-pair consists of two insulated copper wires, each about **1 mm thick**, arranged in a regular spiral pattern.
- The wires are twisted together to reduce the electrical interference from similar pairs close by.
- Typically, a number of pairs are bundled together in a cable by wrapping the pairs in a protective shield.
- A wire pair constitutes a single communication link.
- **Data rates range from 10Mbps to 10Gbps**

Types of UTPs

- **Category 1 or Cat 1** – UTP cables with data rate < 0.1 Mbps, used in telephone lines
- **Category 2 or Cat 2** – UTP cables with a data rate of 2 Mbps, used in transmission lines
- **Category 3 or Cat 3** – UTP cables with a data rate of 10 Mbps, used in LANs or 10baseT Ethernet
- **Category 4 or Cat 4**– UTP cables with a data rate of 20 Mbps, used in token ring networks
- **Category 5 or Cat 5** – UTP cables with a data rate of 100 Mbps, used in LANs or 100baseT Ethernet
- **Category 5e or Cat 5e** – 1000baseT Ethernet with a data rate of 1000 Mbps
- **Category 6 or Cat 6** – UTP cables with a data rate of 200 Mbps, used in high-speed LANs
- **Category 7 or Cat 7** – STP used in super high-speed Gigabit Ethernet.



Most common twisted pair ethernet cables used presently are:
•100BASE-TX or Fast Ethernet (transmission speed 100 Mbps)
•1000BASE-T or Gigabit Ethernet (1 Gbps speed)

Twisted Pair

Advantages

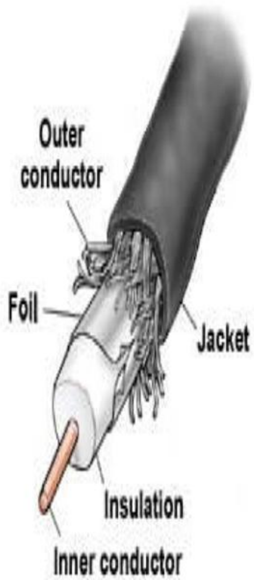
- Cost-effective
- Easy to install
- Flexibility
- Suitable for short distances

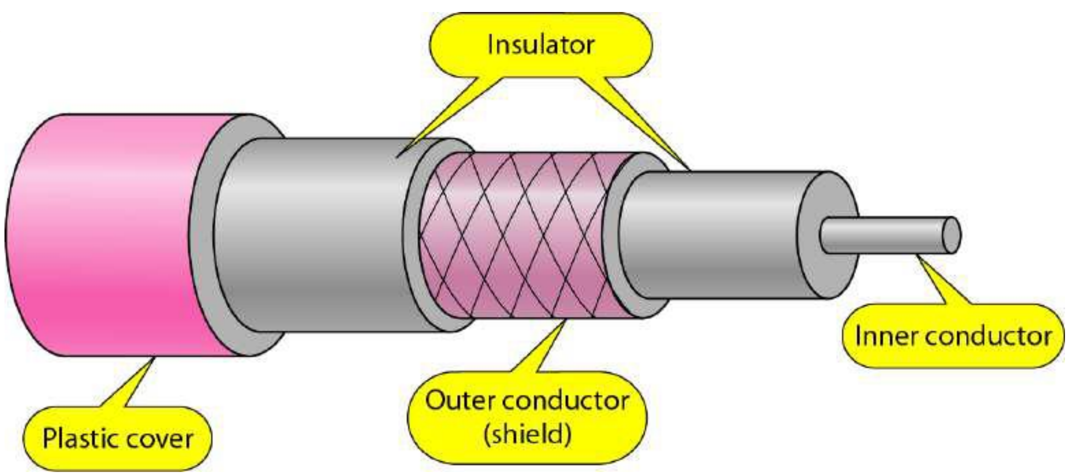
Disadvantages:

- Limited bandwidth
- Susceptible to interference
- Limited distance

Coaxial cable

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple frequency channels on cable
  - 100's Mbps per channel





Co-Axial Cable

- Coaxial cable consists of two copper conductors
- A special insulation and shielding
- Coaxial cable has higher bit rates than twisted pair.
- Coaxial cable comes in two varieties:

1. Baseband coaxial cable

2. Broadband coaxial cable.

- Baseband coaxial cable, also called 50-ohm cable, is about a centimetre thick, lightweight, and easy to bend.
- It is commonly used in LANs
- Computer is typically connected to a LAN with either baseband coaxial cable or with UTP.
- Baseband cable is less expensive, easier to physically handle, and does not require attachment cables.

- If you see a telephone-like jack and some wire that resembles telephone wire, you are using UTP

.

- If you see a T-connector and a cable running out of both sides of the T - connector, you are using baseband coaxial cable.

- Broadband coaxial cable, also called 75 -ohm cable, is quite a bit thicker, heavier, and stiffer than the baseband variety.
- Broadband cable is quite common in **cable television systems**.
- Cable television systems have recently been coupled with cable modems to provide residential users with Web access at rates of **10Mbps**

Things to Remember:

Coaxial cable:

Two concentric copper conductors

It is Bidirectional

Common use in 10 Mbps Ethernet

Baseband: single channel on cable,
legacy Ethernet

Broadband: multiple channel on cable, HFC

Co-axial Cable

Advantages:

- Better bandwidth
- Longer distance transmission
- Resistance to interference

Disadvantages:

- More expensive
- Difficult to install
- Limited flexibility

Fibre Optics

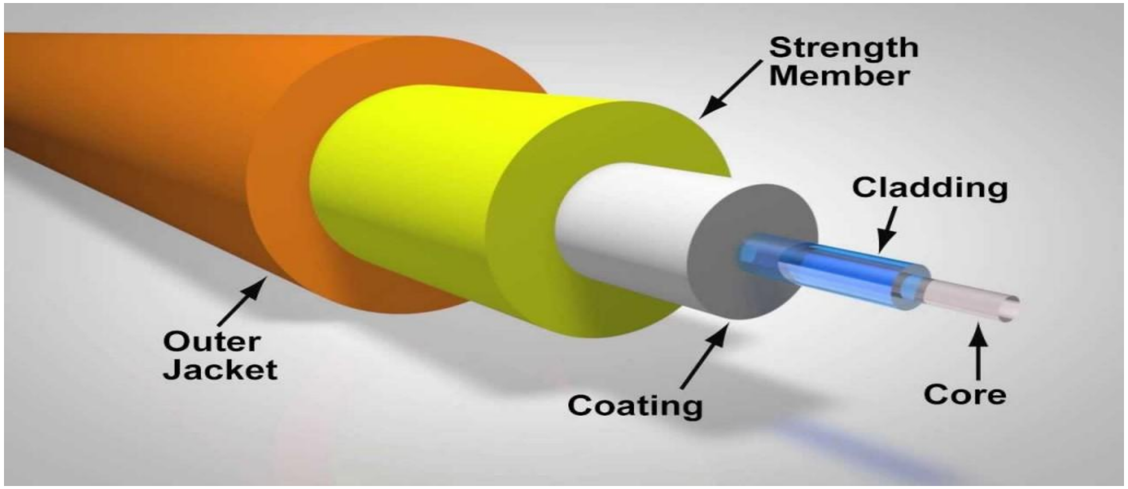
- An optical fibre is a thin, flexible medium that conducts pulses of light, with each pulse representing a bit.
- **A single optical fibre can support 10Gbps or 100Gbps.**
- Immune to electromagnetic interference
- Preferred for long-haul guided transmission media, particularly for **overseas links.**
- Many of the long-distance telephone networks in the United States and elsewhere now use fibre optics exclusively.

Things to Remember:

Fiber optic cable:
glass fiber carrying light pulses, each pulse a bit

High-speed operation: 100 Mbps Ethernet,
high-speed point-to-point transmission (e.g., 5 Gps)

Low error rate: repeaters spaced far apart ; immune to electromagnetic noise



Why use optic fiber cable?

- High carrying capacity (very broad bandwidth, THz or Tbits/s)
- Very low transmission losses
- Do not dissipate heat
- Immune to cross-talk and electromagnetic interference

Fiber Optics

Advantages:

- High-speed data transmission
- Immunity to electromagnetic interference
- Lower power consumption

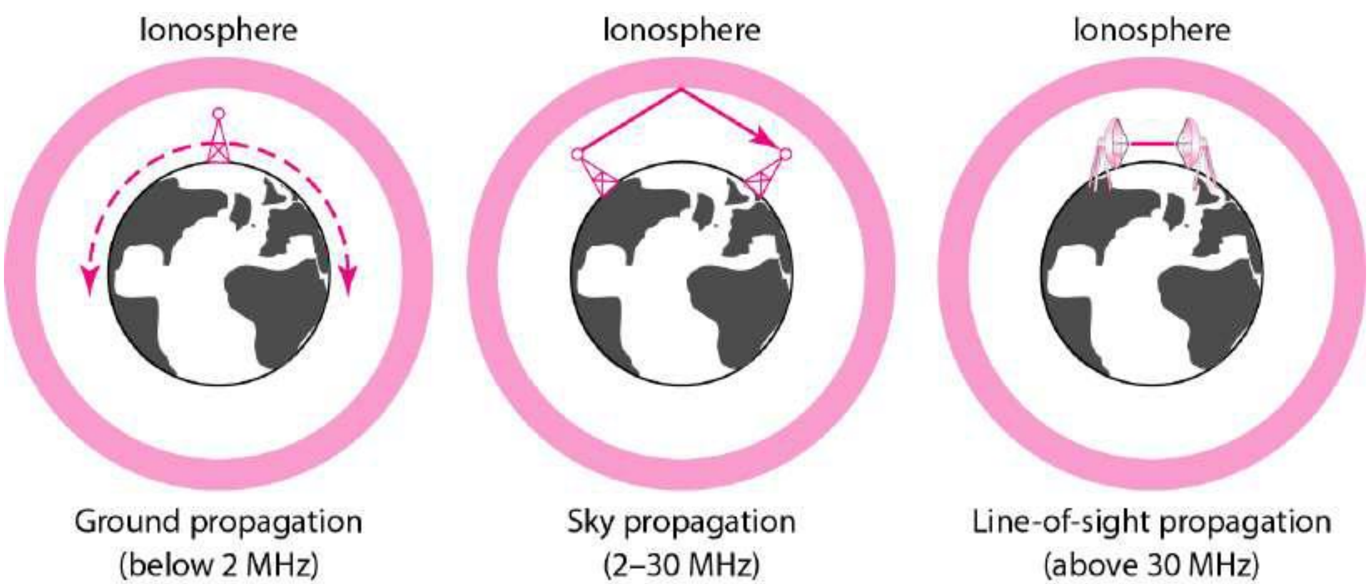
Disadvantages:

- Cost
- Fragility
- Difficult to install

Transmission Media

UNGUIDED MEDIA: WIRELESS

- This type of communication is often referred to as wireless communication.



- Unguided signals can travel from the source to destination in several ways:

ground propagation, sky propagation, and line-of-sight propagation

1. Ground Propagation (Surface Wave Propagation)

- In ground propagation, radio waves travel close to the Earth's surface, following the curvature of the planet. These waves are generally low-frequency (up to 3 MHz) and have longer wavelengths.

Examples:

- AM radio signals
- Submarine communication using very low frequency (VLF) waves

Applications:

- **AM Radio Broadcasting:** Ground waves carry AM signals over large distances, especially in rural areas.
- **Maritime Navigation:** Used for communication with ships and submarines over long distances.
- **Military Communication:** VLF waves are used to communicate with submarines underwater.
- **Disaster Communication:** Used for long-range communication during emergencies.

2. Sky Propagation (Ionospheric Propagation)

In sky propagation, radio waves are reflected or refracted back to Earth by the ionosphere. These waves are typically medium-frequency (MF) to high-frequency (HF) waves (3 MHz to 30 MHz).

Examples:

- Shortwave radio broadcasts
- International broadcasting stations (e.g., BBC World Service, Voice of America)

Applications:

- **Global Communication:** Shortwave radios use ionospheric reflection to transmit signals across continents.
- **Aviation and Marine Communication:** HF radio bands are used for communication between aircraft/ships and control centers.
- **Military Communication:** Used for secure, long-range communication during operations.

3. Line-of-Sight (LOS) Propagation

In line-of-sight propagation, radio waves travel in straight lines between the transmitter and receiver. This type of propagation is generally used for very high-frequency (VHF) and higher-frequency bands, such as UHF and microwave.

Examples:

- Television signals (UHF/VHF)
- Cellular communication (4G/5G)
- Satellite communication
- Wi-Fi and Bluetooth

Applications:

- **Television Broadcasting:** VHF and UHF bands transmit TV signals directly to antennas within line-of-sight range.
- **Mobile Communication:** Cellular towers use LOS propagation to transmit signals to mobile devices.
- **Satellite Communication:** Direct line-of-sight between satellites and ground stations enables global communication.
- **Microwave Links:** Used in point-to-point communication systems like backhaul networks for telecom providers.
- **Radar Systems:** Line-of-sight is crucial for detecting and tracking objects such as airplanes and weather systems.

If You Don't Know What's Happening Here, You're Too Young

UNGUIDED MEDIA: WIRELESS

1. Radio Waves

- **Wavelength Range:** 1 mm to 100 km
  Frequency Range: 3 Hz to 300 GHz

Examples:

- FM/AM radio signals
- Television broadcasts
- Wi-Fi signals
- GPS communication

Applications:

- **Communication Systems:** Used in AM/FM radio, television, and satellite communication.
- **Navigation Systems:** GPS devices rely on radio waves.
- **Astronomy:** Radio telescopes detect cosmic phenomena.
- **Mobile Networks:** Cellular communication (4G/5G) operates in radio wave frequencies.

2. Microwaves

- **Wavelength Range:** 1 mm to 1 m
  Frequency Range: 300 MHz to 300 GHz

Examples:

- Microwave ovens
- Radar signals
- Bluetooth and Wi-Fi
- Satellite communication

Applications:

- **Cooking:** Microwave ovens use microwaves to heat food.
- **Radar Systems:** Used in air traffic control, weather forecasting, and military surveillance.
- **Telecommunication:** Long-distance phone calls, satellite TV, and internet services.
- **Medical Applications:** Microwave ablation for cancer treatment.

3. Infrared Waves

- **Wavelength Range:** 700 nm to 1 mm
  Frequency Range: 300 GHz to 430 THz

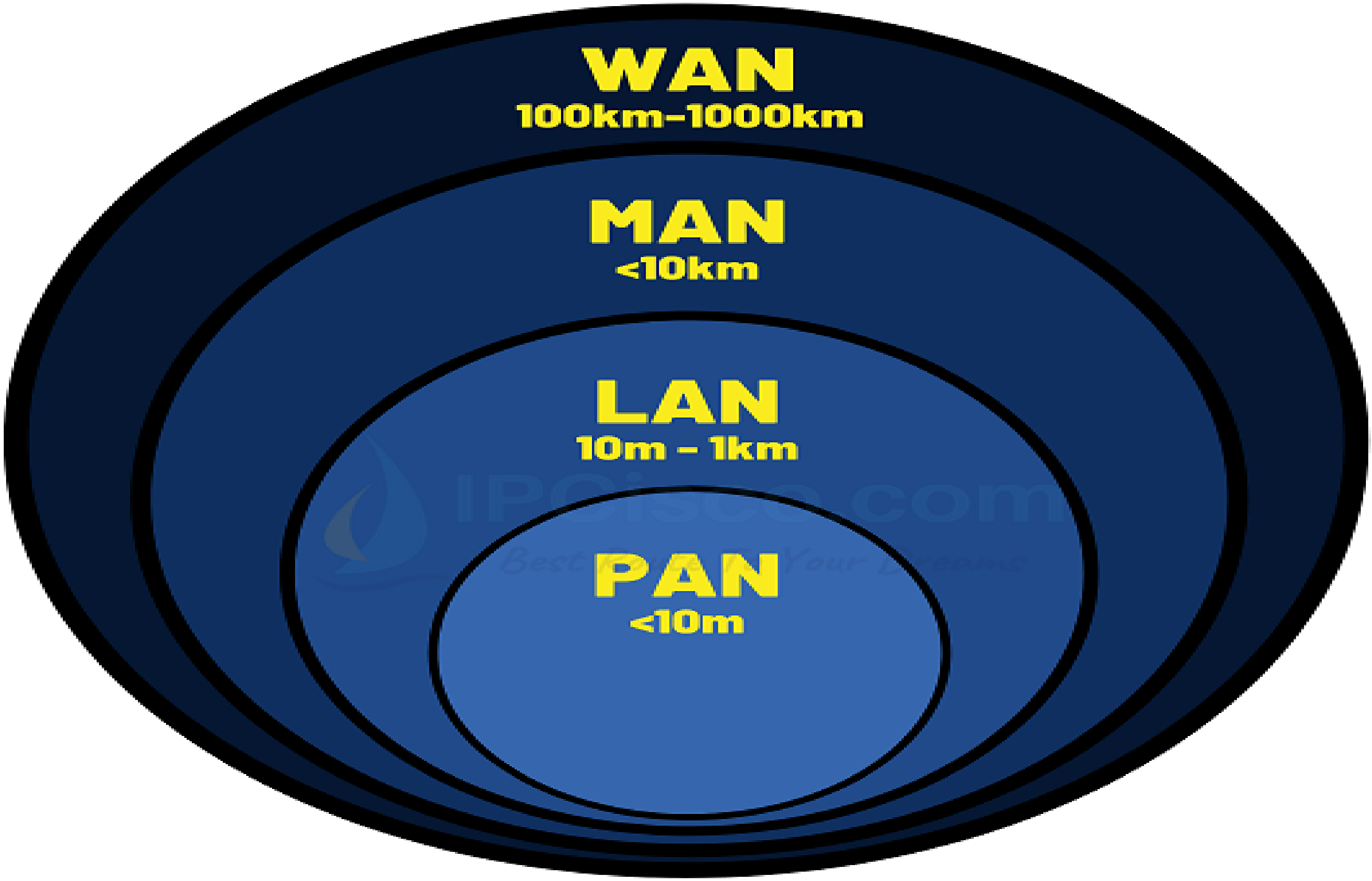
Examples:

- Heat lamps
- Remote control signals
- Night vision devices
- Thermal imaging cameras

Applications:

- **Heating:** Used in infrared heaters and saunas.
- **Remote Controls:** TV and AC remotes operate on infrared signals.
- **Surveillance:** Night vision goggles and thermal cameras detect infrared radiation.
- **Astronomy:** Infrared telescopes observe distant stars and galaxies.
- **Medical Imaging:** Used for detecting circulation problems and inflammatory conditions.

Categories of Networks

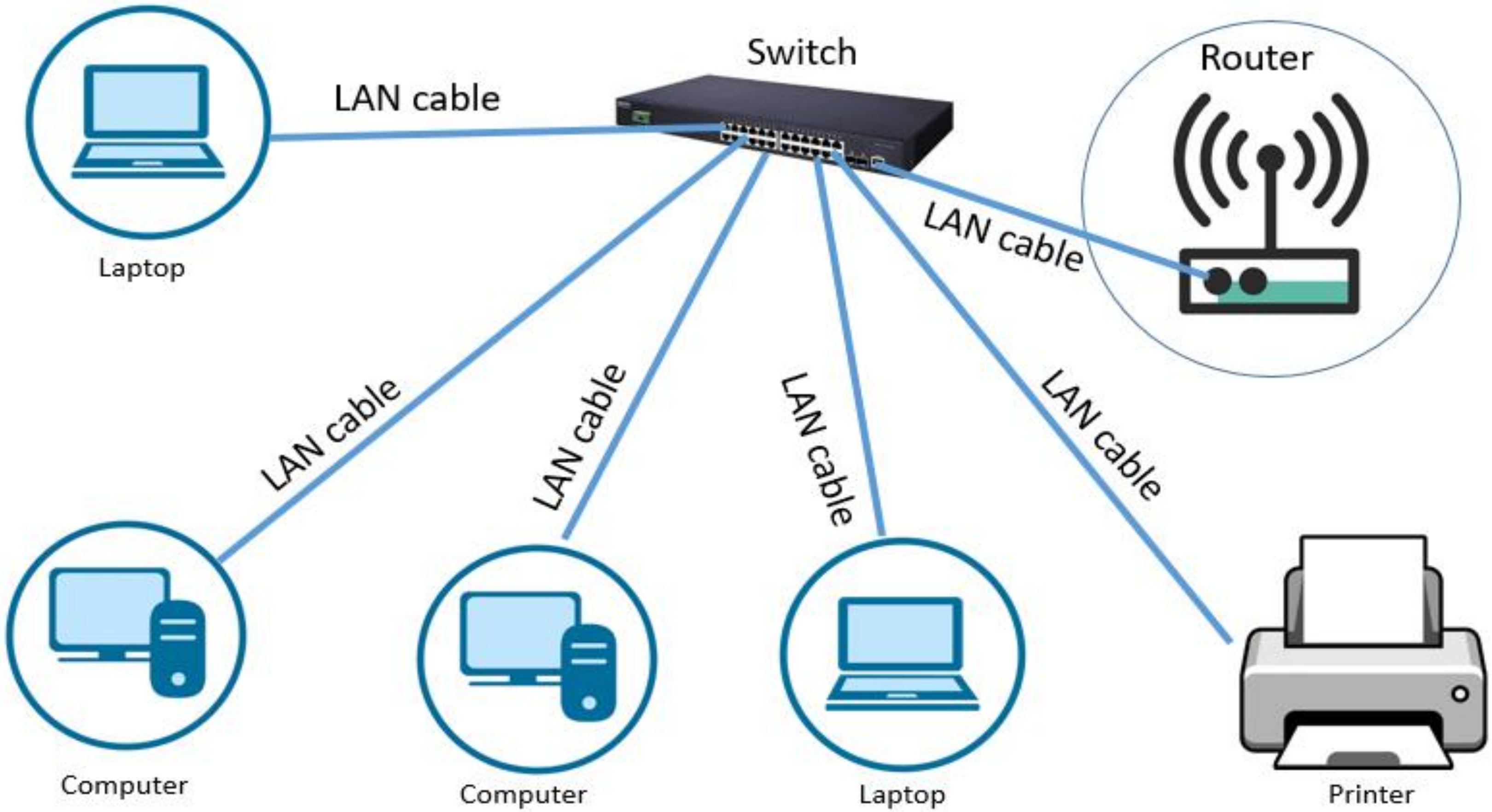


Categories of Networks

- Local Area Networks (LANs)
  - Short distances
  - Designed to provide local interconnectivity
- Wide Area Networks (WANs)
  - Long distances
  - Provide connectivity over large areas
- Metropolitan Area Networks (MANs)
  - Provide connectivity over areas such as a city, a campus

