UNIT-03

- Bandwidth Utilization: Multiplexing
- Transmission Media: Guided Media, Unguided Media
- Switching: Introduction, Circuit Switched Networks and Packet switching, Structure of a Switch.

- 08 hours of duration

Bandwidth Utilization

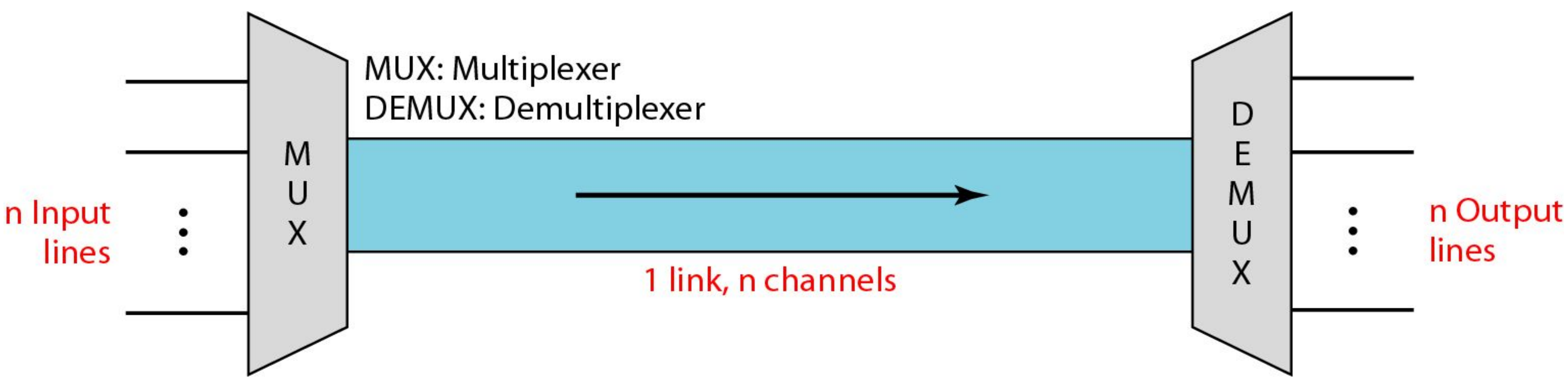
- We have links with limited bandwidths, the main challenges of data communications is to use them wisely.
- Sometimes we need to combine several low-bandwidth channels to make use of one channel with a larger bandwidth.
- Sometimes we need to expand the bandwidth of a channel to achieve goals such as privacy and anti jamming.
- The unit mainly speaks about two broad categories: Multiplexing and spreading.

Bandwidth utilization is the wise use of available bandwidth to achieve specific goals.