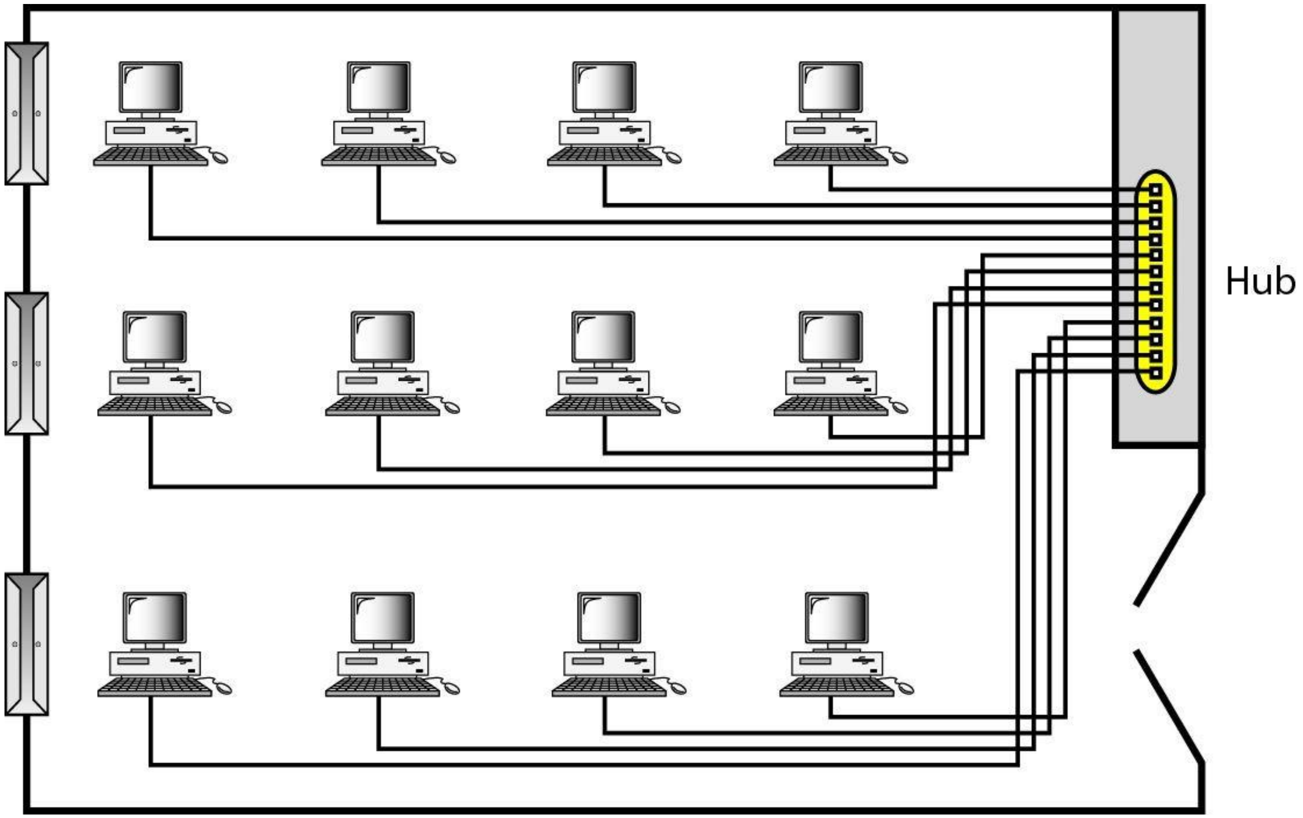
Local Area Network (LAN)

- A local area network (LAN) is a network limited to a particular geographic area. A switch, or stack of switches, connects a group of computers and devices using the TCP/IP protocol's private addressing mechanism.
- Data is transmitted at a high-speed rate because the number of computers linked is limited. The connections must, by definition, be high-speed, and hardware must be reasonably inexpensive (such as hubs, network adapters, and Ethernet cables).
- In a LAN, the propagation delay is relatively short. Larger LANs can accommodate thousands of computers, whereas smaller LANs may only employ two computers.
- A LAN usually has wired connections; however, wireless connectivity can also be used. A LAN's fault tolerance is higher, and the network is less congested.



Local Area Network

Figure 1.10 *An isolated LAN connecting 12 computers to a hub in a closet*



LAN

Advantages:

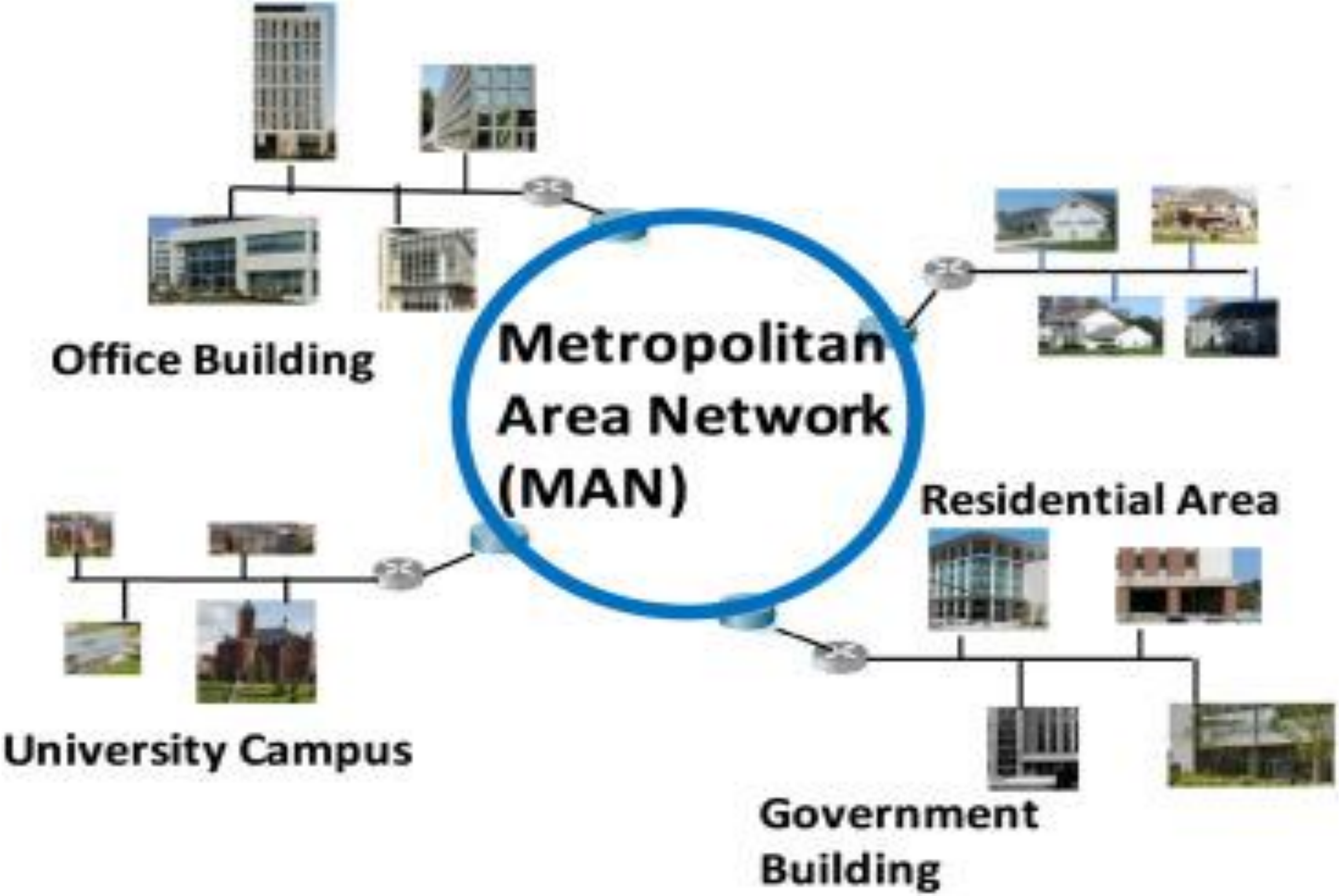
- Provides fast data transfer rates and high-speed communication.
- Easy to set up and manage.
- Can be used to share peripheral devices such as printers and scanners.
- Provides increased security and fault tolerance compared to WANs.

Disadvantages:

- Limited geographical coverage.
- Limited scalability and may require significant infrastructure upgrades to accommodate growth.
- May experience congestion and network performance issues with increased usage.

Metropolitan Area Network (MAN)

- MAN or Metropolitan area Network covers a larger area than that covered by a LAN and a smaller area as compared to WAN.
- It connects two or more computers that are apart but reside in the same or different cities.
- It covers a large geographical area and may serve as an ISP (Internet Service Provider).
- MAN is designed for customers who need high-speed connectivity. Speeds of MAN range in terms of Mbps.
- It’s hard to design and maintain a Metropolitan Area Network.


Office Building
Metropolitan Area Network (MAN)
Residential Area
University Campus
Government Building

MAN

Advantages:

- Provides high-speed connectivity over a larger geographical area than LAN.
- Can be used as an ISP for multiple customers.
- Offers higher data transfer rates than WAN in some cases.

Disadvantages:

- Can be expensive to set up and maintain.
- May experience congestion and network performance issues with increased usage.
- May have limited fault tolerance and security compared to LANs.

Wide Area Network (WAN)

- WAN or Wide Area Network is a computer network that extends over a large geographical area, although it might be confined within the bounds of a state or country.
- A WAN could be a connection of LAN connecting to other LANs via telephone lines and radio waves and may be limited to an enterprise (a corporation or an organization) or accessible to the public.
- The technology is high-speed and relatively expensive.
- There are two types of WAN: Switched WAN and Point-to-Point WAN.
- WAN is difficult to design and maintain.
- Fault tolerance of a WAN is less and there is more congestion in the network.
- A Communication medium used for WAN is PSTN(Public Switched Telephone Network) or Satellite Link.
- Due to long-distance transmission, the noise and error tend to be more in WAN.

WIDE AREA NETWORK (WAN)

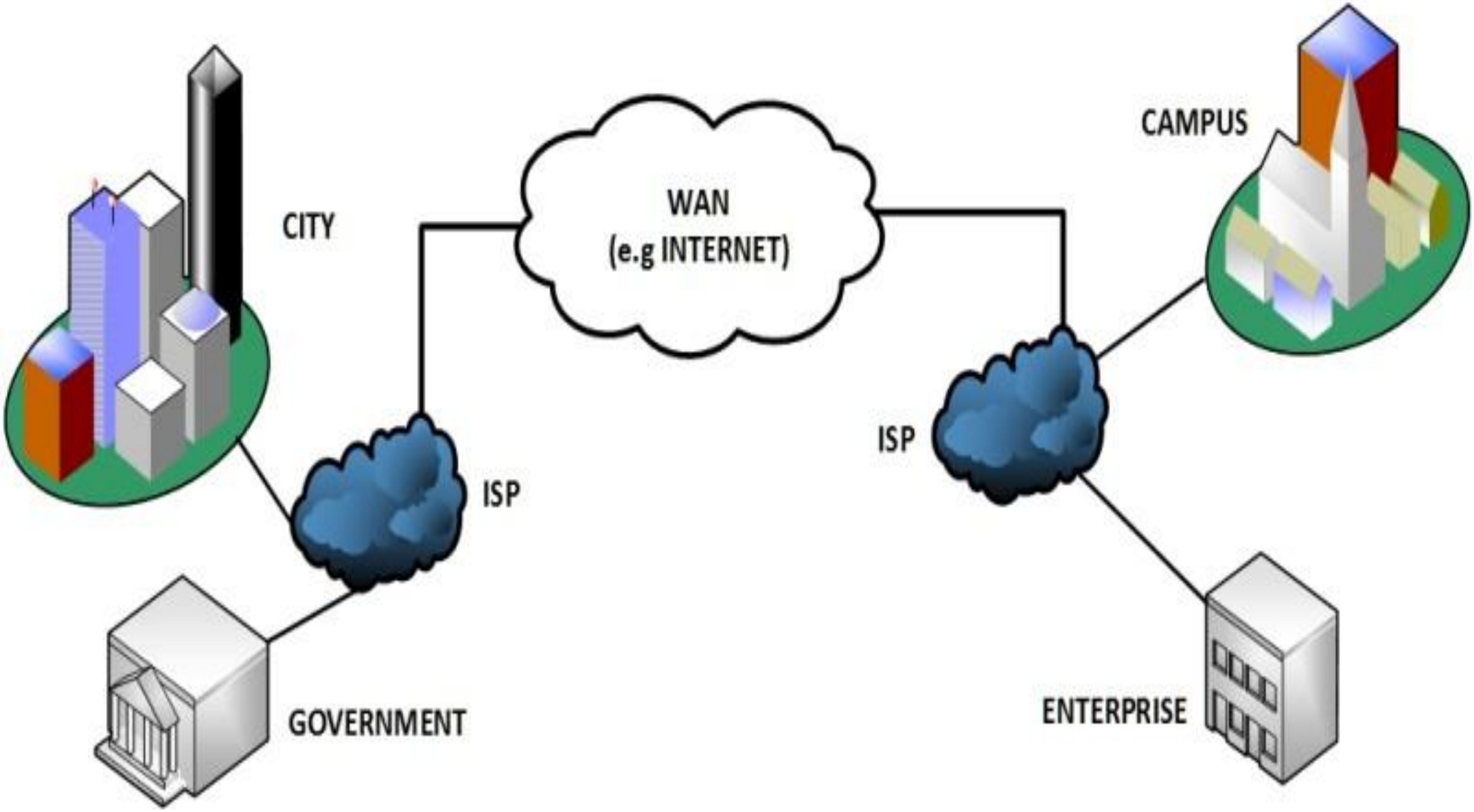
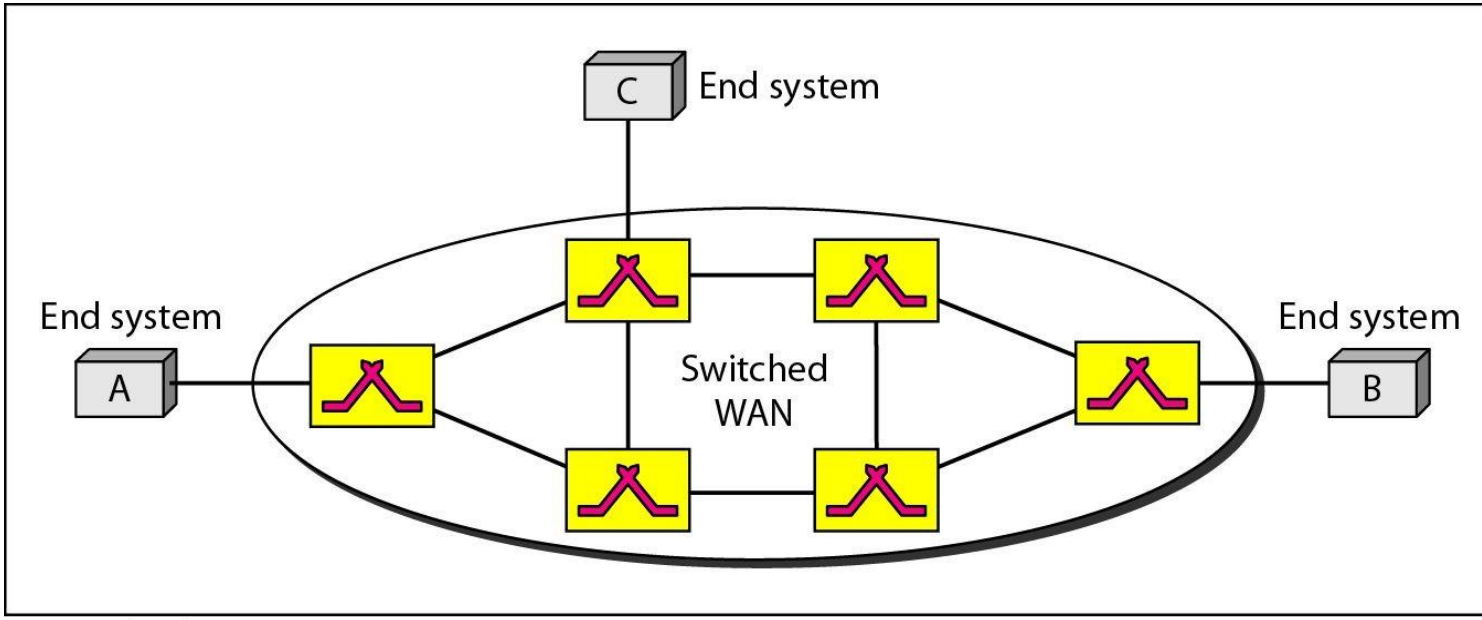
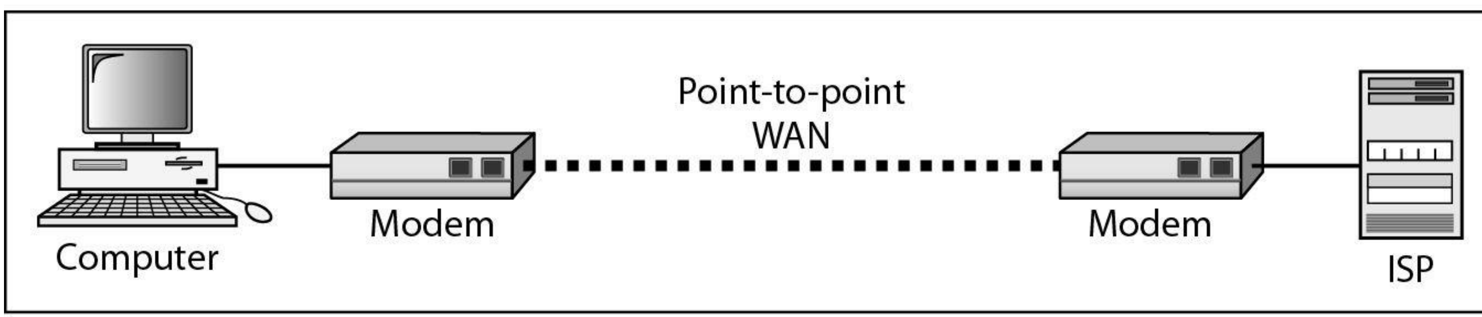


Figure 1.11 *WANs: a switched WAN and a point-to-point WAN*

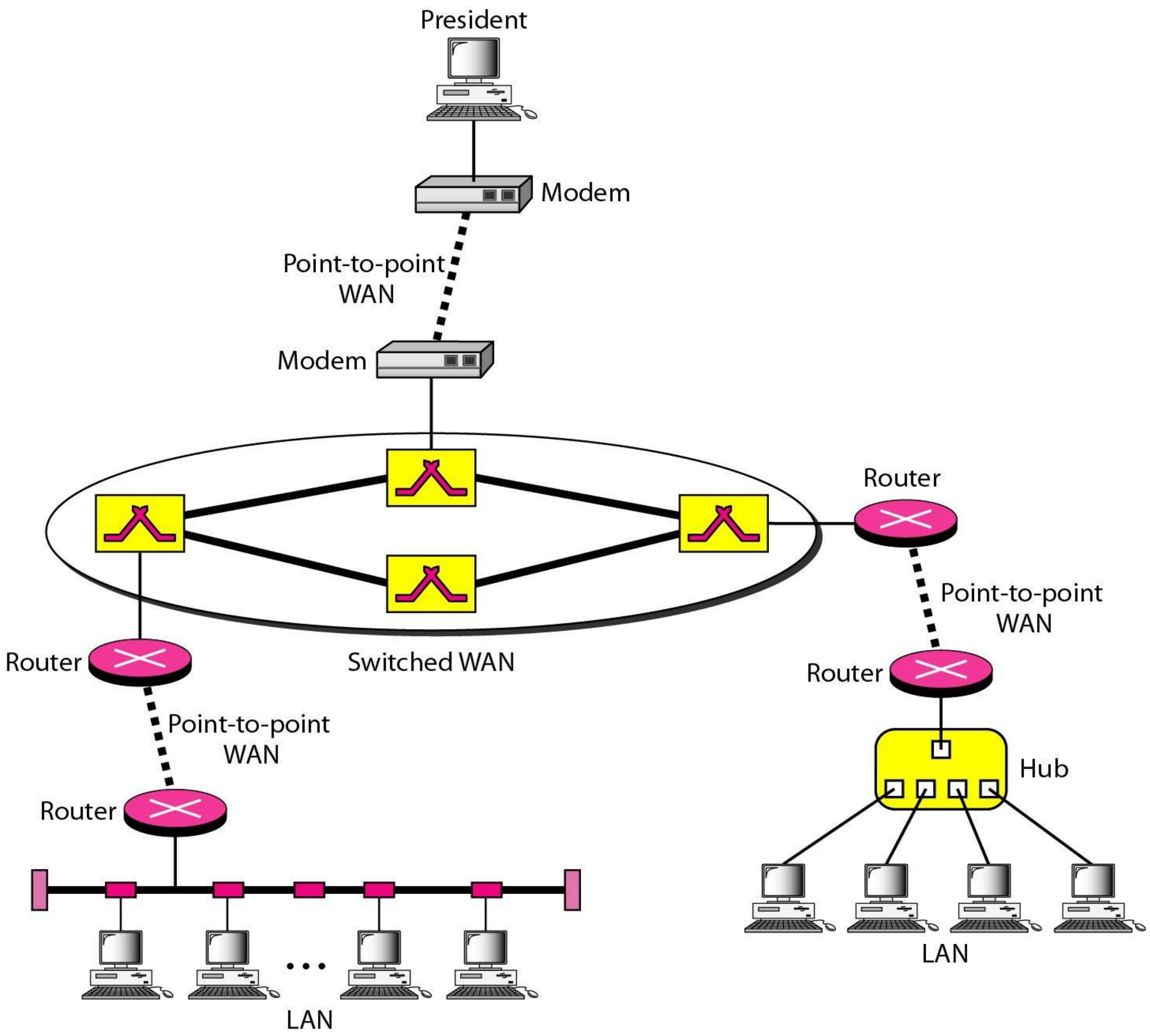


a. Switched WAN



b. Point-to-point WAN

Figure 1.12 *A heterogeneous network made of four WANs and two LANs*



WAN

Advantages:

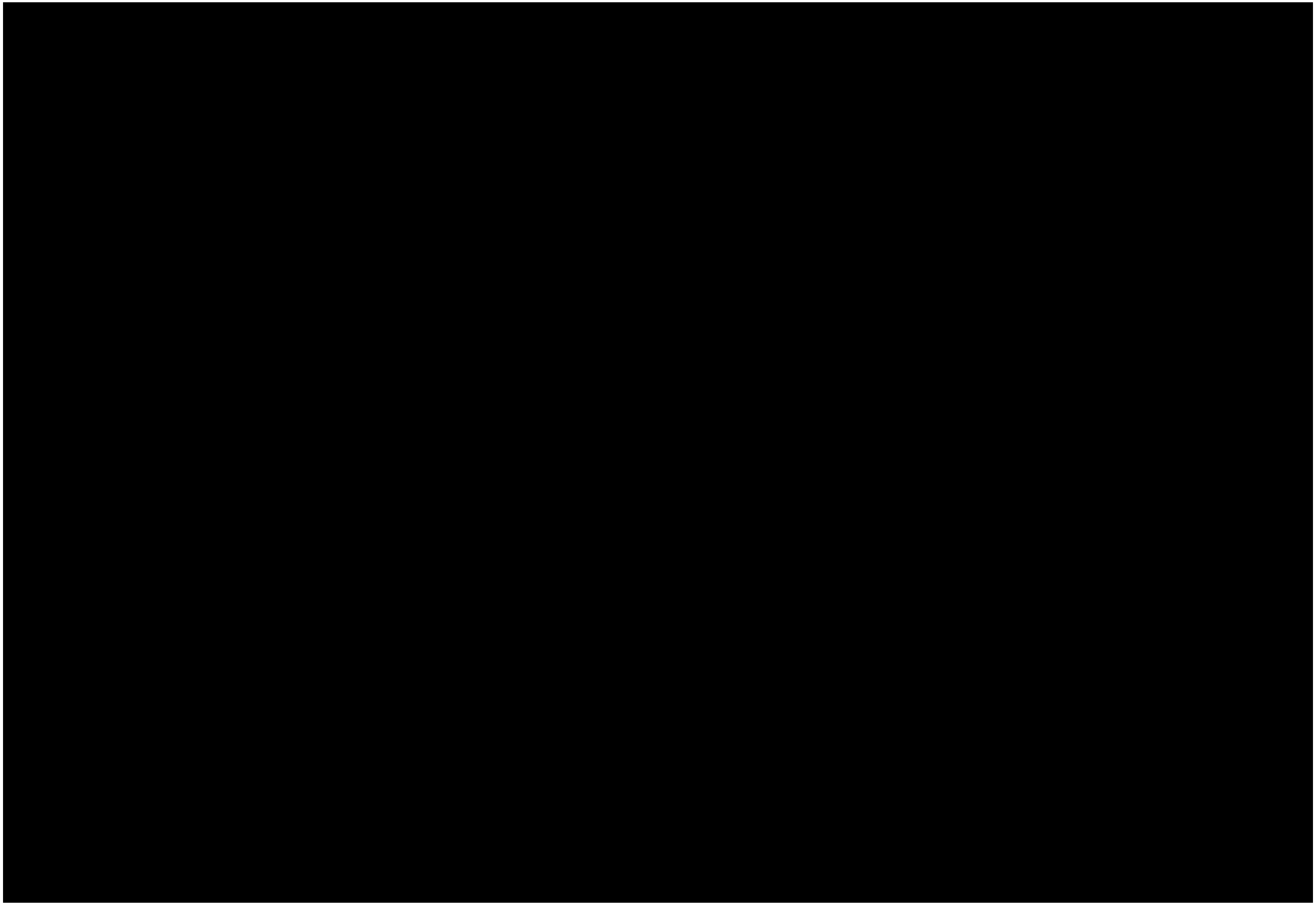
- Covers large geographical areas and can connect remote locations.
- Provides connectivity to the internet.
- Offers remote access to resources and applications.
- Can be used to support multiple users and applications simultaneously.

Disadvantages:

- Can be expensive to set up and maintain.
- Offers slower data transfer rates than LAN or MAN.
- May experience higher latency and longer propagation delays due to longer distances and multiple network hops.
- May have lower fault tolerance and security compared to LANs.

V-Local Area Network (VLAN)

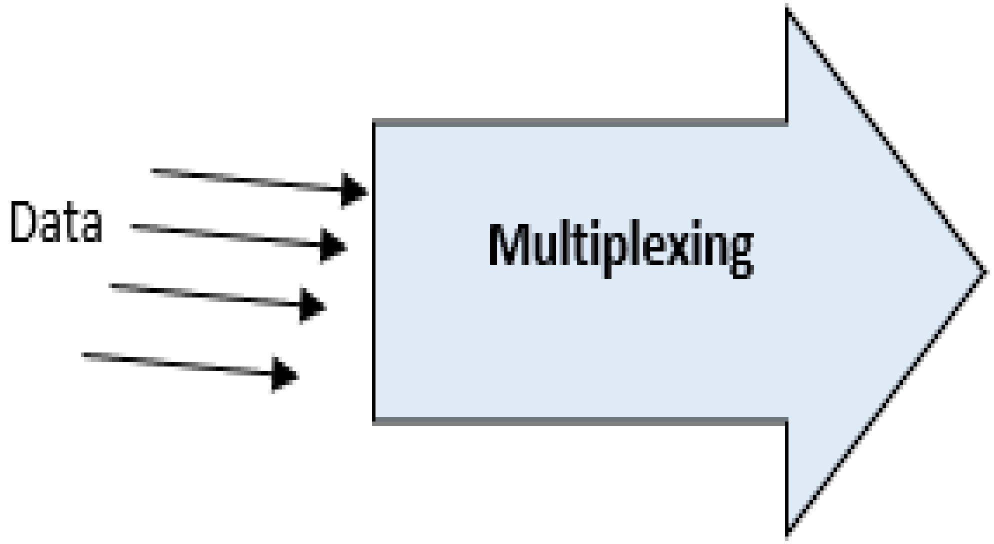
- The data link layer of the OSI network model is used to create a Virtual Local Area Network (VLAN). VLANs are created with isolated partitions in workstations.
- An individual node address moves with the virtual division, not the physical workstation, unlike a physical local area network or LAN.
- A VLAN enables several networks to function as if they were all part of the same LAN. One of the most advantageous features of a VLAN is that it reduces network latency, saving network resources, and increasing network efficiency.
- VLANs are also used to provide segmentation and help with security, network management, and scalability. VLANs can also be used to regulate traffic flows efficiently.



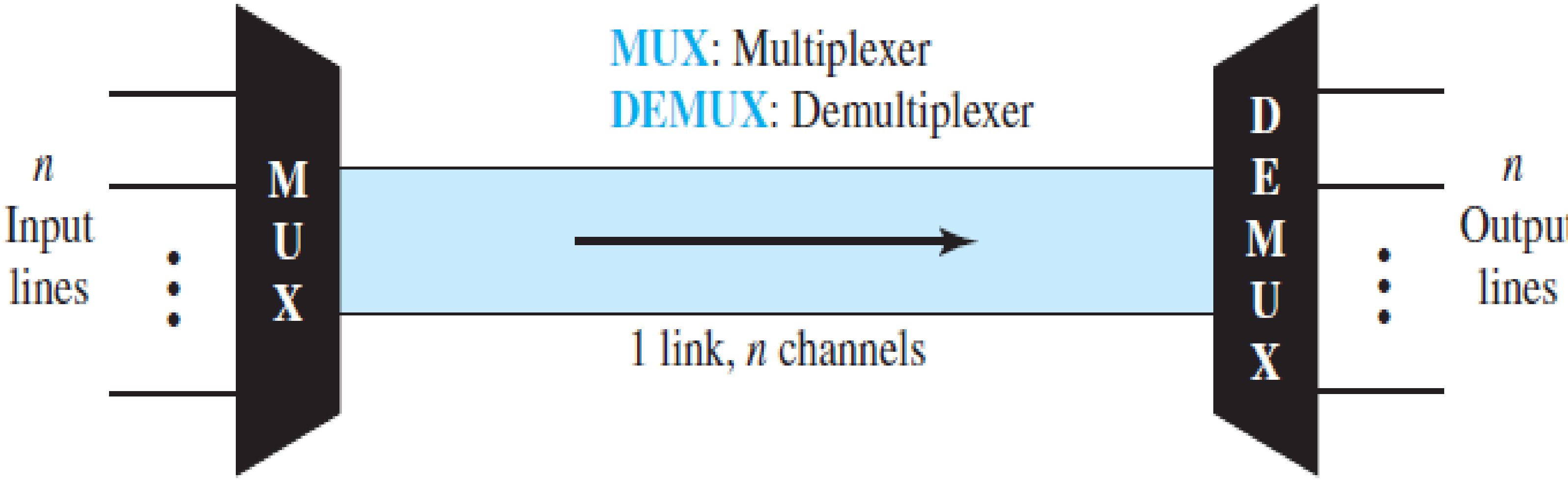
Techniques for Bandwidth utilization: Multiplexing - Frequency division, Time division and Wave division, Concepts on spread spectrum.

Multiplexing

- Multiplexing is the set of techniques that allow the simultaneous transmission of multiple signals across a single data link.



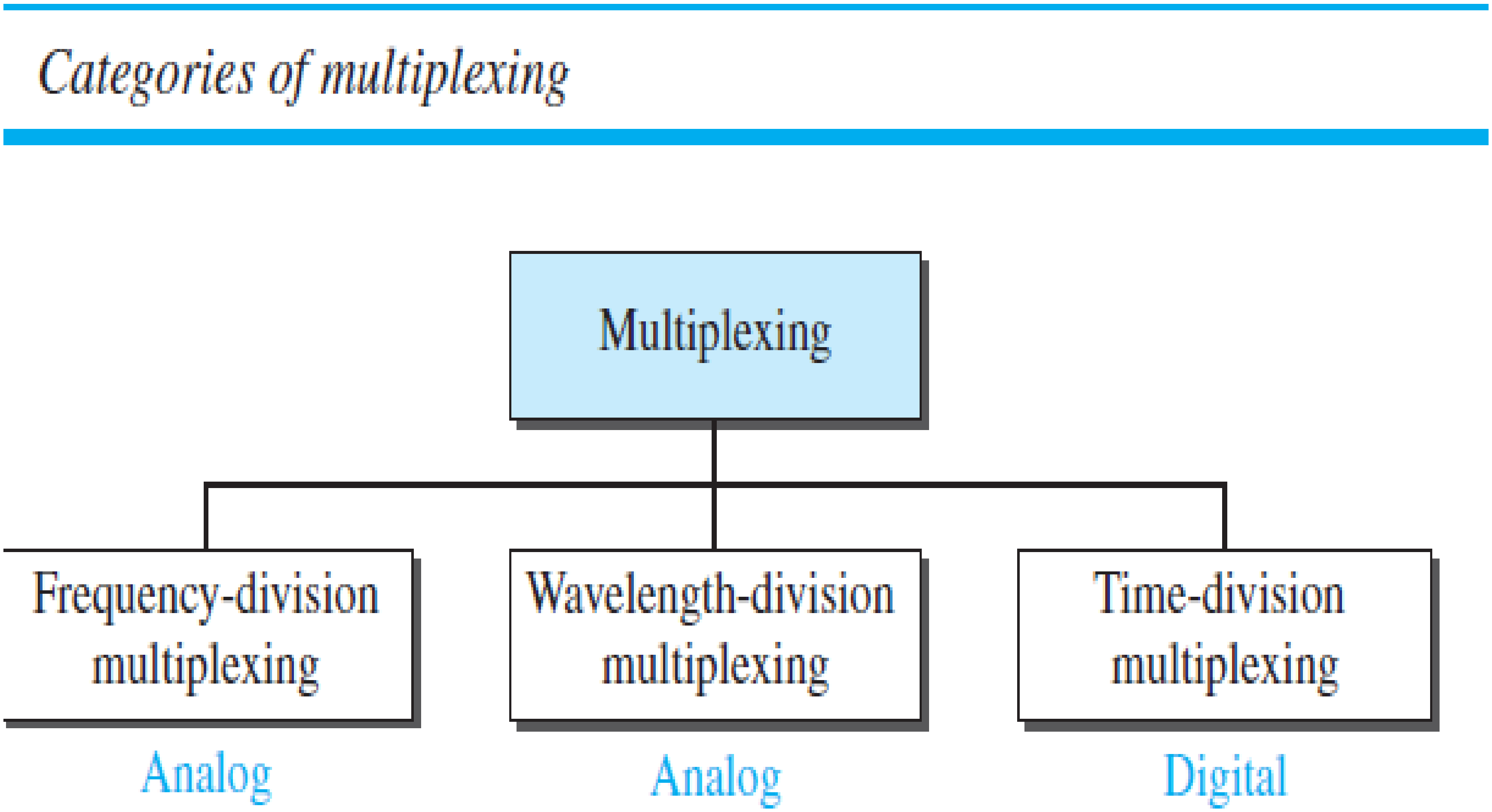
Dividing a link into channels



Note

- In a multiplexed system, *n* lines share the bandwidth of one link.
- The lines on the left direct their transmission streams to a **multiplexer (MUX),** which combines them into a single stream (many-to-one).
- At the receiving end, that stream is fed into a **demultiplexer (DEMUX),** which separates the stream back into its component transmissions (one-to-many) and directs them to their corresponding lines.
- **Link** refers to the physical path.
- **Channel** refers to the portion of a link that carries a transmission between a given pair of lines.
- One link can have many (*n*) channels.

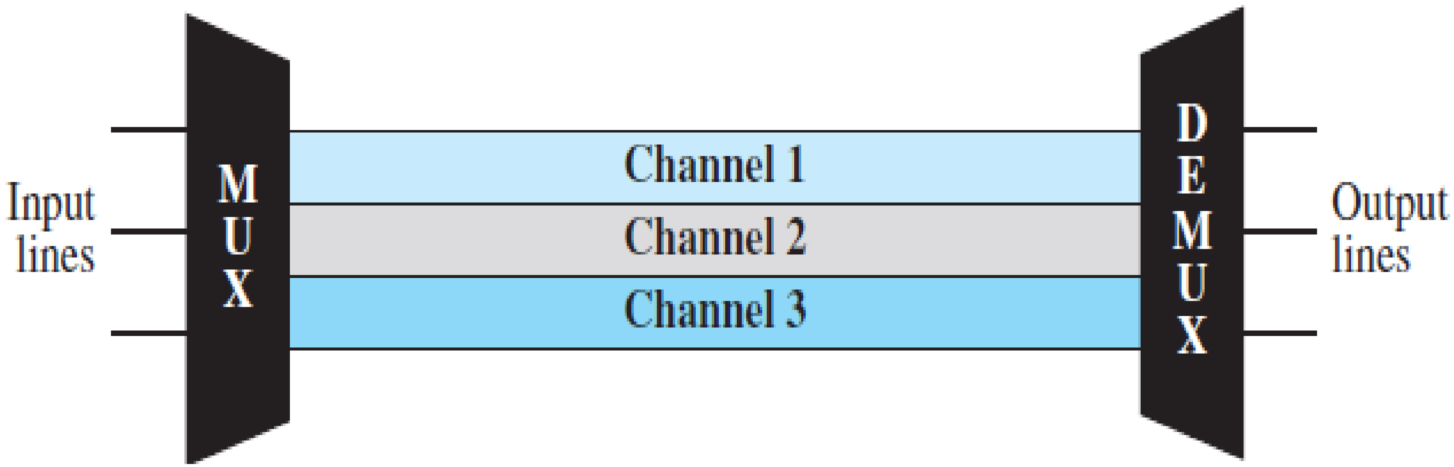
Categories of multiplexing



Frequency-Division Multiplexing

- Frequency-division multiplexing (FDM) is an analog technique that can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted.
- In FDM, signals generated by each sending device modulate different carrier frequencies. These modulated signals are then combined into a single composite signal that can be transported by the link.
- Carrier frequencies are separated by sufficient bandwidth to accommodate the modulated signal.
- Channels can be separated by strips of unused bandwidth—guard bands—to prevent signals from overlapping.
- FDM divides the available bandwidth into non-overlapping frequency bands, where each band carries a separate signal.

We consider FDM to be an analog multiplexing technique; however, this does not mean that FDM cannot be used to combine sources sending digital signals.



The transmission path is divided into three parts, each representing a channel that carries one transmission

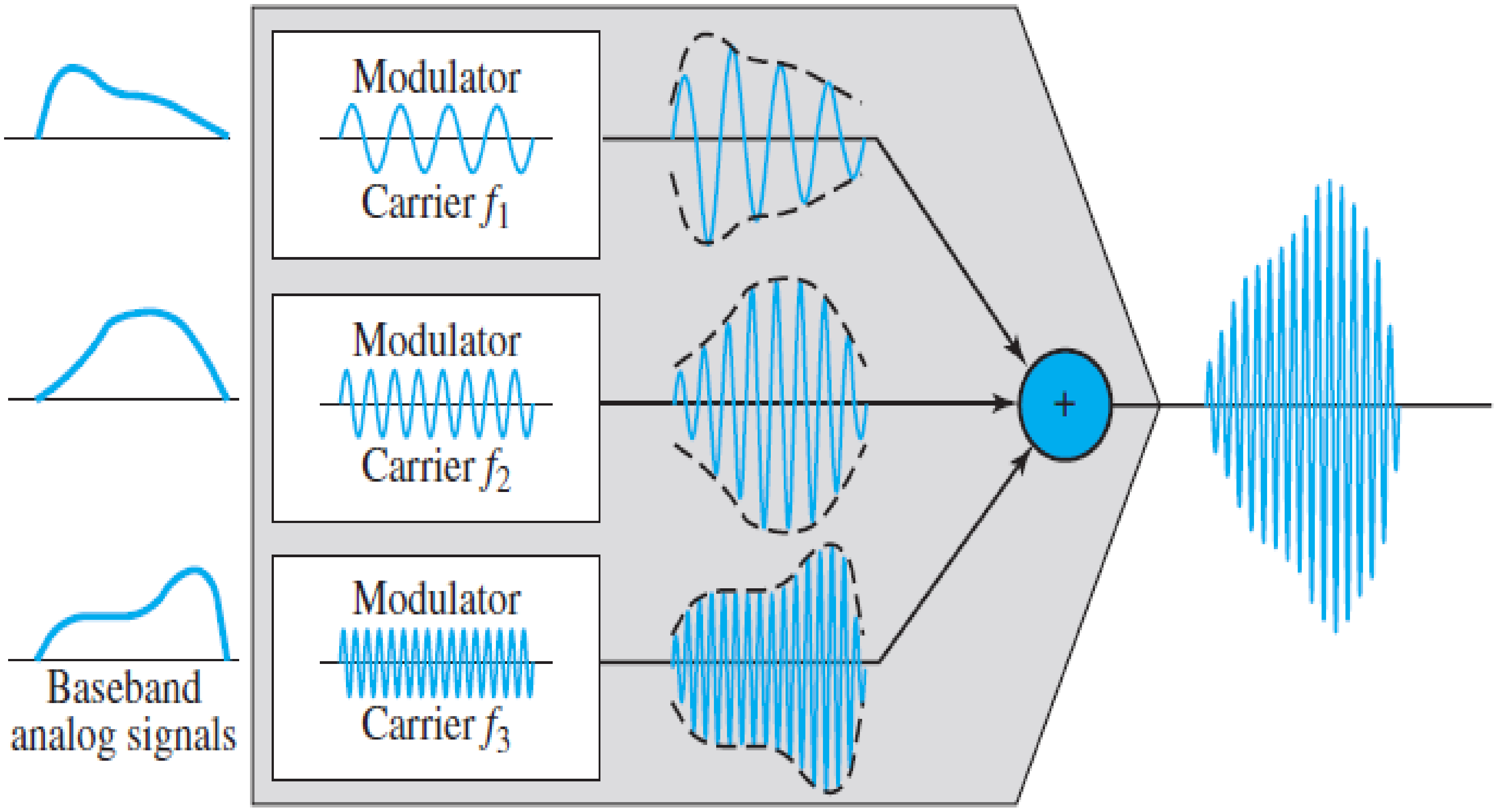
Note

FDM is an analog multiplexing technique that combines analog signals.

Multiplexing Process

- Each source generates a signal of a similar frequency range.
- Inside the multiplexer, these similar signals modulate different carrier frequencies (f1, f2, and f3).
- The resulting modulated signals are then combined into a single composite signal that is sent out over a media link that has enough bandwidth to accommodate it.

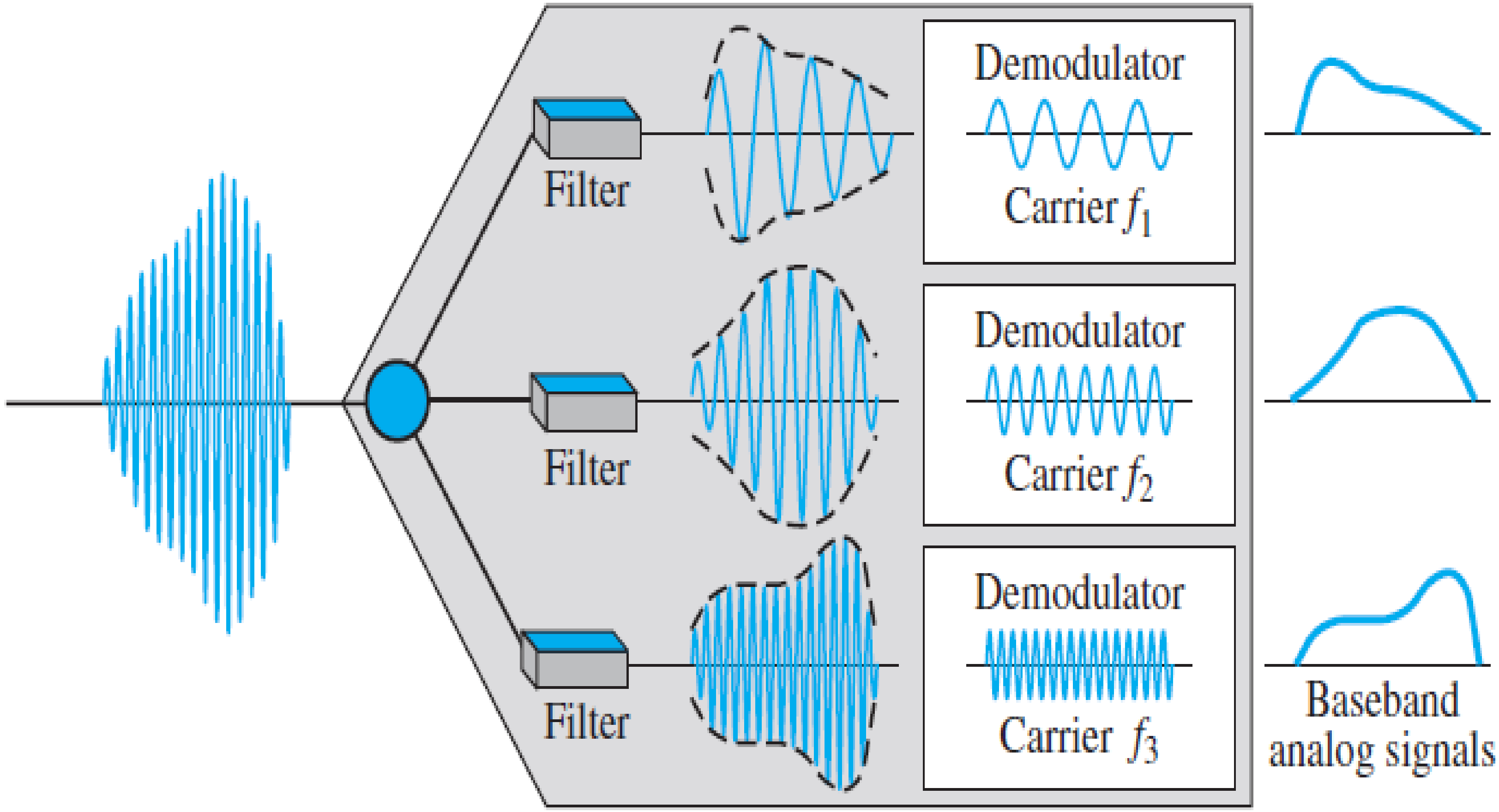
FDM multiplexing example



Demultiplexing Process

- The demultiplexer uses a series of filters to decompose the multiplexed signal into its constituent component signals.
- The individual signals are then passed to a demodulator that separates them from their carriers and passes them to the output lines.

FDM demultiplexing example

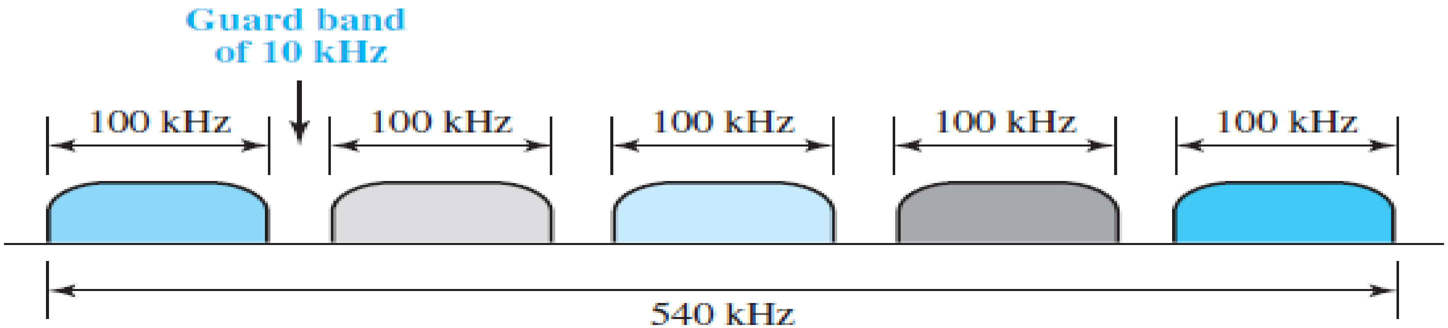


EXAMPLE

- 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 × 100 + 4 × 10 = **540 kHz**



Applications of FDM

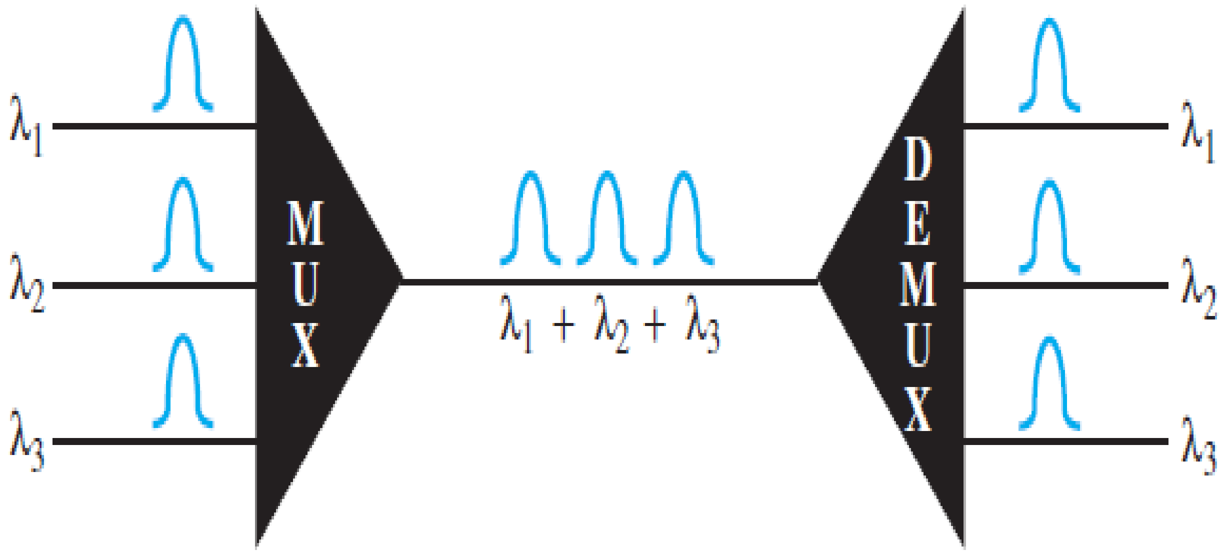
1. **Radio and Television Broadcasting**:
   Used to allocate different frequency bands to different radio or TV channels.
2. **Cable TV**:
   Multiple channels are transmitted simultaneously over the same coaxial cable using different frequency bands.
3. **Telephone Systems**:
   Traditional analog telephone systems used FDM to combine multiple voice calls over a single communication link.
4. **Satellite Communication**:
   Multiple data streams are sent using different frequency bands to maximize satellite channel usage.
5. **Wireless Communication**:
   Used in mobile communication systems like GSM to allow simultaneous transmission of multiple calls over the same spectrum.

Wavelength-Division Multiplexing

- Wavelength-division multiplexing (WDM) is designed to use the high-data-rate capability of fiber-optic cable.
- The optical fiber data rate is higher than the data rate of metallic transmission cable, but using a fiber-optic cable for a single line wastes the available bandwidth.
- WDM is conceptually the same as FDM, except that the multiplexing and demultiplexing involve optical signals transmitted through fiber-optic channels.
- The idea is the same: We are combining different signals of different frequencies.
- The difference is that the frequencies are very high.
- At the receiver, the signals are separated by the demultiplexer.
- WDM is used in fiber-optic communication and works by assigning different wavelengths (colors of light) to different signals.

SASTRA
ENGINEERING · MANAGEMENT · LAW · SCIENCES · HUMANITIES · EDUCATION
DEEMED TO BE UNIVERSITY
(U/S 3 OF THE UGC ACT, 1956)
THINK MERIT | THINK TRANSPARENCY | THINK SASTRA

Conceptual view of a WDM multiplexer and demultiplexer.



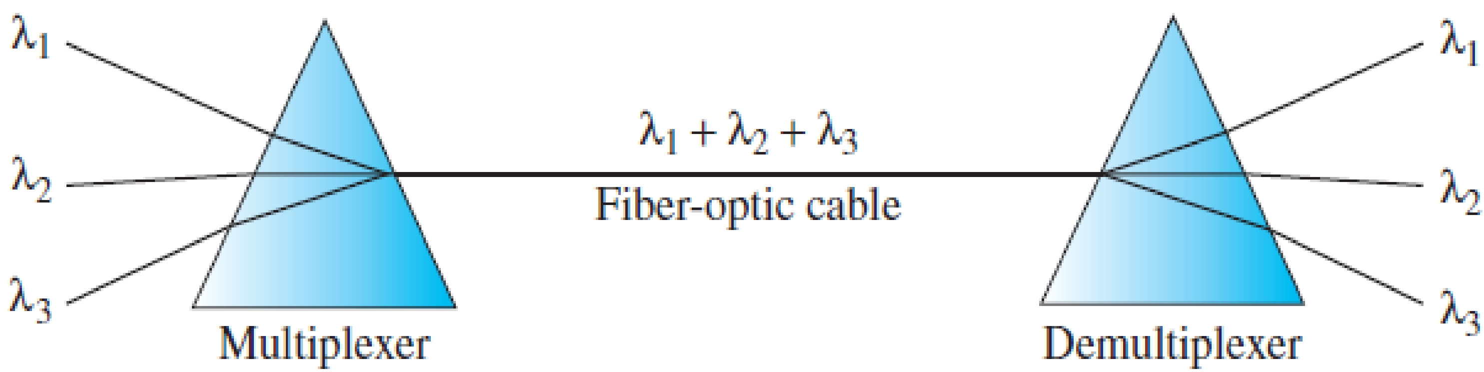
WDM is an analog multiplexing technique to combine optical signals.

WDM

- Multiple light sources are combined into one single light at the multiplexer and the reverse at the demultiplexer.
- The combining and splitting of light sources are easily handled by a prism.
- Recall from basic physics that a prism bends a beam of light based on the angle of incidence and the frequency.
- Using this technique, a multiplexer can be made to combine several input beams of light, each containing a narrow band of frequencies, into one output beam of a wider band of frequencies.
- A demultiplexer can also be made to reverse the process.

Prisms in wavelength-division multiplexing and demultiplexing

- One application of WDM is the SONET network, in which multiple optical fiber lines are multiplexed and demultiplexed.
- A new method, called dense WDM (DWDM), can multiplex a very large number of channels by spacing channels very close to one another. It achieves even greater efficiency.



Prism is a transparent object that bends light as it passes through it, a process called refraction.

Applications of WDM

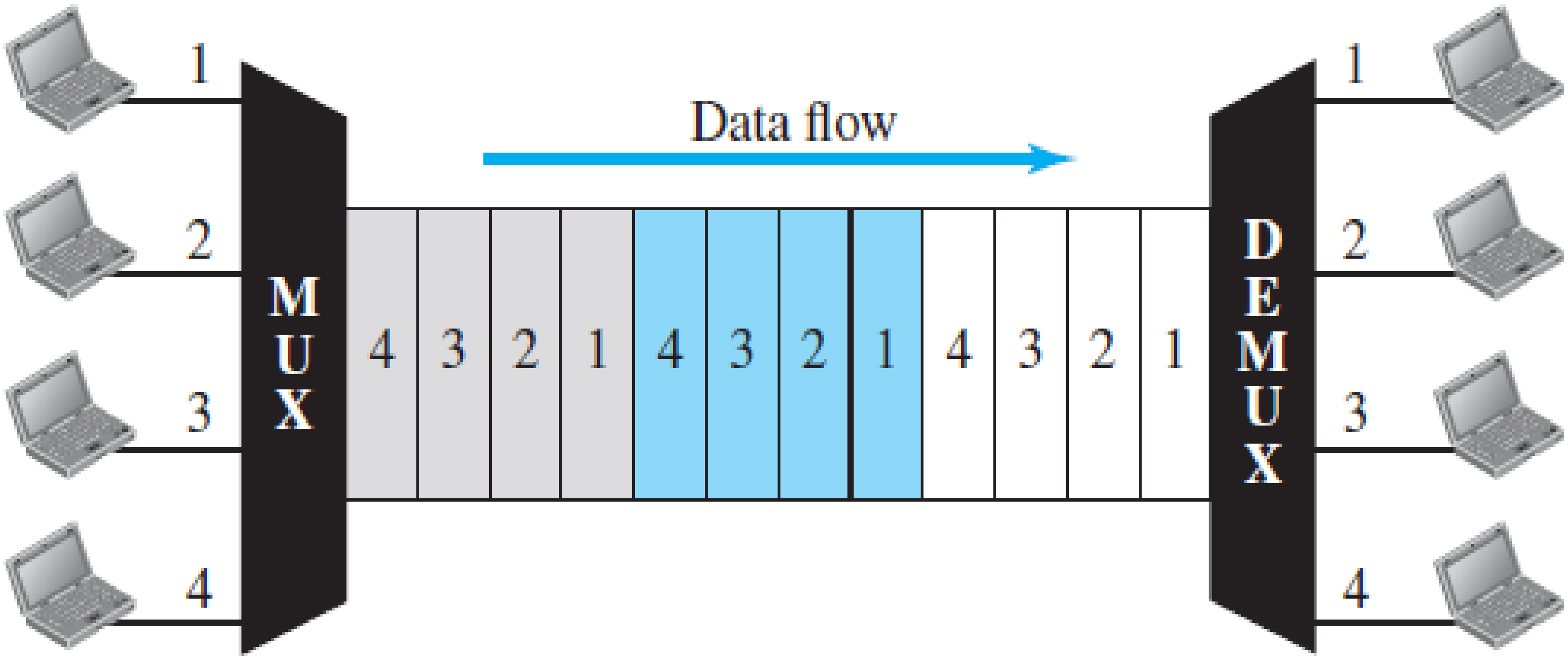
1. **High-Speed Internet**:
   Used in fiber-to-the-home (FTTH) systems for delivering internet, TV, and phone services.
2. **Long-Distance Optical Communication**:
   Used in undersea cables and metro networks to transmit data over thousands of kilometers.
3. **Dense Wavelength Division Multiplexing (DWDM)**:
   Applied in core and backbone optical networks for high-capacity transmission.
4. **Data Centers**:
   Interconnects data center components to handle large data volumes.
5. **Cloud Computing**:
   Facilitates high-speed connections for distributed cloud computing systems.

Time-Division Multiplexing

- Time-division multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a link.
- Instead of sharing a portion of the bandwidth as in FDM, time is shared.
- Each connection occupies a portion of time in the link.
- Note that the same link is used as in FDM;
- However, the link is sectioned by time rather than by frequency.
- In the figure, portions of signals 1, 2, 3, and 4 occupy the link sequentially.

Conceptual view of TDM

TDM



Note

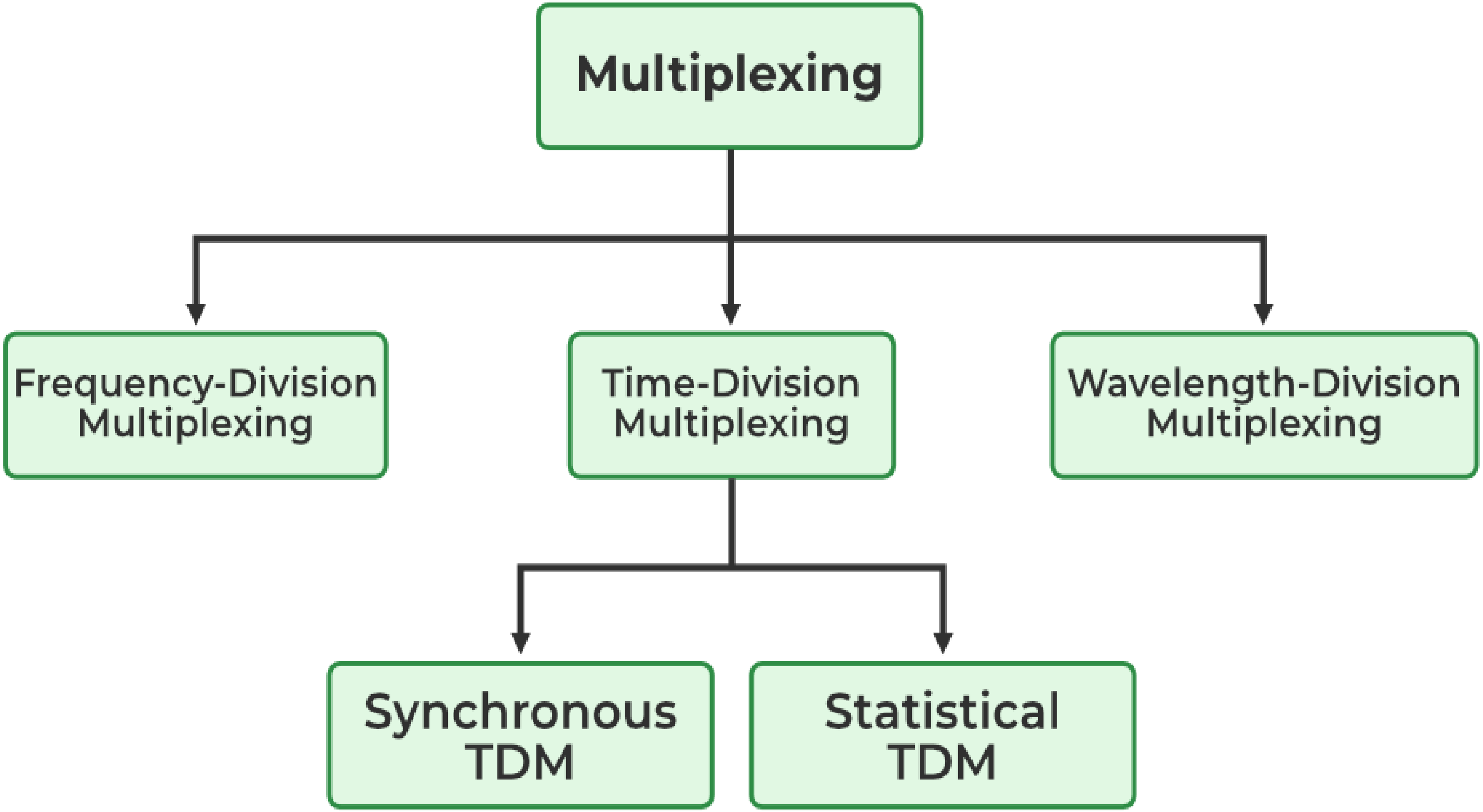
- This means that all the data in a message from source 1 always go to one specific destination, be it 1, 2, 3, or 4.
- The delivery is fixed and unvarying, unlike switching.
- Digital data from different sources are combined into one timeshared link.
- However, this does not mean that the sources cannot produce analog data; analog data can be sampled, changed to digital data, and then multiplexed by using TDM.

Note

TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.

Applications of TDM

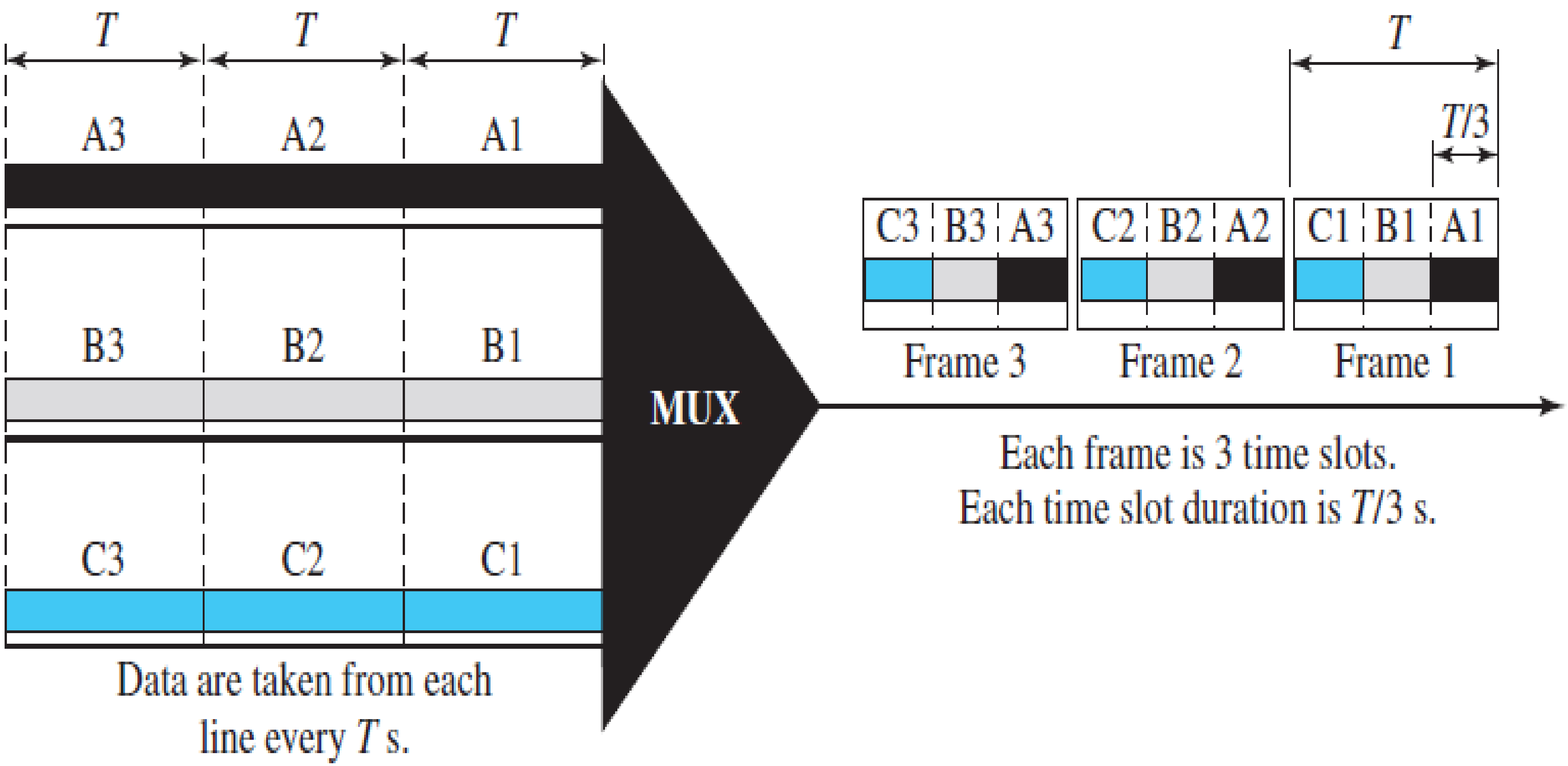
1. **Digital Telephony**:
   Used in T1 and E1 lines to transmit multiple voice calls digitally over the same link.
2. **Cellular Networks**:
   GSM technology uses TDM in combination with FDM for dividing communication channels.
3. **Data Communication**:
   Applied in synchronous data transmission systems such as SONET/SDH.
4. **Satellite Communication**:
   Multiple ground stations use TDM to share the satellite's communication channel.
5. **ISDN (Integrated Services Digital Network)**:
   Transmits multiple types of data (voice, video, and text) over the same digital link.