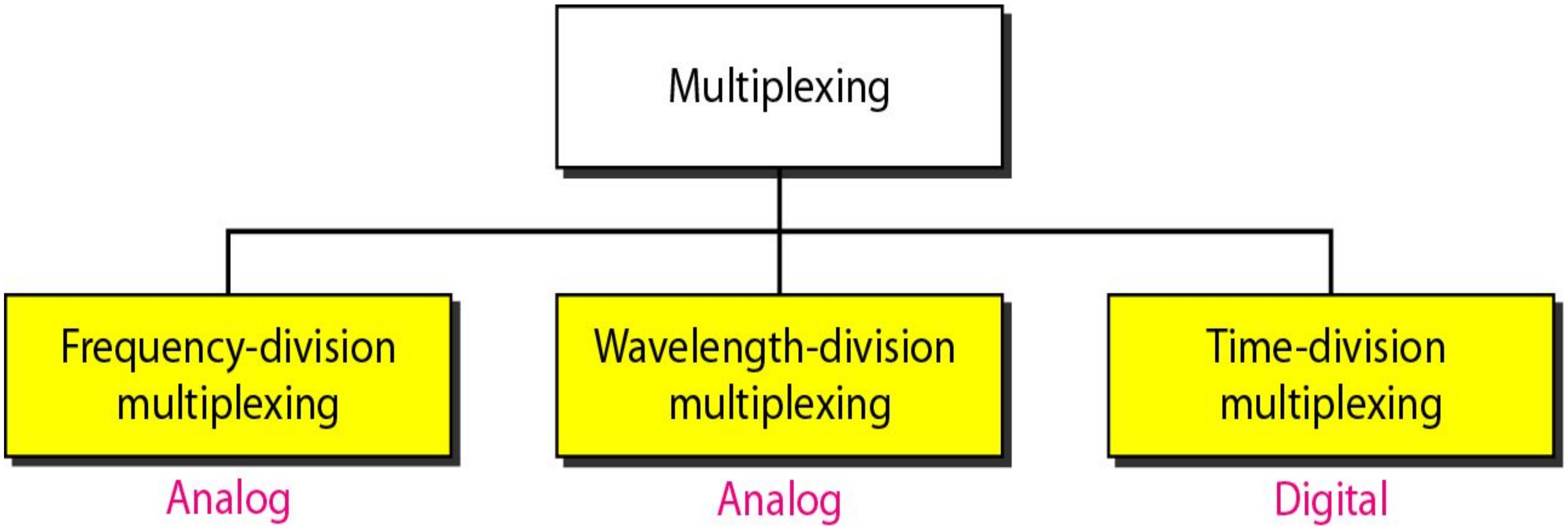
Efficiency can be achieved by multiplexing; i.e., sharing of the bandwidth between multiple users.

Multiplexing

- Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, the link can be shared.
- Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link.
- In a multiplexed system, n lines share the bandwidth of one link.
- *Dividing a link into channels*



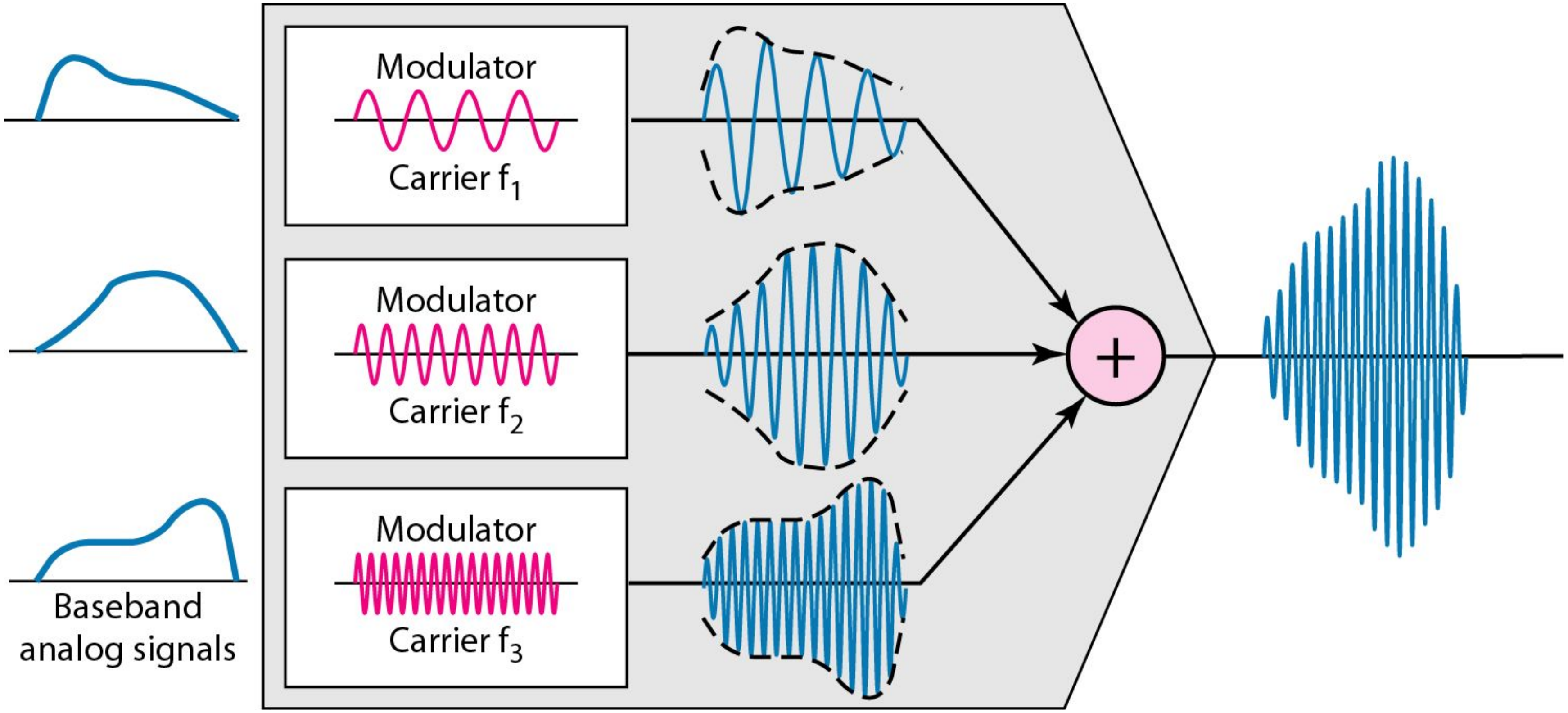
- There are three basic multiplexing techniques:
  1. frequency-division multiplexing
  2. wavelength-division multiplexing
  3. Time-division multiplexing.
- The first two are techniques designed for analog signals, the third, for digital signals