Multiplexing
Frequency-Division Multiplexing
Time-Division Multiplexing
Wavelength-Division Multiplexing
Synchronous TDM
Statistical TDM

Synchronous TDM

- In synchronous TDM, each input connection has an allotment in the output even if it is not sending data.
- In synchronous TDM, the data flow of each input connection is divided into units, where each input occupies one input time slot.
- A unit can be 1 bit, one character, or one block of data.
- Each input unit becomes one output unit and occupies one output time slot.
- However, the duration of an output time slot is n times shorter than the duration of an input time slot.
- If an input time slot is **T** s, the output time slot is **T/n** s, where n is the number of connections.

Synchronous TDM[n=3]



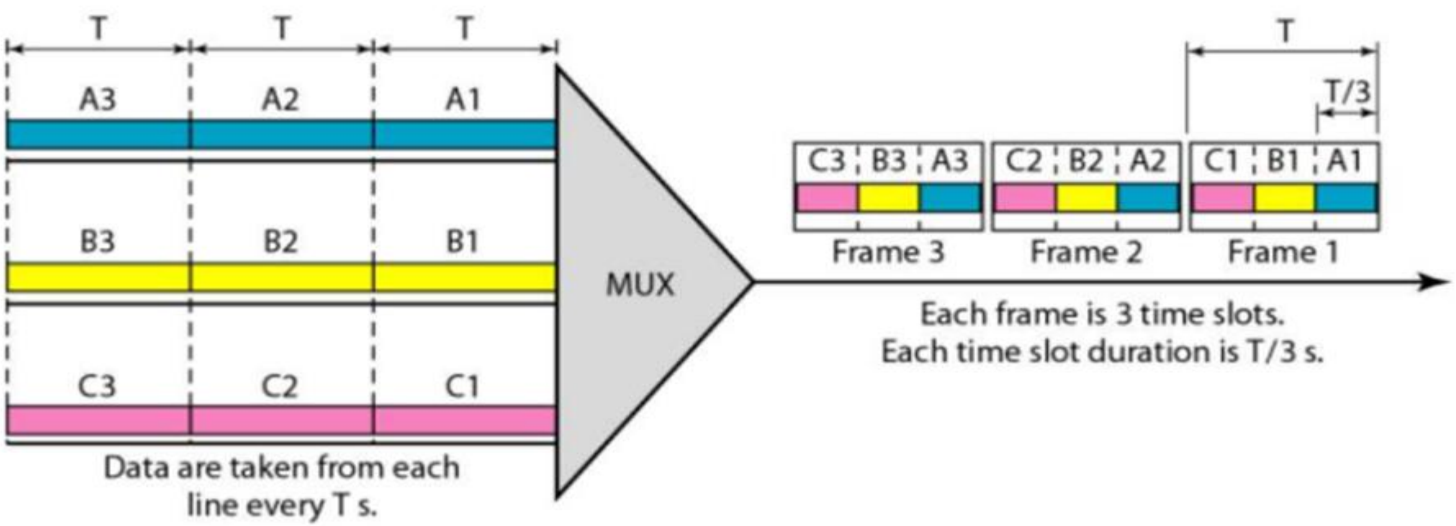
Time slots are grouped into frames. A frame consists of one complete cycle of time slots, with one slot dedicated to each sending device. In a system with n input lines, each frame has n slots, with each slot allocated to carrying data from a specific input line.

In synchronous TDM, the data rate of the link is *n* times faster, and the unit duration is *n* times shorter.

Problem

- In Figure, the data rate for each input connection is 1 kbps. If 1 bit at a time is multiplexed (a unit is 1 bit), what is the duration of

1. each input slot,
2. each output slot, and
3. each frame?



Solution

1. The data rate of each input connection is 1 kbps. This means that the bit duration is 1/1000 s or 1 ms. The duration of the input time slot is **1 ms** (**same as bit duration**).

2. The duration of each output time slot is one-third of the input time slot. This means that the duration of the output time slot is **1/3 ms.**

3. Each frame carries three output time slots. So the duration of a frame is 3 × 1/3 ms, or **1 ms.**

The duration of a frame is the same as the duration of an input unit.

Problem

- Figure shows synchronous TDM with a data stream for each input and one data stream for the output. The unit of data is 1 bit.

Find

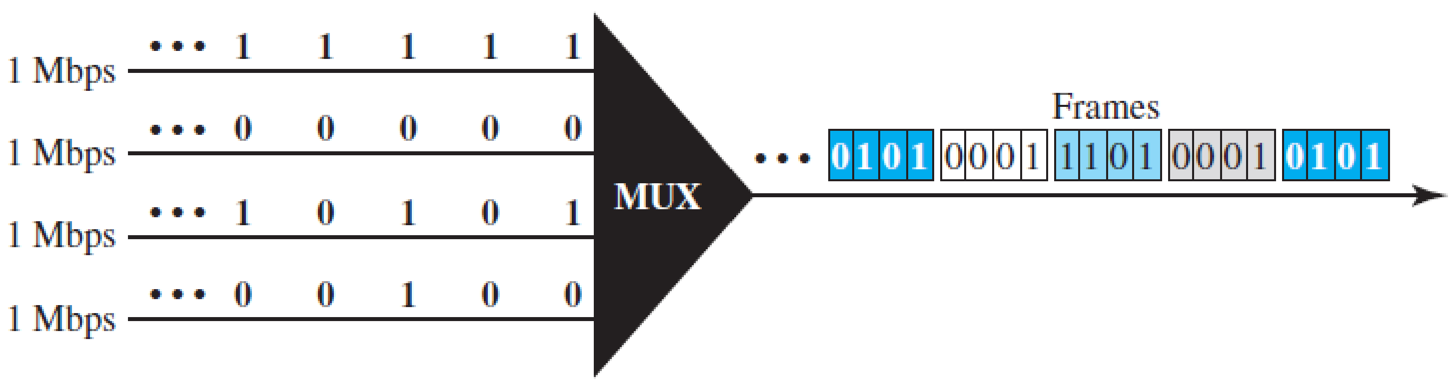
(1) the input bit duration,

(2) the output bit duration,

(3) the output bit rate, and

(4) the output frame rate.

Figure 6.14 *Example 6.6*



Solution

1. The input bit duration is the inverse of the bit rate: 1/1 Mbps = **1 μs.**

2. The output bit duration is one-fourth of the input bit duration, or **1/4 μs.**

3. The output bit rate is the inverse of the output bit duration, or 1/4 μs, or 4 Mbps. This can also be deduced from the fact that the output rate is 4 times as fast as any input rate; so the

output rate = 4 × 1 Mbps = 4 Mbps.

4. **The frame rate is always the same as any input rate**. So the frame rate is 1,000,000 frames per second. Because we are sending 4 bits in each frame.

Problem

- Four 1-kbps connections are multiplexed together. A unit is 1 bit. Find

(1) the duration of 1 bit before multiplexing,

(2) the transmission rate of the link,

(3) the duration of a time slot, and

(4) the duration of a frame.

Solution

1. The duration of 1 bit before multiplexing is 1/1 kbps, or **0.001 s (1 ms).**

2. The rate of the link is 4 times the rate of a connection, or **4 kbps.**

3. The duration of each time slot is one-fourth of the duration of each bit before multiplexing, or **1/4 ms or 250 μs**. Note that we can also calculate this from the data rate of the link, 4 kbps. The bit duration is the inverse of the data rate, or 1/4 kbps or 250 μs.

4. The duration of a frame is always the same as the duration of a unit before multiplexing, or 1 ms.

Or

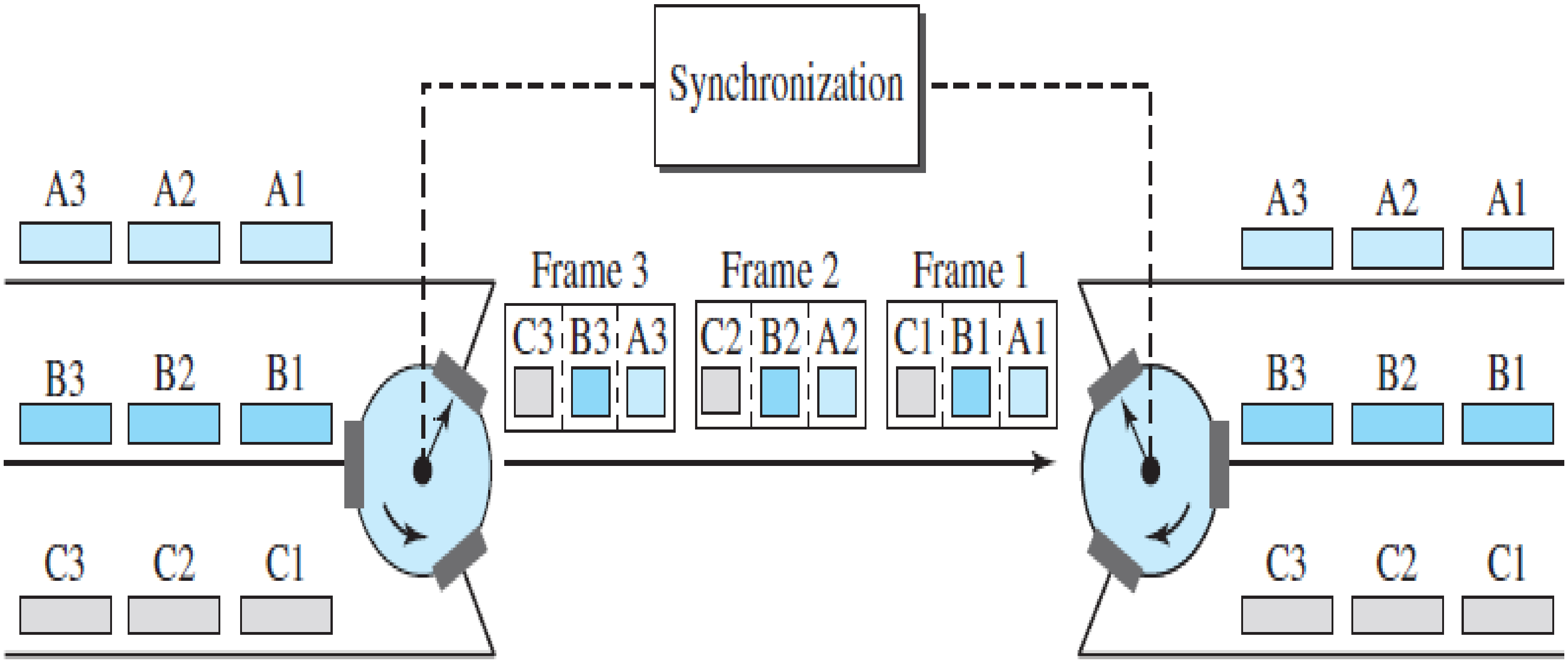
Each frame in this case has four time slots.

So the duration of a frame is 4 times 250 μs, or 1 ms.

Interleaving

- TDM can be visualized as two fast-rotating switches, one on the multiplexing side and the other on the demultiplexing side.
- The switches are synchronized and rotate at the same speed, but in opposite directions.
- On the multiplexing side, as the switch opens in front of a connection, that connection has the opportunity to send a unit onto the path. This process is called interleaving.
- On the demultiplexing side, as the switch opens in front of a connection, that connection has the opportunity to receive a unit from the path.

Figure 6.15 *Interleaving*



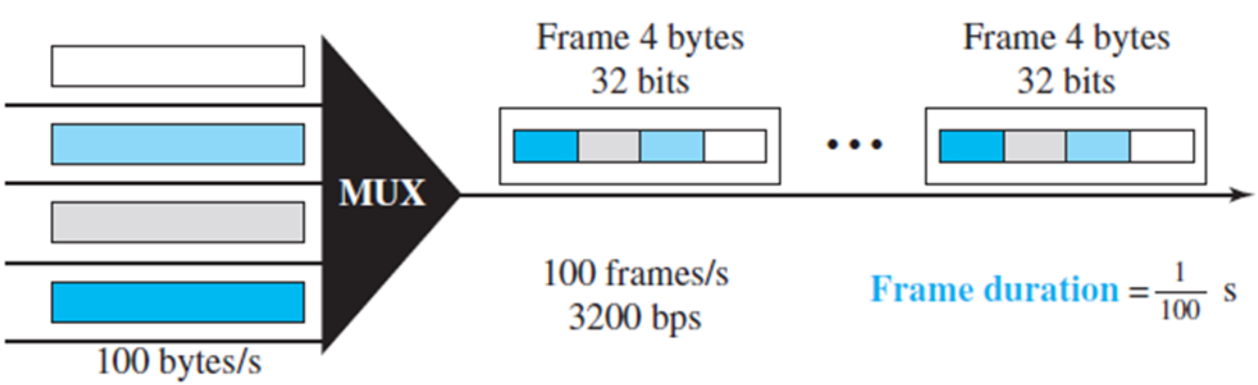
Problem

- Four channels are multiplexed using TDM. If each channel sends 100 bytes/s and we multiplex 1 byte per channel, show the frame traveling on the link, the size of the frame, the duration of a frame, the frame rate, and the bit rate for the link.

Solution

- Each frame carries 1 byte from each channel; the size of each frame, therefore, is **4 bytes, or 32 bits.**
- Because each channel is sending 100 bytes/s and a frame carries 1 byte from each channel, the frame rate must be 100 frames per second. The duration of a frame is therefore **1/100 s.**
- The link is carrying 100 frames per second, and since each frame contains 32 bits, the bit rate is 100 × 32, or **3200 bps.** This is actually 4 times the bit rate of each channel, which is 100 × 8 = 800 bps.

Figure 6.16 *Example 6.8*



Problem

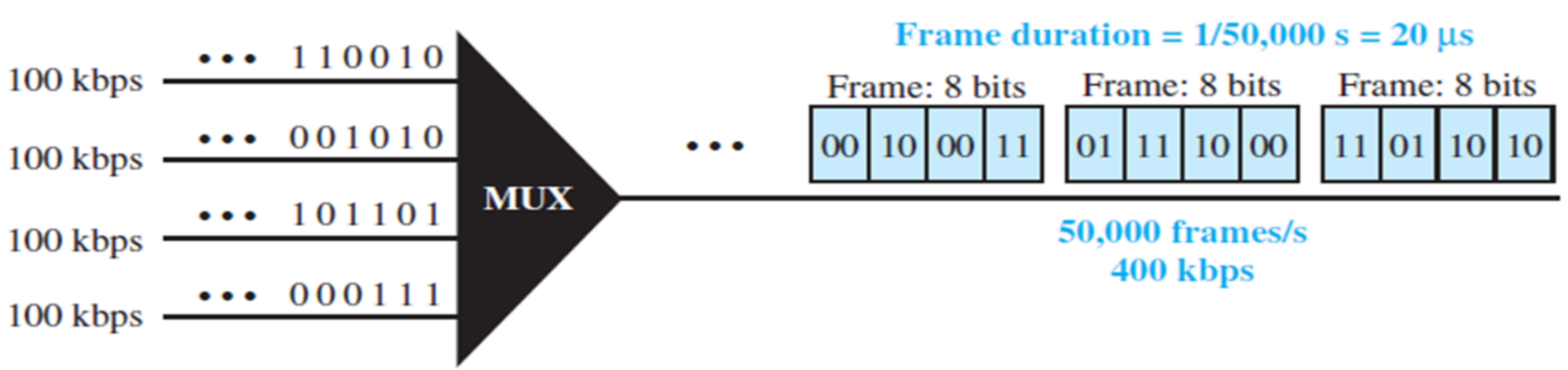
A multiplexer combines four 100-kbps channels using a time slot of 2 bits. Show the output with four arbitrary inputs.

- What is the frame rate?
- What is the frame duration?
- What is the bit rate?
- What is the bit duration?

Solution

- The link carries 50,000 frames per second since each frame contains 2 bits per channel.
- The frame duration is therefore 1/50,000 s or 20 µs.
- The frame rate is 50,000 frames per second, and each frame carries 8 bits;
- The bit rate is 50,000 ×8 = 400,000 bits or 400 kbps.
- The bit duration is 1/400,000 s, or 2.5 µs. Note that the frame duration is 8 times the bit duration because each frame is carrying 8 bits.

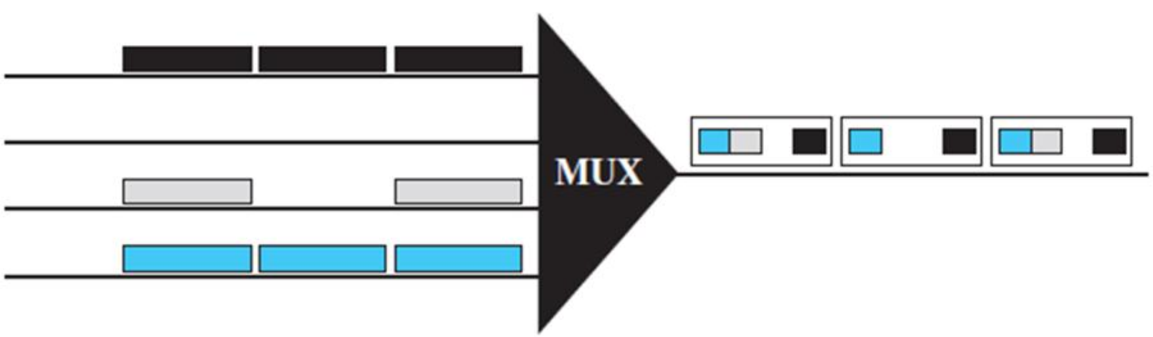
Figure 6.17 *Example 6.9*



Empty Slots

- Synchronous TDM is not as efficient as it could be. If a source does not have data to send, the corresponding slot in the output frame is empty.
- Figure shows a case in which one of the input lines has no data to send and one slot in another input line has discontinuous data.
- The first output frame has three slots filled, the second frame has two slots filled, and the third frame has three slots filled. No frame is full.

Figure 6.18 *Empty slots*



Data Rate Management

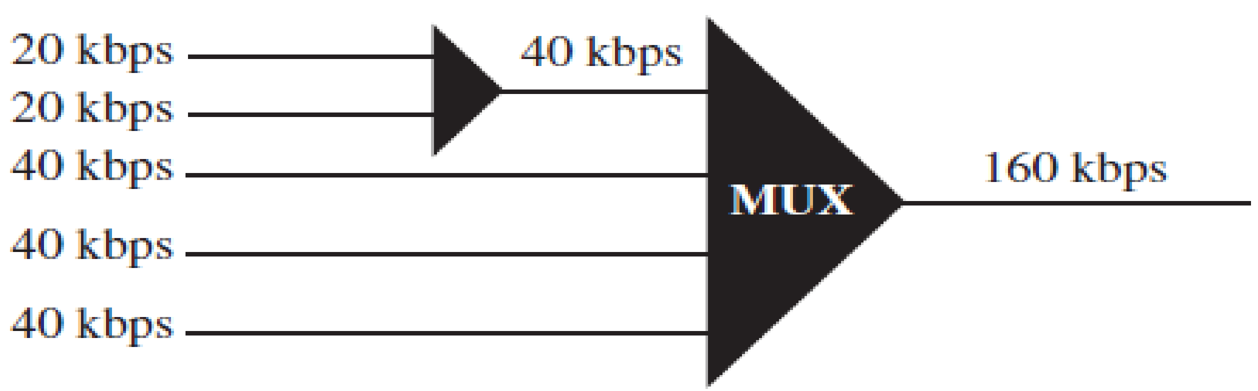
- One problem with TDM is how to handle a disparity in the input data rates.
- If data rates are not the same, three strategies, or a combination of them, can be used.

1. Multilevel multiplexing,
2. Multiple-slot allocation, and
3. Pulse stuffing.

1. Multilevel Multiplexing

- Multilevel multiplexing is a technique used *when the data rate of an input line is a multiple of others.*
- For example, in Figure, we have two inputs of 20 kbps and three inputs of 40 kbps.
- The first two input lines can be multiplexed together to provide a data rate equal to the last three. A second level of multiplexing can create an output of 160 kbps.