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 FOM, 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.

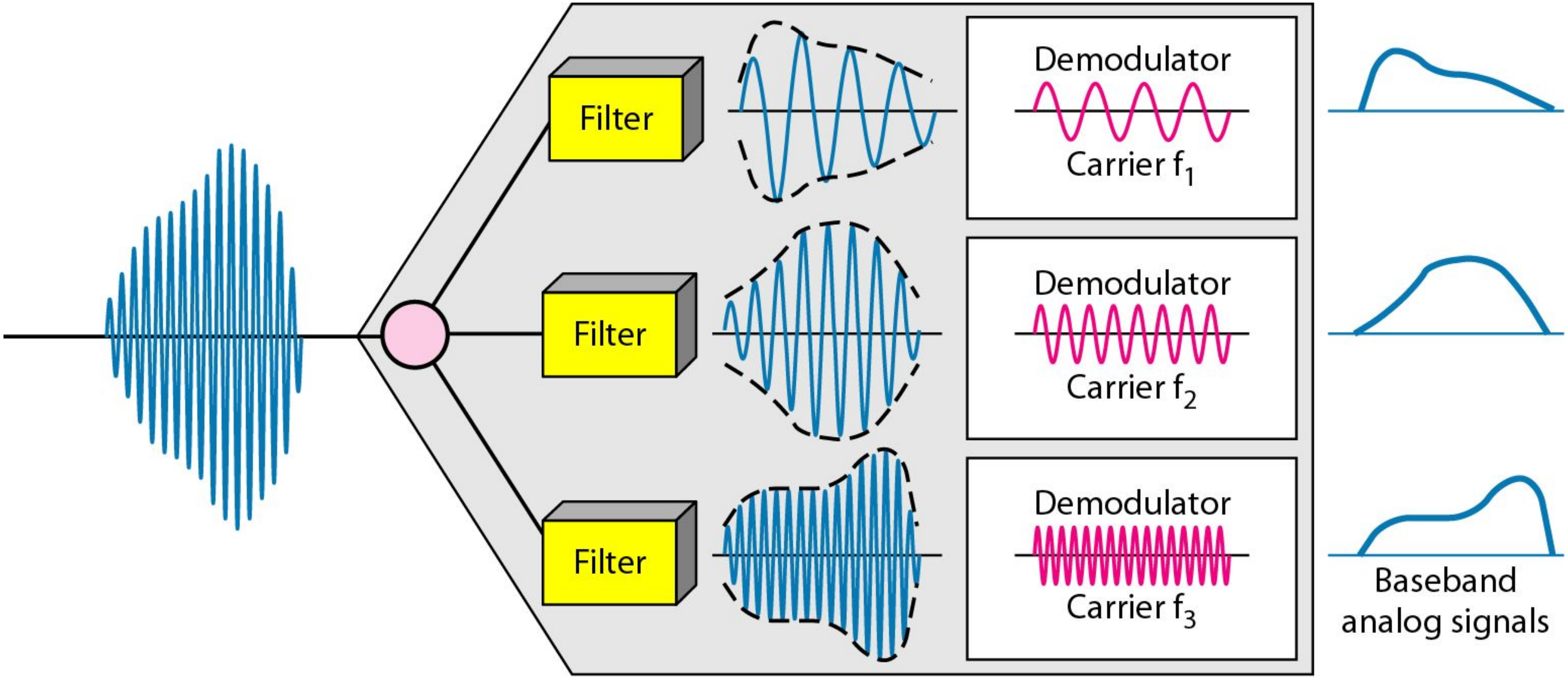
Multiplexing Process



Multiplexing and Demultiplexing process

- Each source generates a signal of a similar frequency range.
- Inside the multiplexer, these similar signals modulates 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.
- 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.