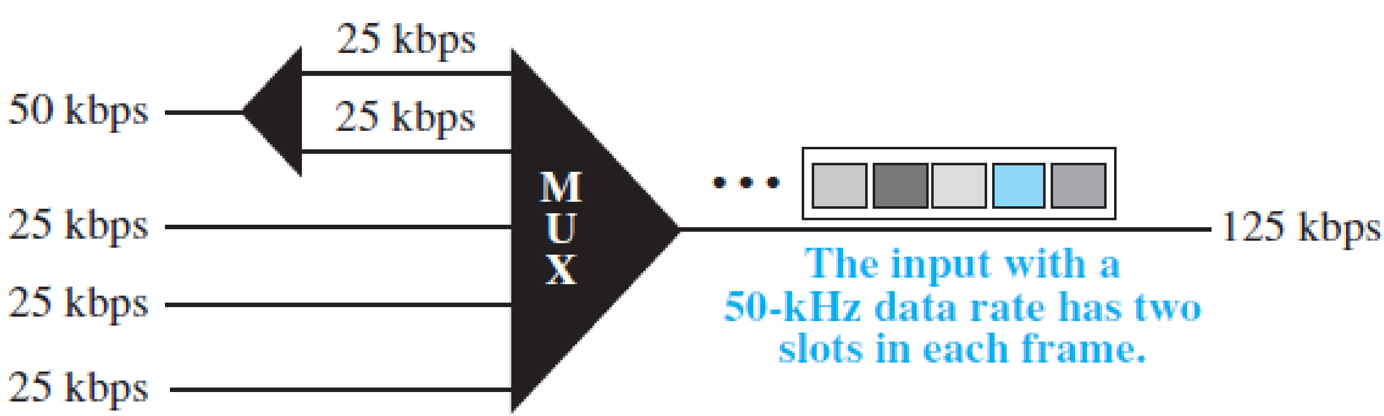
Multilevel multiplexing



2. Multiple-Slot Allocation

- Sometimes it is more efficient to allot more than one slot in a frame to a single input line.
- For example, we might have an input line that has a data rate that is a multiple of another input.
- In Figure , the input line with a 50-kbps data rate can be given two slots in the output. We insert a demultiplexer in the line to make two inputs out of one.

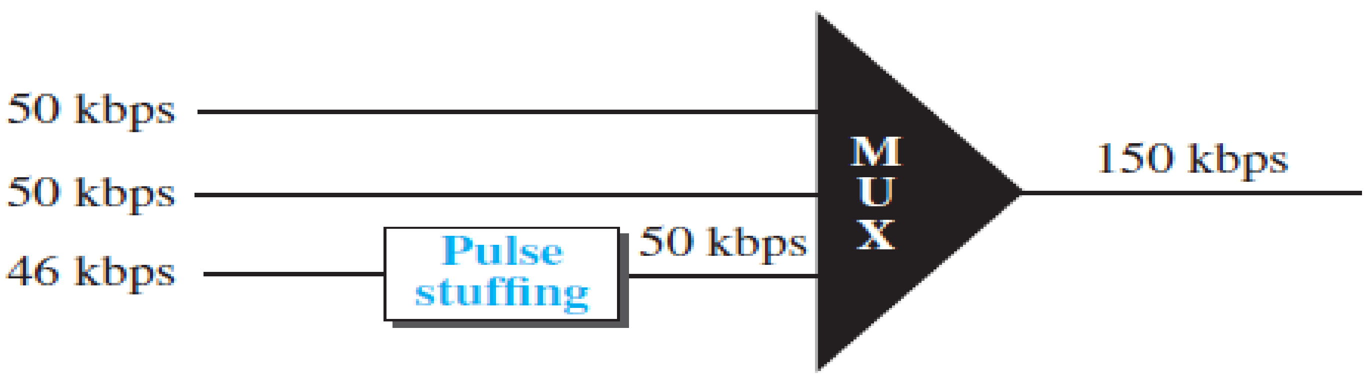
Multiple-slot multiplexing



3. Pulse Stuffing

- Sometimes the bit rates of sources are not multiple integers of each other. Therefore, neither of the above two techniques can be applied.
- One solution is to make the highest input data rate the dominant data rate and then add dummy bits to the input lines with lower rates. This will increase their rates. This technique is called pulse stuffing, bit padding, or bit stuffing.
- The input with a data rate of 46 is pulse-stuffed to increase the rate to 50 kbps. Now multiplexing can take place.

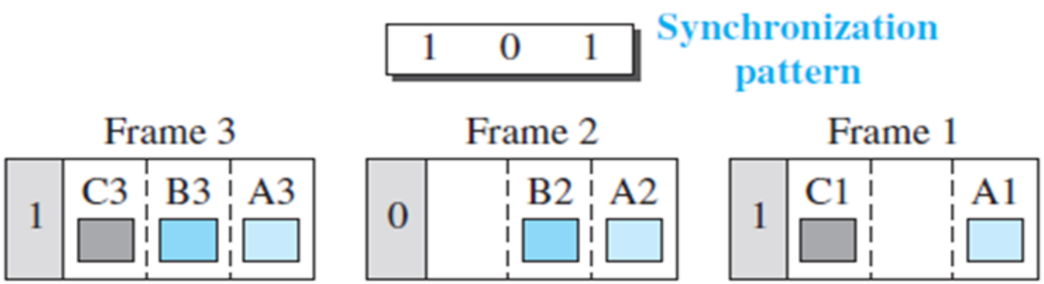
Pulse stuffing



Frame Synchronizing

- If the multiplexer and the demultiplexer are not synchronized, a bit belonging to one channel may be received by the wrong channel.
- For this reason, one or more synchronization bits are usually added to the beginning of each frame.
- These bits, called framing bits, follow a pattern, frame to frame, that allows the demultiplexer to synchronize with the incoming stream so that it can separate the time slots accurately.
- In most cases, this synchronization information consists of 1 bit per frame, alternating between 0 and 1, as shown in Figure.

Framing bits



Problem

- We have four sources, each creating 250 characters per second. If the interleaved unit is a character and 1 synchronizing bit is added to each frame, find

(1) the data rate of each source,

(2) the duration of each character in each source,

(3) the frame rate,

(4) the duration of each frame,

(5) the number of bits in each frame, and

(6) the data rate of the link.

Solution

1. The data rate of each source is 250 × 8 = 2000 bps = 2 kbps.

2. Each source sends 250 characters per second; therefore, the duration of a character is 1/250 s, or 4 ms.

3. Each frame has one character from each source, which means the link needs to send 250 frames per second to keep the transmission rate of each source.

4. The duration of each frame is 1/250 s, or 4 ms. Note that the duration of each frame is the same as the duration of each character coming from each source.

5. Each frame carries 4 characters and 1 extra synchronizing bit. This means that each frame is 4 × 8 + 1 = 33 bits.

6. The link sends 250 frames per second, and each frame contains 33 bits. This means that the data rate of the link is 250 × 33, or 8250 bps.

Problem

- Two channels, one with a bit rate of 100 kbps and another with a bit rate of 200 kbps, are to be multiplexed.

1. How this can be achieved?
2. What is the frame rate?
3. What is the frame duration?
4. What is the bit rate of the link?

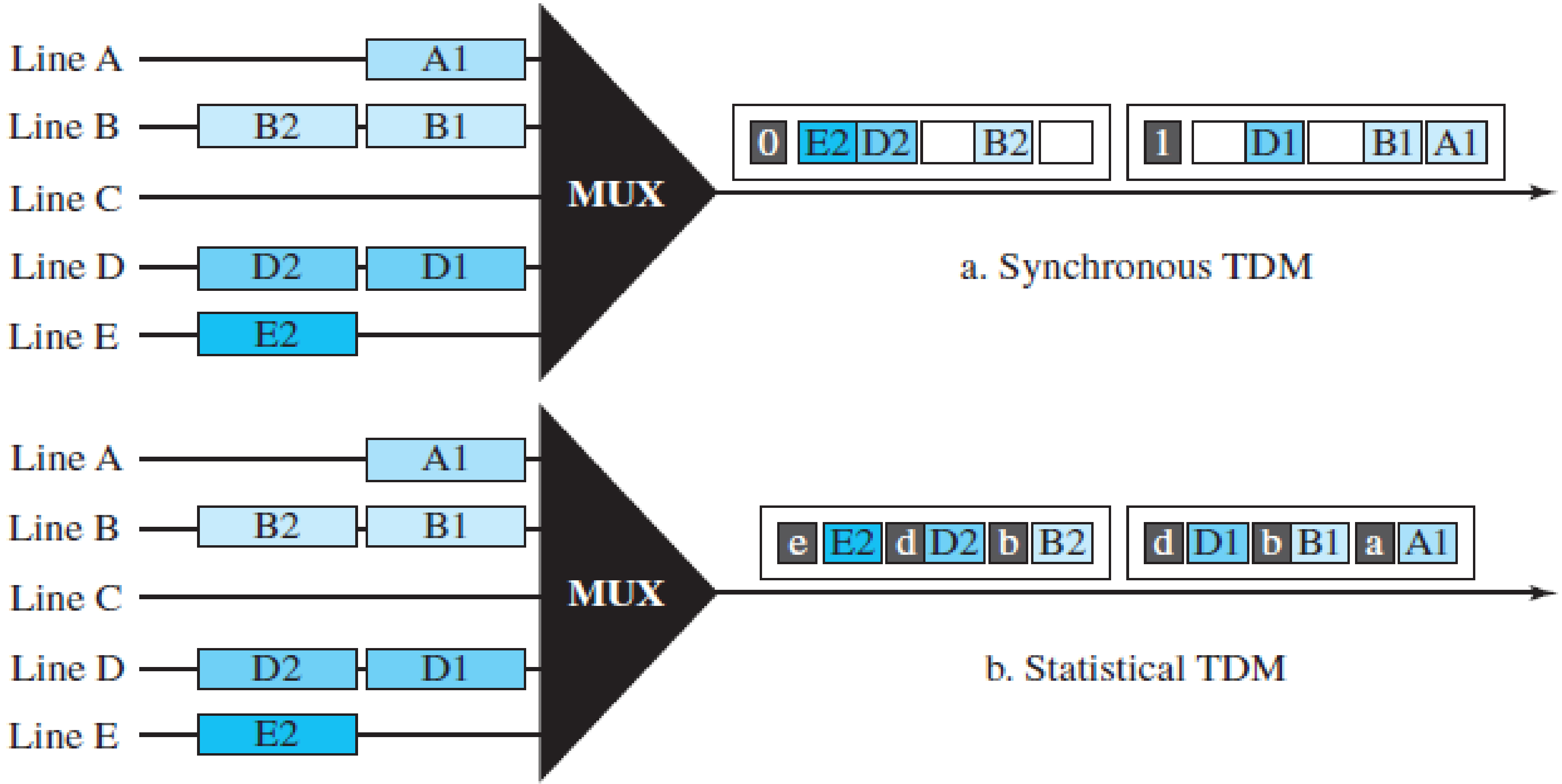
Solution

- We can allocate one slot to the first channel and two slots to the second channel.
- Each frame carries 3 bits. The frame rate is 100,000 frames per second because it carries 1 bit from the first channel.
- The frame duration is 1/100,000 s, or 10 ms.
- The bit rate is 100,000 frames/s × 3 bits per frame, or 300 kbps.

Statistical Time-Division Multiplexing

- In synchronous TDM, each input has a reserved slot in the output frame. This can be inefficient if some input lines have no data to send.
- In statistical time-division multiplexing, slots are dynamically allocated to improve bandwidth efficiency.
- Only when an input line has a slot’s worth of data to send is it given a slot in the output frame.
- In statistical multiplexing, the number of slots in each frame is less than the number of input lines.
- The multiplexer checks each input line in round robin fashion; it allocates a slot for an input line if the line has data to send; otherwise, it skips the line and checks the next line.

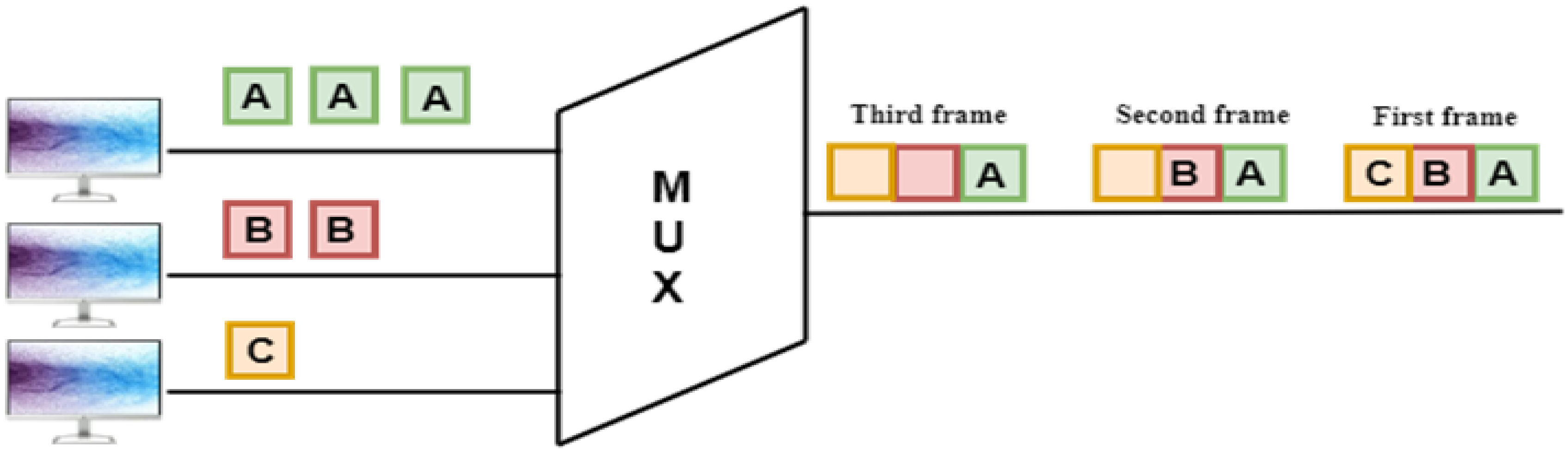
TDM slot comparison

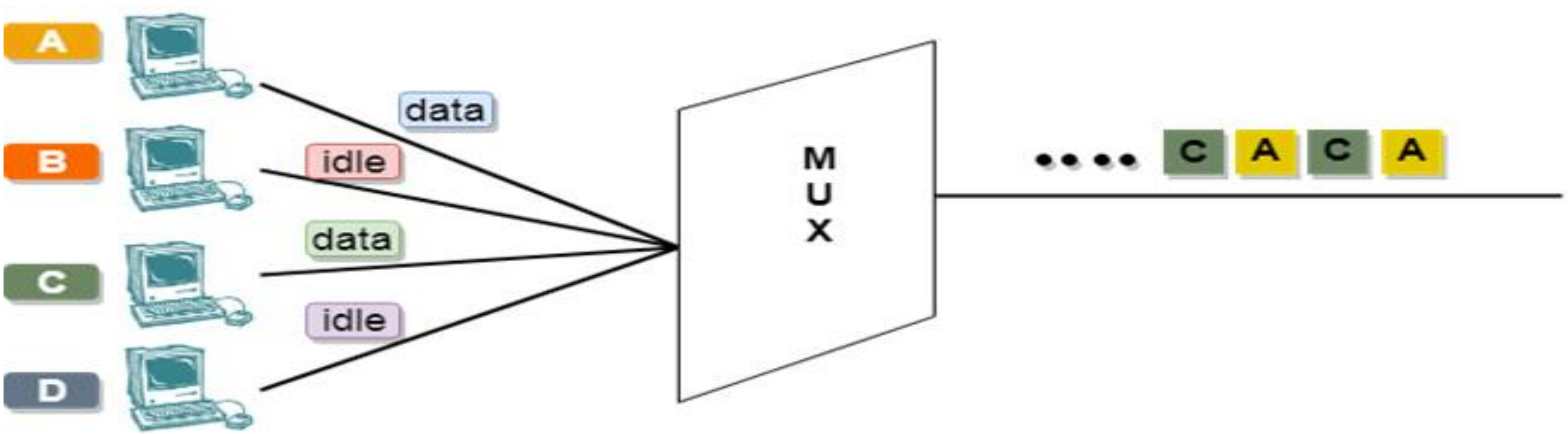


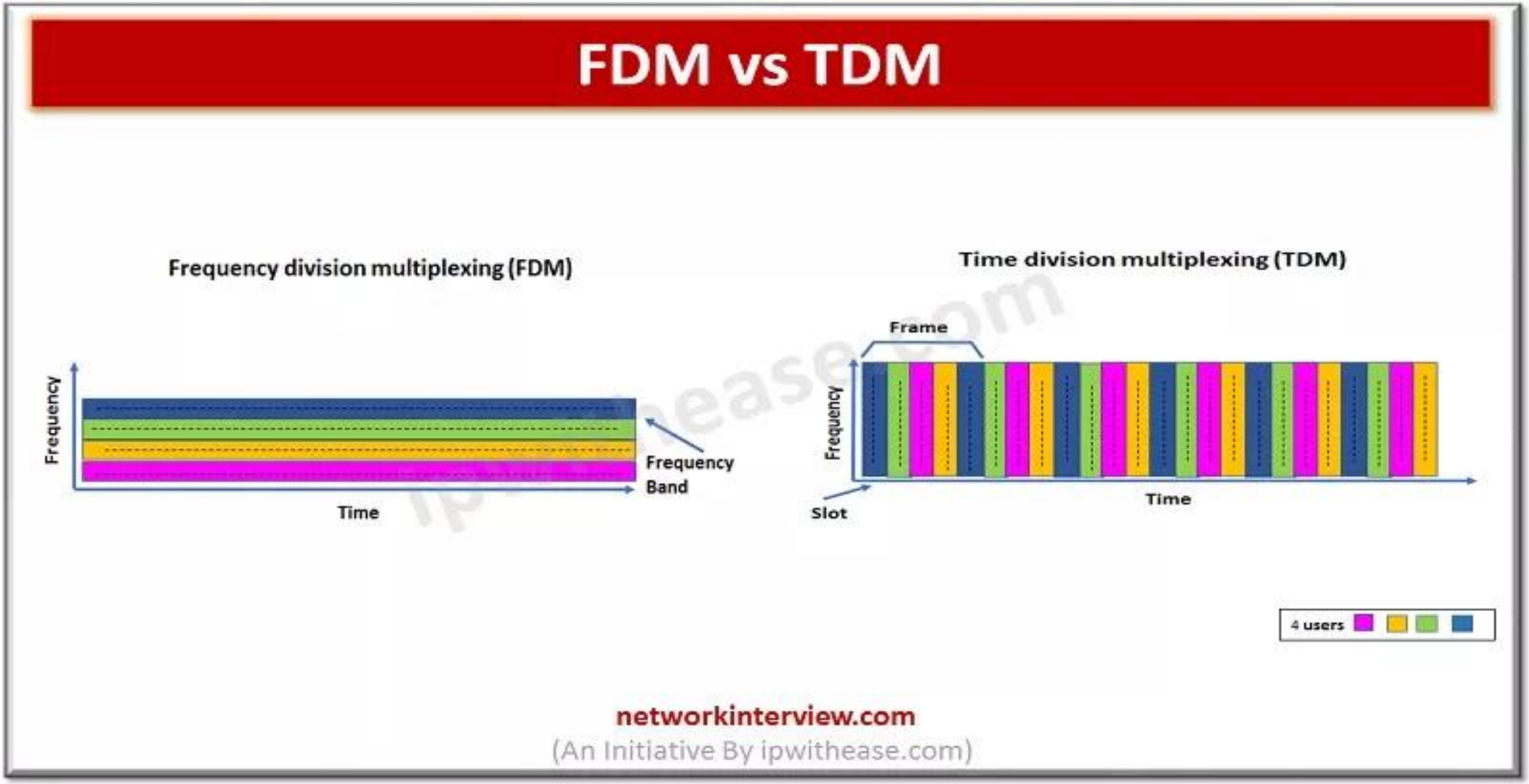
In Synchronous, some slots are empty because the corresponding line does not have data to send.

In the Statistical, no slot is left empty as long as there are data to be sent by any input line.

Guess??


A
A
A
B
B
C
M
U
X
Third frame
A
Second frame
B
A
First frame
C
B
A

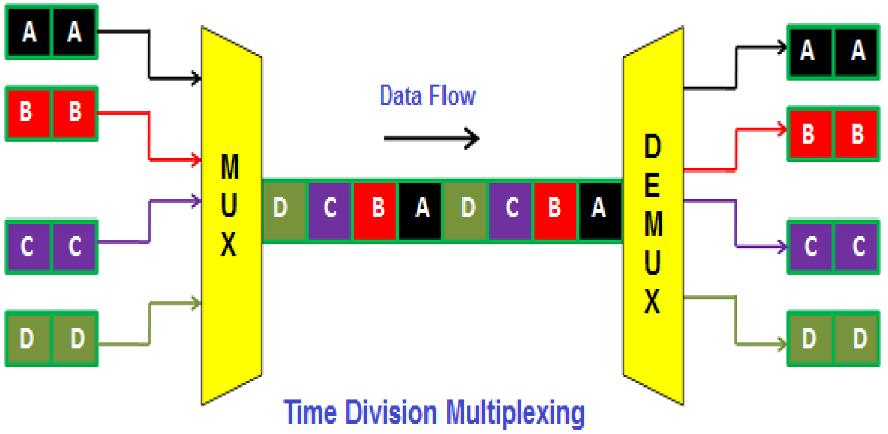

A
B
C
D
data
idle
data
idle
M
U
X
C
A
C
A



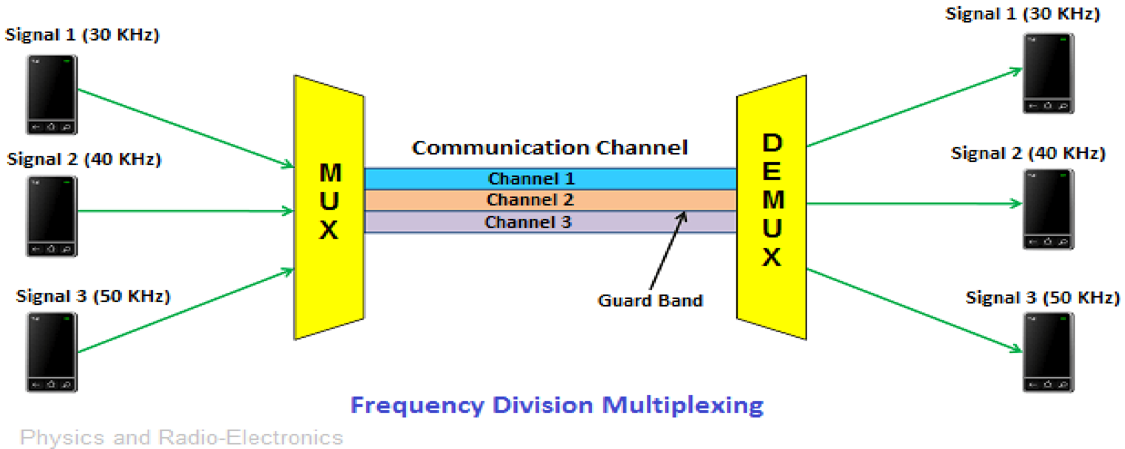
TDM is a process of transmitting multiple data streams over a single channel. Where each signal is divided into a fixed-length time slot.