Demultiplexing process



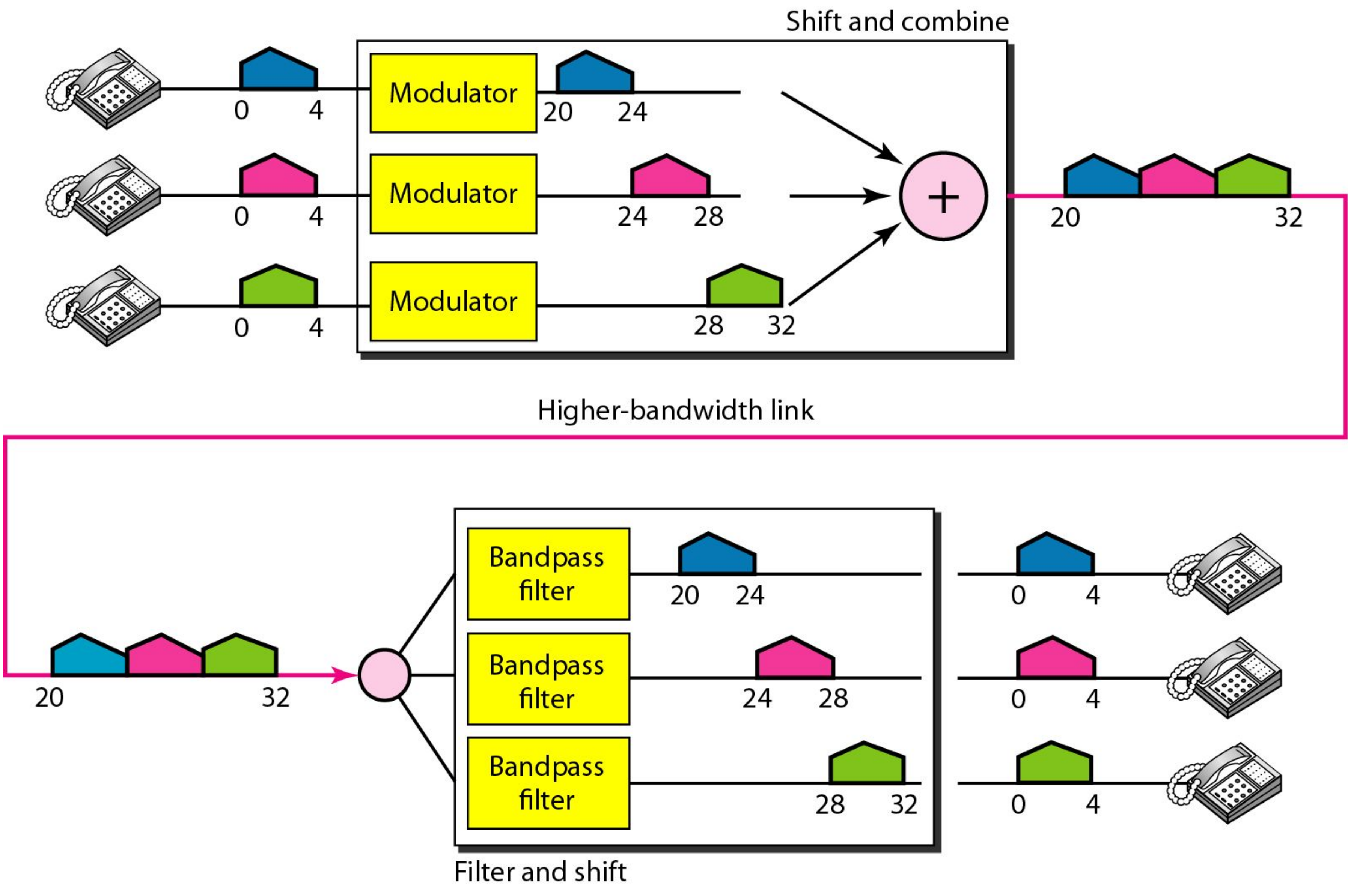
Example-01

Assume that a voice channel occupies a bandwidth of 4 kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32 kHz. Show the configuration, using the frequency domain. Assume there are no guard bands.

Solution

We shift (modulate) each of the three voice channels to a different bandwidth, as shown in Figure 6.6. We use the 20- to 24-kHz bandwidth for the first channel, the 24- to 28-kHz bandwidth for the second channel, and the 28- to 32-kHz bandwidth for the third one. Then we combine them as shown in Figure 6.6.

Example figure-6.6



Example-02

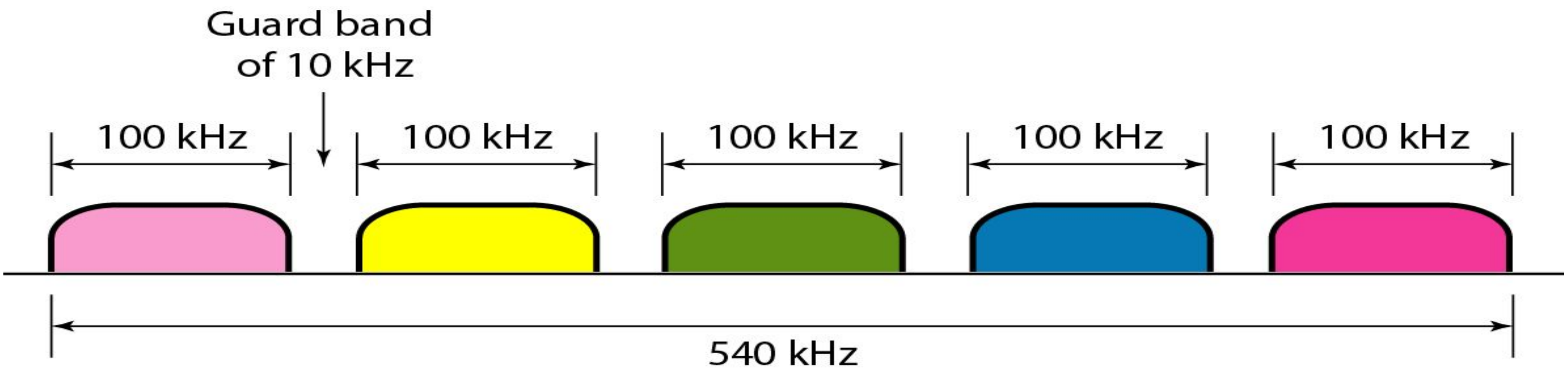
Five channels, each with a 100-kHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10 kHz between the channels to prevent interference?