FDM is a process in which the total available bandwidth is divided into a series of non-overlapping frequency bands where each band carries a separate signal.

In time division multiplexing, all signals are not transmitted simultaneously; instead, they are transmitted one after another. For example,at first, we send signal A. Then after second signal B and then after third signal C and finally, we send last signal D. Thus, each user occupies an entire bandwidth for a short period of time.
In time division multiplexing, each user is allotted a particular time interval called time slot during which data is transmitted.

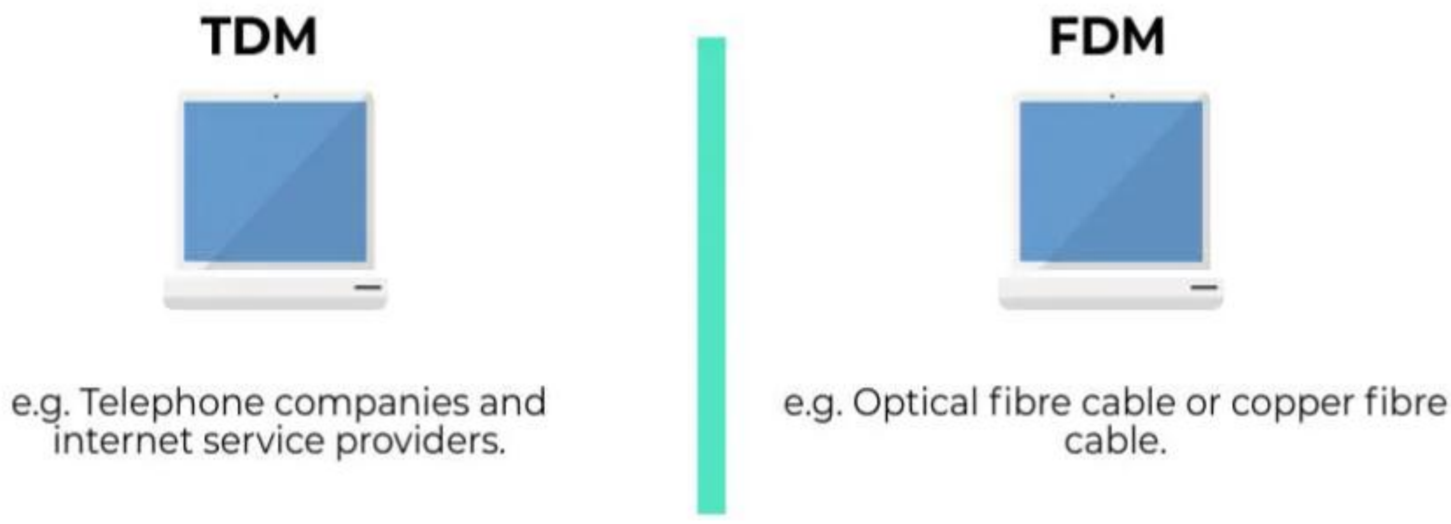


FDM - all the signals are transmitted at the same time but are allocated a separate frequency band. Each frequency band is separated by a suitable gap so as to avoid overlapping. This gap frequency is referred to as guard bands.



FDM Vs TDM

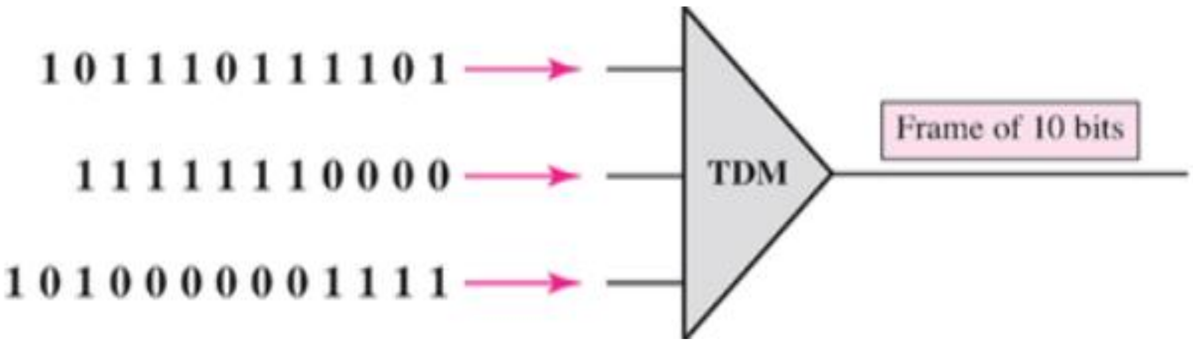
- FDM is meant for analog signals, while TDM works well with both analog as well as digital signals.
- TDM is mostly used in digital communications only.
- In TDM, synchronization pulse is important; whereas in FDM, Guard Band is required.
- FDM is widely used in analog telephony, such as AM and FM radio, and cable TV.
- TDM is widely used in digital telephony, such as ISDN, T1, and E1 lines.



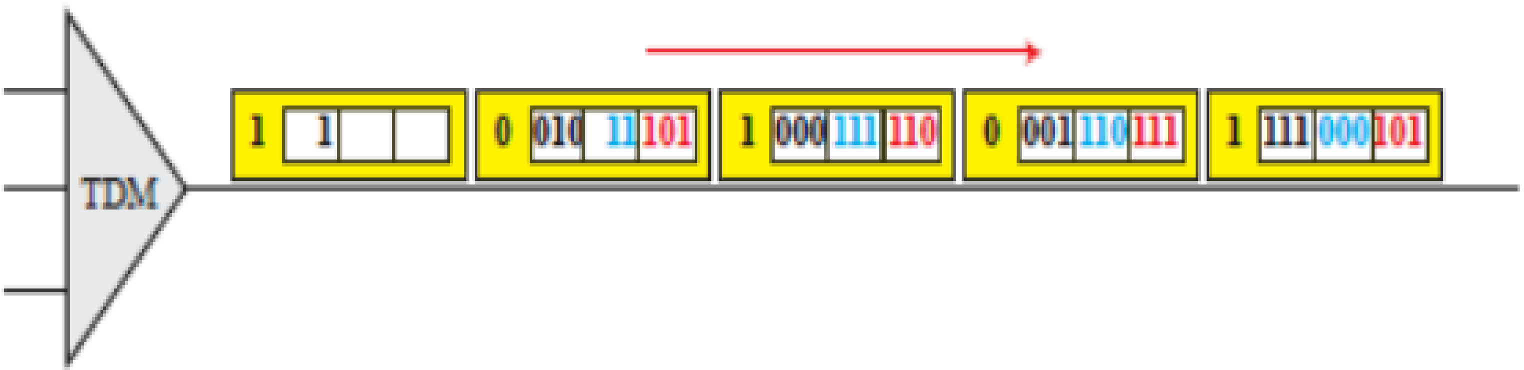
Basis for Comparison	FDM	TDM
Definition	A technique that allows transmission of multiple signals using different frequency slots over a common link.	A technique that permits the flow of multiple data signal over a communication link in different time domains.
Stands for	Frequency Division Multiplexing	Time Division Multiplexing
Multiplexing technique	Analog	Digital
Synchronization	Not Needed	Necessary
Circuit Orientation	Complex	Comparatively simple.
Cross talk	Exist	Does not exist
Propagation Delay	Not sensitive	Sensitive
Efficiency	Less	More efficient than FDM system
Cost	High	Comparatively low.

Problem #1

- In a synchronous TDM system, each O/p slot is only 9 bits long. What is the output stream?

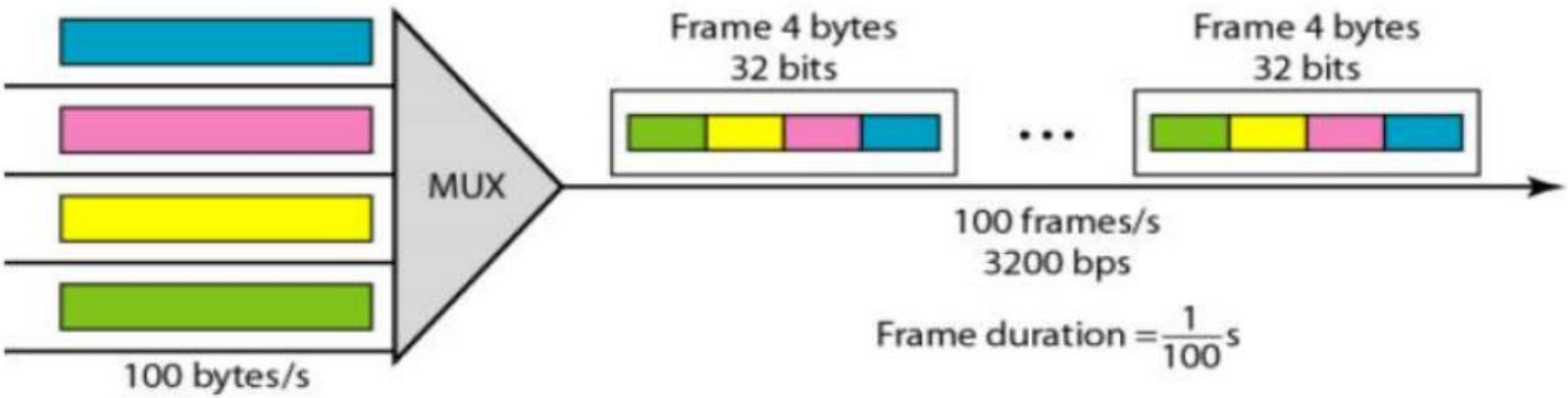


Solution



Problem #2

- Four channels are multiplexed using TDM. If each channel sends 100 bytes /s and we multiplex 1 byte per channel, show the frame traveling on the link, the size of the frame, the duration of a frame, the frame rate, and the bit rate for the link.



Solution

- Each frame carries 1 byte from each channel; the size of each frame, therefore, is 4 bytes, or 32 bits.
- Because each channel is sending 100 bytes/s and a frame carries 1 byte from each channel, the frame rate must be 100 frames per second.
- The bit rate is 100×32, or 3200 bps.

??

If there are n signal sources of same data rate, then the TDM link has ________ slots.

a) n

b) n/2

c) n*2

d) 2^n

Summary

- FDM is primarily analog-based and used in traditional broadcasting and older communication systems.
- WDM is specific to fiber-optic systems and is crucial for high-speed, high-capacity networks.
- TDM is mostly used in digital communication for efficient time-based sharing of resources.

SPREAD SPECTRUM

Spread Spectrum

- Spread spectrum is designed to be used in wireless applications (LANs and WANs).
- Spread spectrum is a radio frequency (RF) communication technique that spreads data over a wide range of frequencies.
- It's used to improve signal clarity, increase resistance to interference, and prevent detection.
- An analogy is the sending of a delicate, expensive gift. We can insert the gift in a special box to prevent it from being damaged during transportation, and we can use a superior delivery service to guarantee the safety of the package.

Key Features of Spread Spectrum:

1. **Wideband Transmission**: The signal occupies a bandwidth much larger than the original signal.
2. **Interference Rejection**: It is resistant to narrowband interference as the spread spectrum signal can be distinguished from the interfering signals.
3. **Security**: Provides better security as the signal is difficult to detect or intercept without knowing the spreading code.
4. **Multipath Resistance**: Reduces the impact of multipath propagation (signal reflection causing distortion).
5. **Code-Based Communication**: Data is encoded using spreading codes, enabling multiple users to share the same bandwidth (e.g., in CDMA).

Advantages of Spread Spectrum:

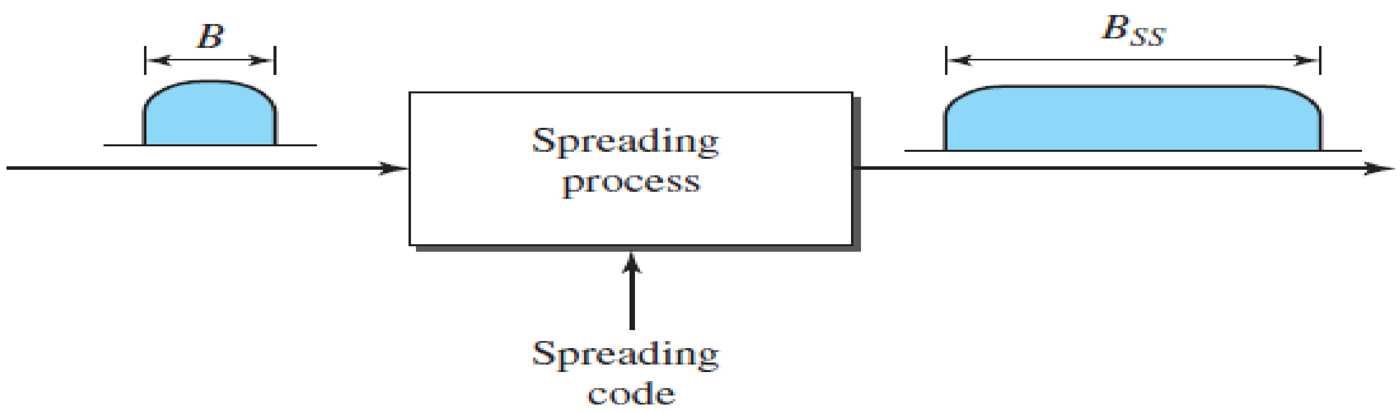
- High Security: Harder for unauthorized parties to intercept or jam the communication.
- Low Interference: Minimizes the effect of narrowband noise or jamming.
- Multiple Access: Allows multiple users to share the same frequency band using unique codes.
- Reliability: Performs well in noisy environments or with fading channels.

Applications of Spread Spectrum:

- Military communications (for secure and robust communication).
- Mobile communication systems (e.g., CDMA in 3G networks).
- Satellite and space communications.
- IoT and low-power wireless networks (e.g., LoRaWAN).GPS (Global Positioning System).

- After the signal is created by the source, the spreading process uses a spreading code and spreads the bandwidth.
- The spreading code is a series of numbers that look random, but are actually a pattern.
- There are two techniques to spread the bandwidth: frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS).

Spread spectrum



Principles

- Spread spectrum achieves its goals through two principles:

1. The bandwidth allocated to each station needs to be, by far, larger than what is needed. This allows redundancy.
2. The expanding of the original bandwidth B to the bandwidth Bss must be done by a process that is independent of the original signal.

- In other words, the spreading process occurs after the signal is created by the source.

Frequency Hopping Spread Spectrum

- **Frequency Hopping Spread Spectrum (FHSS)** is a type of spread spectrum technique in which the carrier signal rapidly switches (hops) between different frequencies within a designated frequency band, according to a predetermined sequence.
- This helps to spread the signal over a wide bandwidth, providing various advantages, including security and resistance to interference.
- The bandwidth occupied by a source after spreading is **$B_{FHSS} \gg B$.**
- The carrier frequency changes rapidly according to a specific pattern (hopping sequence).
- Reduces the probability of interference and eavesdropping.
- **Example: Bluetooth uses FHSS.**

Key Characteristics of FHSS:

1. **Frequency Hopping**: The signal jumps between frequencies in a pseudorandom pattern, which is determined by a sequence known to both the transmitter and the receiver.
2. **Wideband Transmission**: The signal occupies a wide frequency spectrum, increasing the chances of successfully transmitting the signal even in noisy or crowded frequency bands.
3. **Synchronization**: Both the transmitter and receiver must be synchronized to the hopping pattern for proper signal reception and decoding.
4. **Pseudorandom Sequence**: The hopping pattern is typically based on a pseudorandom sequence, making it hard for an eavesdropper to predict the next frequency without knowing the sequence.

How FHSS Works:

- The communication system divides the total available bandwidth into many smaller channels.
- The transmitter and receiver are synchronized to hop between these channels at regular intervals according to the hopping sequence.
- During each hop, the transmitter and receiver communicate using the frequency assigned to that hop.
- After transmitting a signal on one frequency, the transmitter "hops" to the next frequency in the sequence, and this process repeats.

Advantages of FHSS:

1. **Resistance to Jamming**: Since the signal hops between frequencies, it is more difficult for a jammer to disrupt the communication. The jamming would need to cover multiple frequencies simultaneously.
2. **Reduced Interference**: FHSS minimizes the chance of interference from other narrowband signals as the communication spans multiple frequencies over time.
3. **Security**: The pseudorandom hopping pattern makes it difficult for unauthorized users to intercept or decode the signal, increasing communication security.
4. **Multipath Resistance**: By constantly changing frequencies, the system avoids sustained multipath fading (signal interference due to reflections from obstacles).

Disadvantages of FHSS:

1. **Bandwidth Efficiency**: FHSS systems typically require more bandwidth than conventional communication systems, which may be a limiting factor in crowded spectrum environments.
2. **Data Rate**: The hopping process can introduce overhead, potentially reducing the overall data rate.
3. **Synchronization**: Both transmitter and receiver must maintain precise synchronization to correctly decode the signal, which can be challenging in some environments.

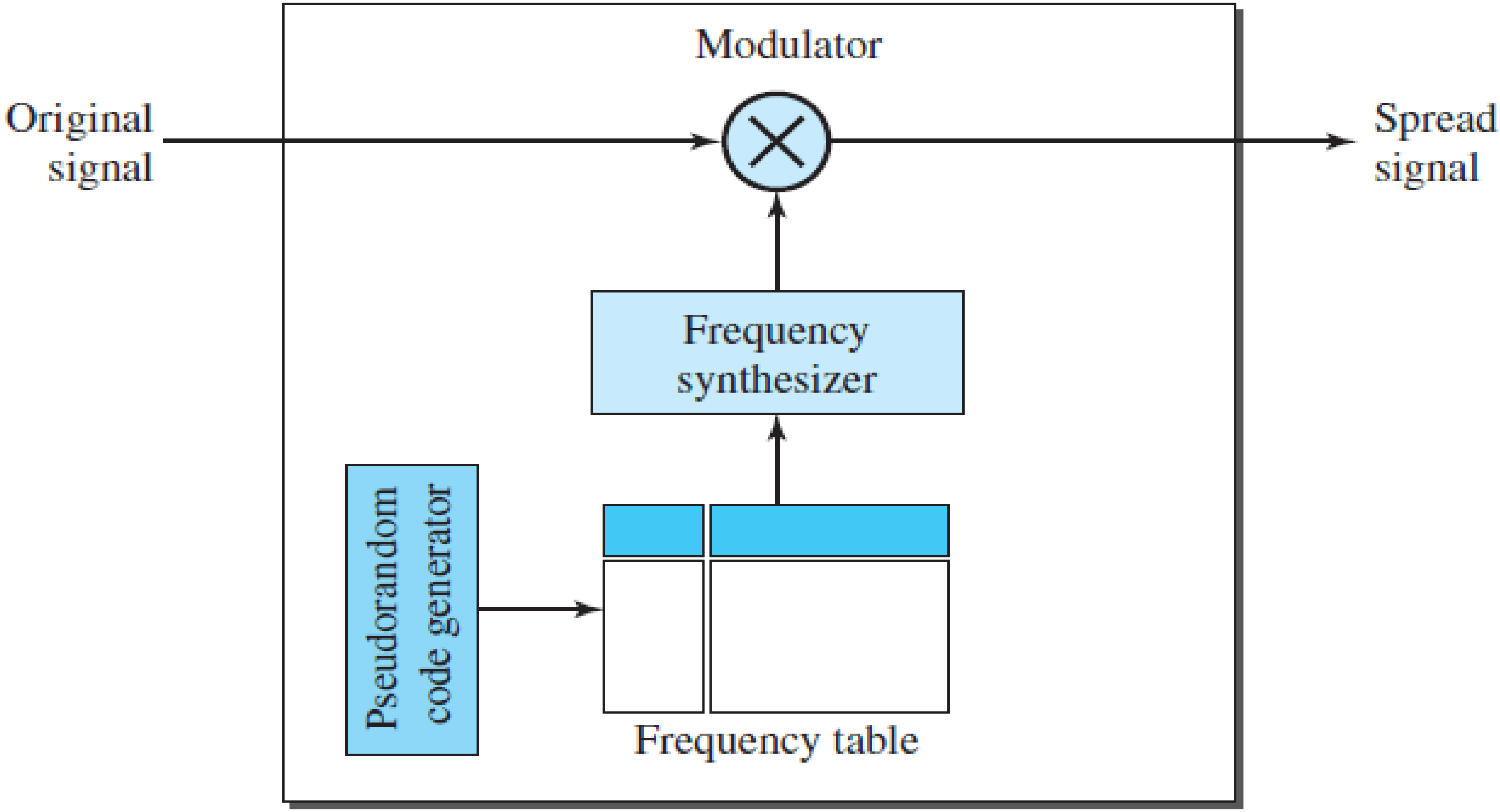
FHSS Applications:

- **Bluetooth**: One of the most common examples of FHSS is Bluetooth, which uses FHSS for short-range wireless communication between devices.
- **Military Communications**: FHSS is often used in military systems for secure communication, where security and resistance to jamming are critical.

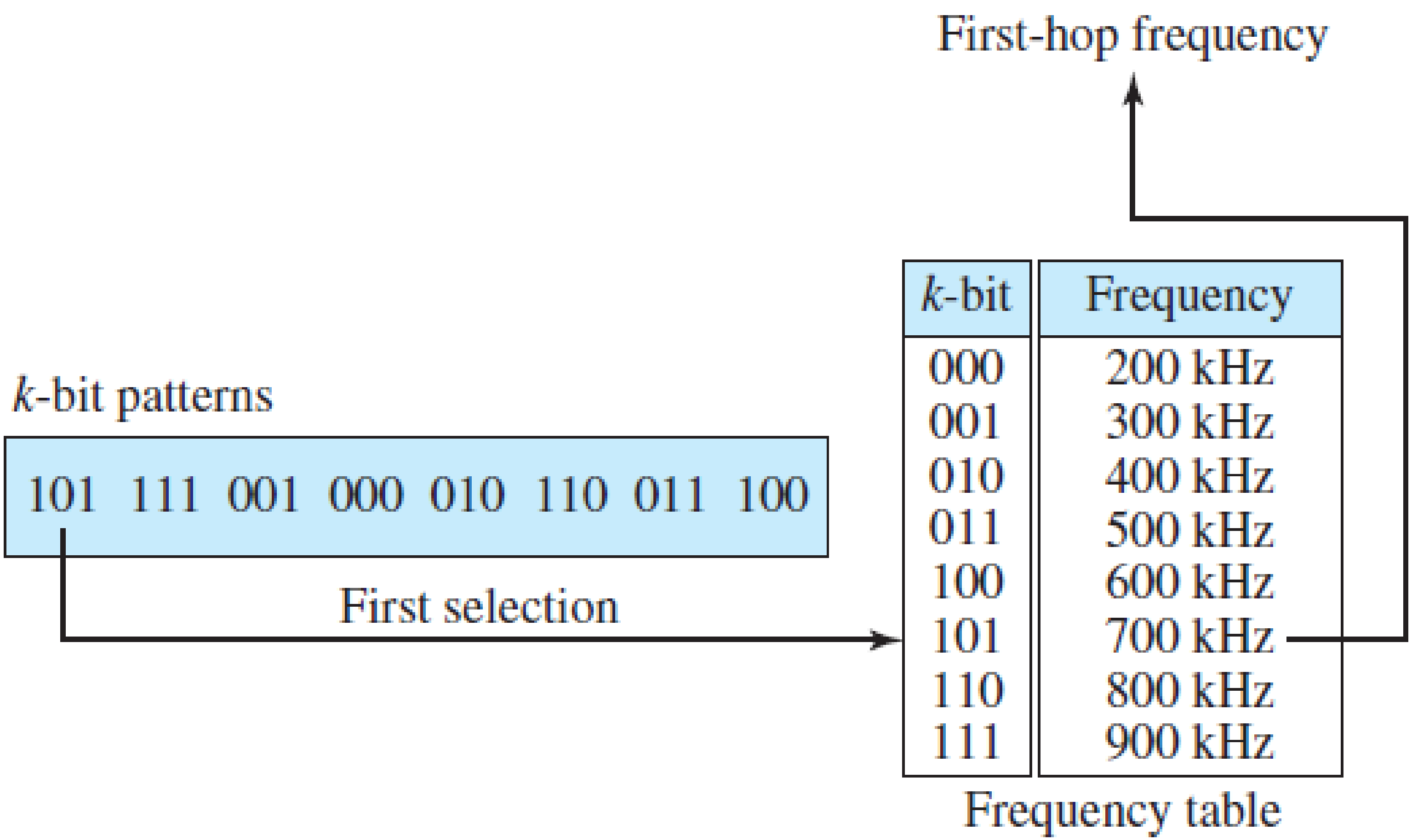
FHSS Example – Bluetooth:

- Bluetooth devices use FHSS to avoid interference in the 2.4 GHz ISM (Industrial, Scientific, and Medical) band, which is crowded with other devices like Wi-Fi routers, microwaves, and cordless phones.
- Bluetooth divides the 2.4 GHz band into 79 channels (each 1 MHz wide), and a Bluetooth device hops through these channels at a rate of 1600 hops per second.
- Each device involved in Bluetooth communication follows the same hopping pattern, ensuring they stay synchronized during communication.

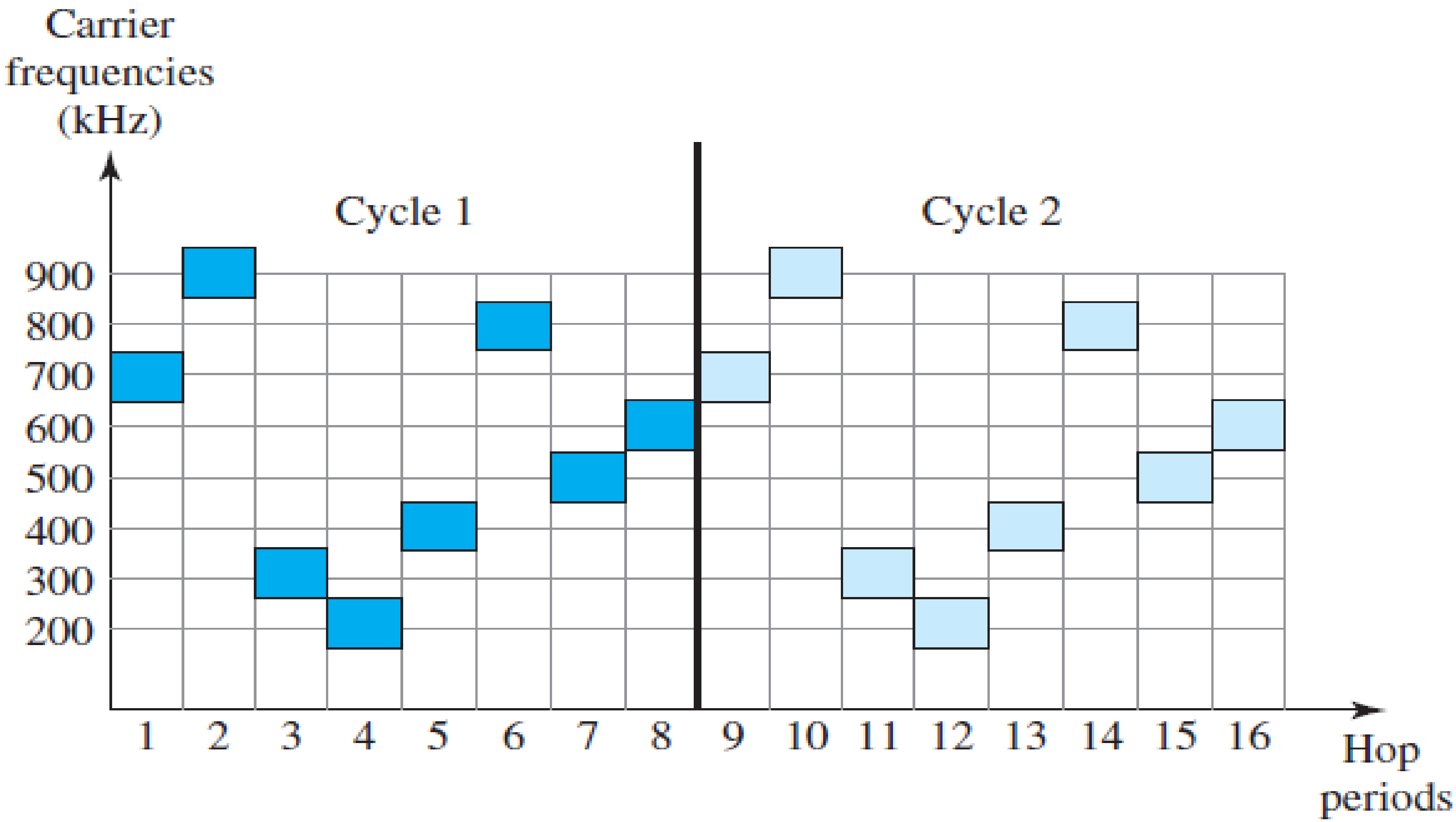
Frequency hopping spread spectrum (FHSS)



Frequency selection in FHSS

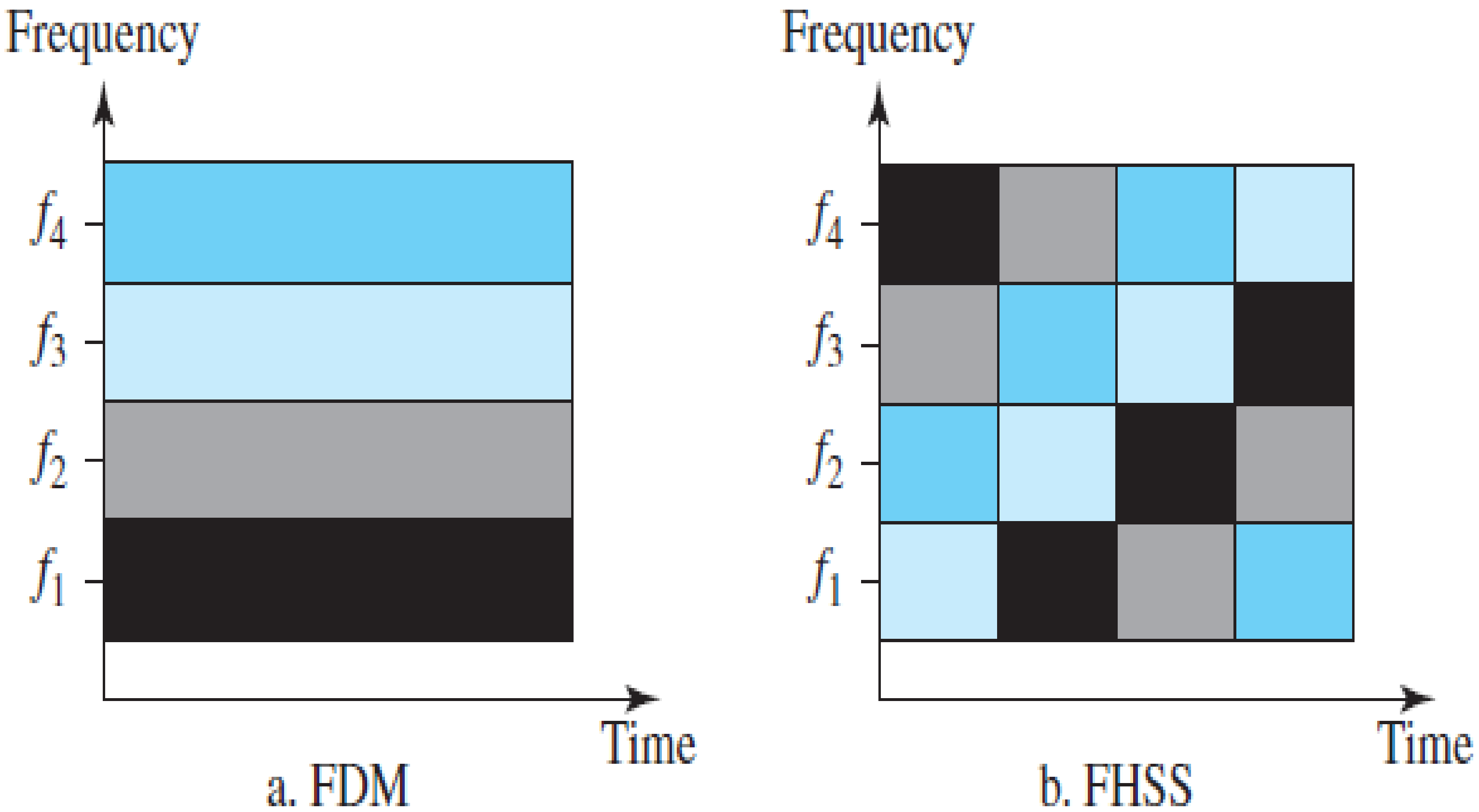


FHSS cycles



Carrier frequencies (kHz)
Cycle 1
Cycle 2
900
800
700
600
500
400
300
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Hop periods

Bandwidth sharing



Direct Sequence Spread Spectrum

- **Direct Sequence Spread Spectrum (DSSS)** is another type of spread spectrum technique where the data signal is multiplied by a high-frequency pseudorandom noise (PN) code, also known as a "chipping code" to spread the signal over a wide frequency band.
- This spreading process results in a signal that appears like random noise, making it difficult to detect or intercept without the proper code.
- Example: Wi-Fi (802.11b) uses DSSS.

Key Features of DSSS:

1. **Signal Spreading**: The baseband data signal is multiplied by a PN code (called the spreading code), which increases the signal's bandwidth. This spreads the data signal across a wide frequency range.
2. **Chip Rate**: The chipping code has a much higher frequency (chip rate) than the data rate, typically many times higher. For example, if the data rate is 1 kbps, the chip rate might be 10 Mbps or more.
3. **Wideband Transmission**: The signal occupies a broad bandwidth, making it more resistant to interference and jamming.
4. **Synchronization**: To decode the received signal, the receiver must synchronize with the correct PN code used at the transmitter. Without synchronization, the received signal will not be correctly decoded.

How DSSS Works:

1. **Data Modulation**: The data signal (e.g., binary "1" or "0") is mapped to a high-frequency PN code (chip sequence), where each bit of data is represented by a sequence of chips.
2. **Spreading the Signal**: The data bits are multiplied by the PN code (which consists of a series of chips, such as +1 or -1) at a much higher rate than the data rate. This results in a signal that is spread over a larger bandwidth.
3. **Transmission**: The spread signal is transmitted over the communication channel. Since the signal is spread out, it is more resistant to noise and interference that may occur within a narrower bandwidth.
4. **Despreading**: At the receiver side, the spread signal is multiplied by the same PN code, effectively "despreading" the signal to recover the original data.

Advantages of DSSS:

1. **Resistance to Interference**: Since the signal is spread over a wide bandwidth, narrowband interference is less likely to affect the entire signal. The system can still operate in noisy environments.
2. **Security**: The use of a pseudorandom PN code increases security. Without knowing the exact spreading code, an eavesdropper cannot easily detect or decode the transmission.
3. **Multipath Fading Resistance**: DSSS can mitigate multipath fading because the spread signal is less affected by signal reflections and delays.
4. **Lower Probability of Interception**: Since the signal appears as noise, it is harder for unauthorized parties to intercept or jam the communication.

Disadvantages of DSSS:

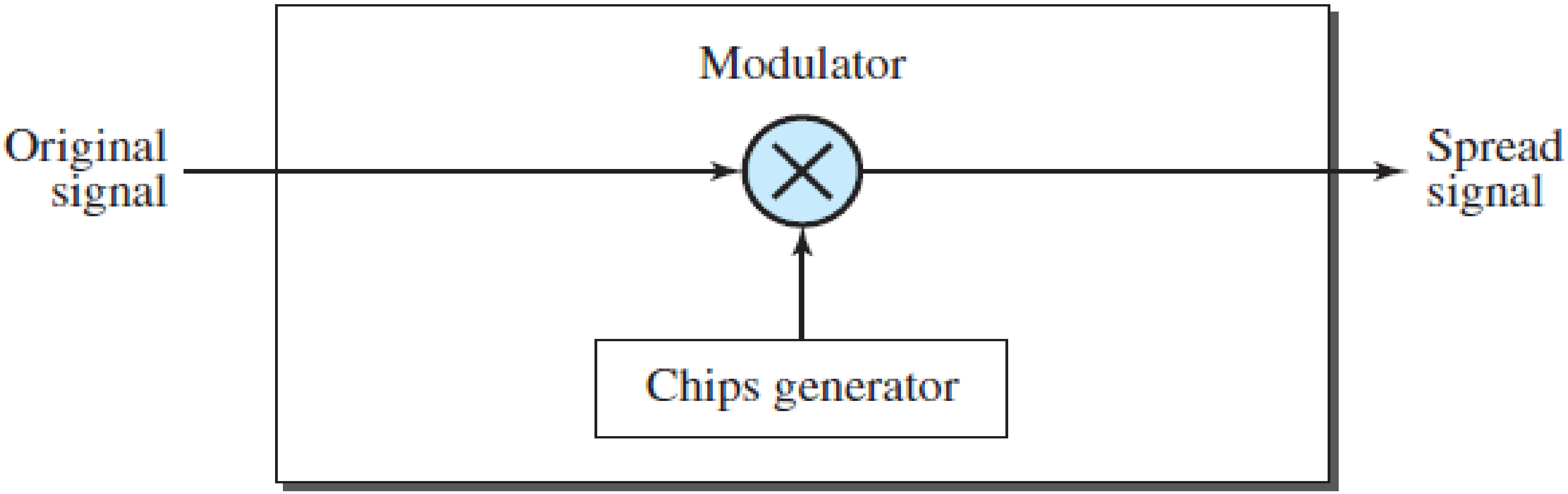
1. **Bandwidth Consumption**: DSSS requires a large bandwidth compared to non-spread spectrum techniques, which can be inefficient in spectrum-constrained environments.
2. **Complexity**: DSSS systems are more complex to implement due to the need for synchronization between the transmitter and receiver, as well as the generation and handling of the spreading codes.
3. **Power Consumption**: Due to the increased bandwidth and processing required for spreading and despreading, DSSS systems may consume more power, making them less suitable for battery-powered devices in some cases.

DSSS Applications:

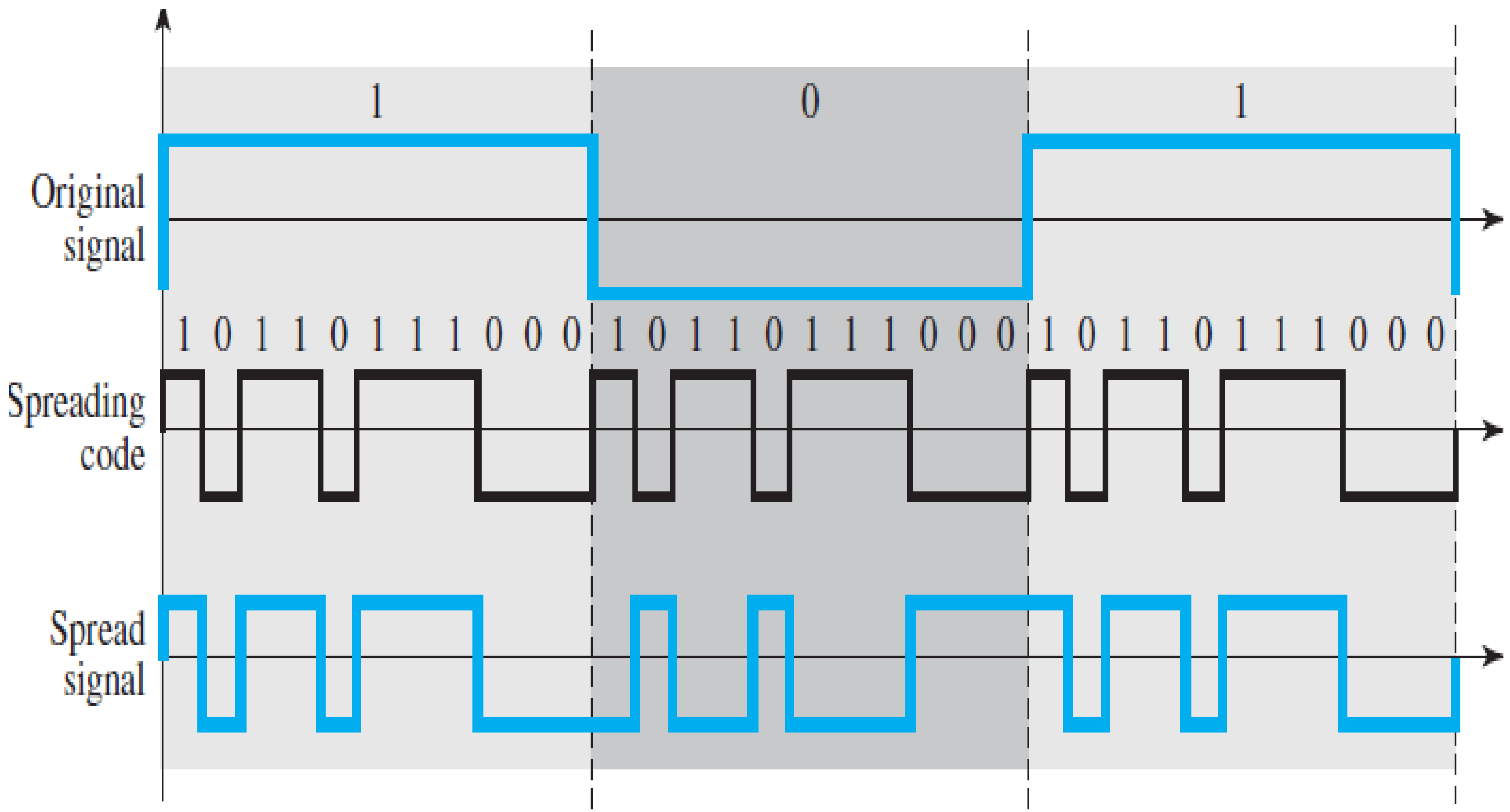
1. **Wi-Fi (802.11b)**: The 802.11b standard for Wi-Fi uses DSSS to provide wireless local area network (WLAN) access. In this case, DSSS operates in the 2.4 GHz ISM (Industrial, Scientific, and Medical) band.
2. **GPS**: Global Positioning System (GPS) uses DSSS to provide accurate positioning data. Each GPS satellite transmits a signal spread over a wide bandwidth using a unique PN code, ensuring that the receiver can distinguish between different satellites.
3. **Cordless Phones**: Early cordless phone systems employed DSSS for communication, making them resistant to interference from other devices.
4. **Military Communications**: DSSS is often used in military systems to provide secure, interference-resistant communications.

- **DSSS Example – Wi-Fi (802.11b):**
- **Wi-Fi (802.11b)** uses DSSS in the 2.4 GHz frequency range to transmit data over wireless networks. The signal is spread over a wide frequency range by multiplying the data signal with a high-rate PN code.
- This spreading technique helps minimize interference from other devices operating in the same frequency band (such as microwave ovens, cordless phones, and Bluetooth devices).
- The receiver synchronizes with the transmitted signal's PN code, despreads it, and recovers the original data.

DSSS



DSSS example



Comparison of DSSS and FHSS:

- **DSSS**: Spreads the signal across a wide bandwidth by multiplying it with a high-frequency code (PN code). It is better suited for environments with high interference and offers higher security but requires more bandwidth.
- **FHSS**: The signal hops between different frequencies in a sequence. It is more efficient in terms of bandwidth usage but offers lower security and resistance to interference compared to DSSS.