Solution

For five channels, we need at least four guard bands. This means that the required bandwidth is at least

$$5 \times 100 + 4 \times 10 = 540 \text{ kHz},$$

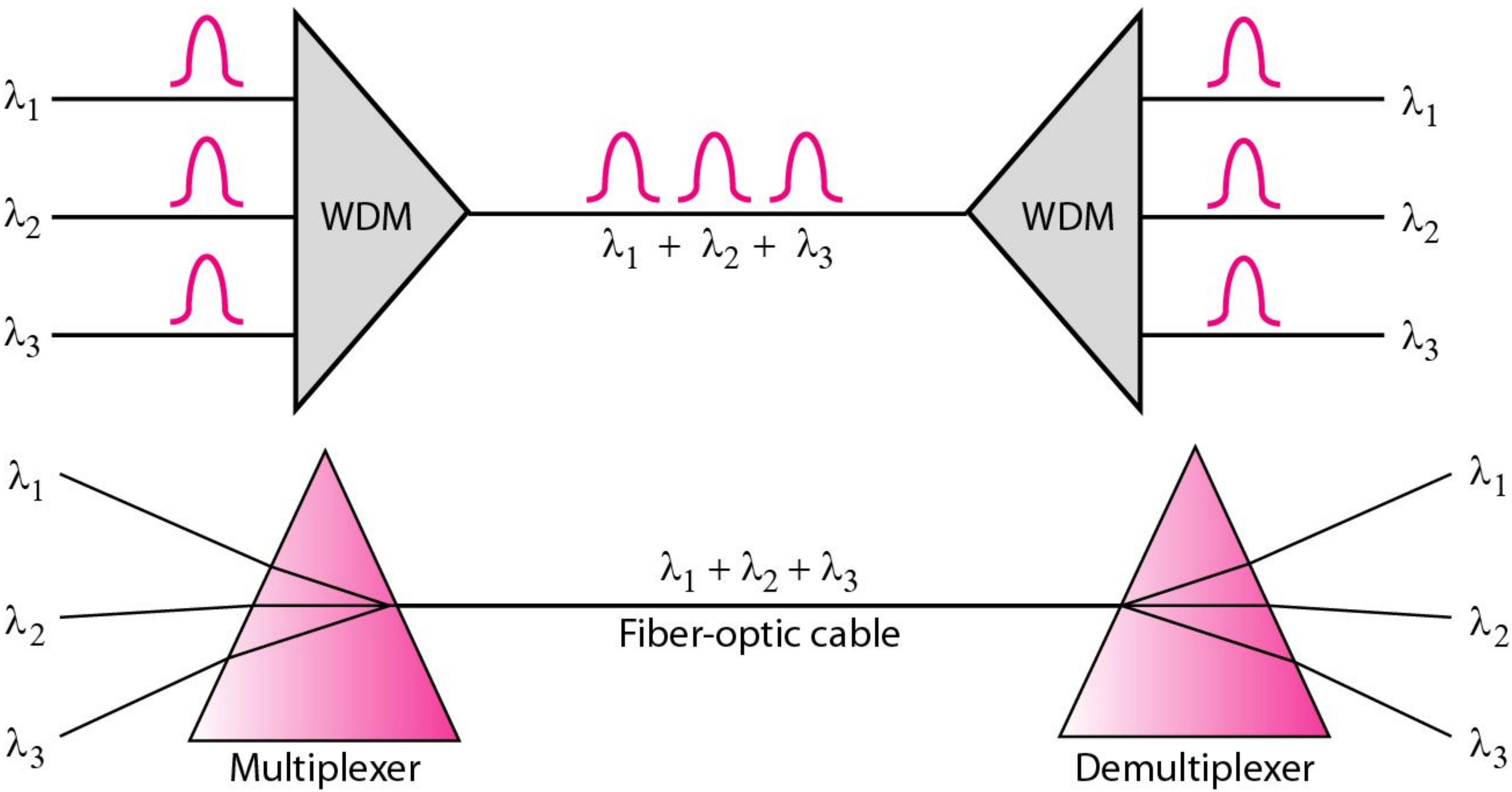
as shown in Figure 6.7.



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.
- Using a fiber-optic cable for one single line wastes the available bandwidth. Multiplexing allows us to combine several lines into one.
- WDM is similar to FDM, except that the multiplexing and demultiplexing involve optical signals transmitted through fiber-optic channels.
- We are combining different signals of different frequencies. The difference is that the frequencies are very high.

WDM

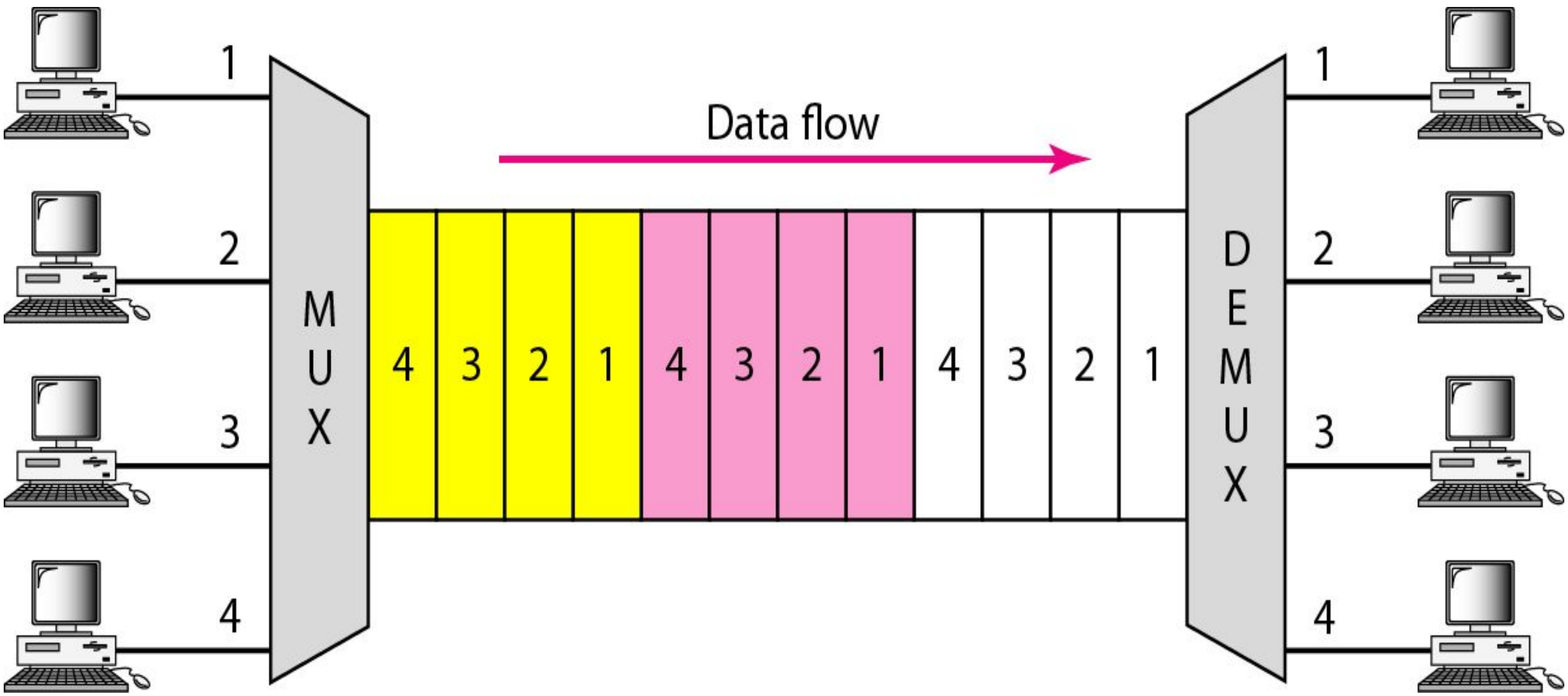


WDM is an analog multiplexing technique to combine optical signals.

Time-Division Multiplexing

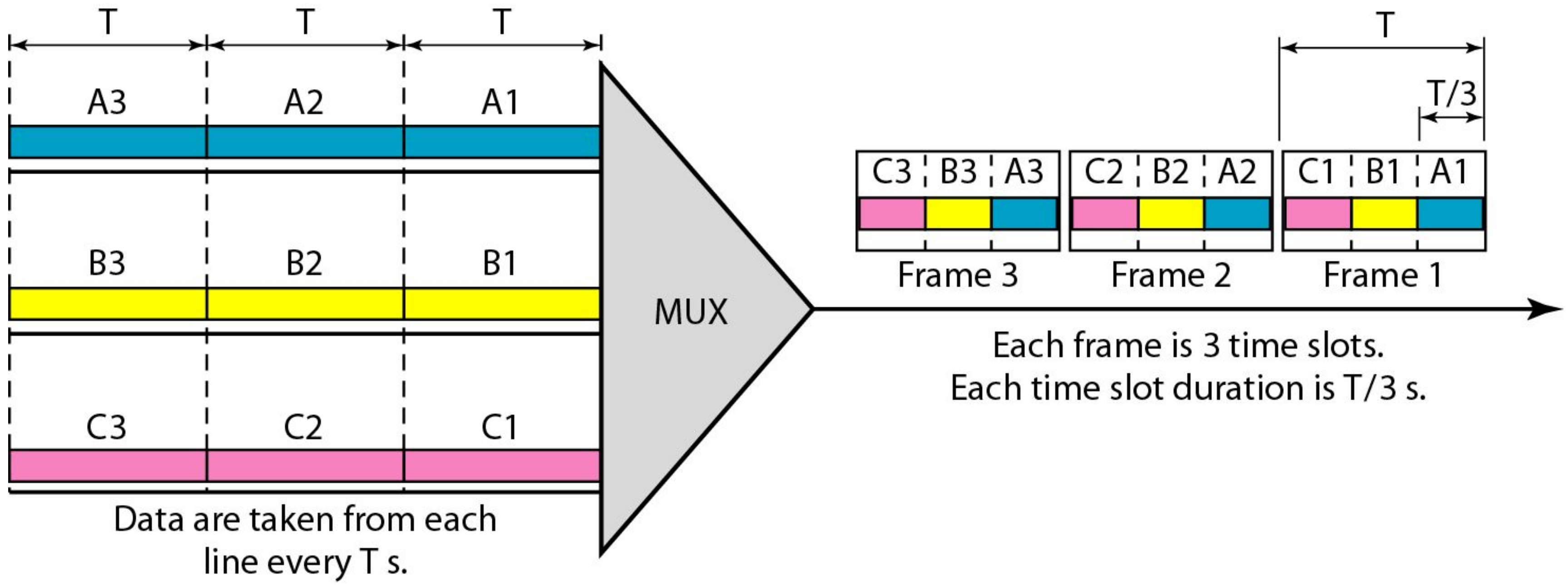
- TDM is a digital process that allows several connections to share the high bandwidth of a line.
- Instead of sharing a portion of the bandwidth as in FDM, time is shared.
- Each connection occupies a portion of time in the link.
- Note that the same link is used as in FDM; here, however, the link is shown sectioned by time rather than by frequency.
- Portions of signals 1,2,3, and 4 occupy the link sequentially.

TDM



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

Synchronous time-division multiplexing



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

Example-01

In the above fig, the data rate for each one of the 3 input connection is 1 kbps. If 1 bit at a time is multiplexed (a unit is 1 bit), what is the duration of (a) each input slot, (b) each output slot, and (c) each frame?

Solution

a. ***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).***

Continuation..

b. ***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.***

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

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

Example-02

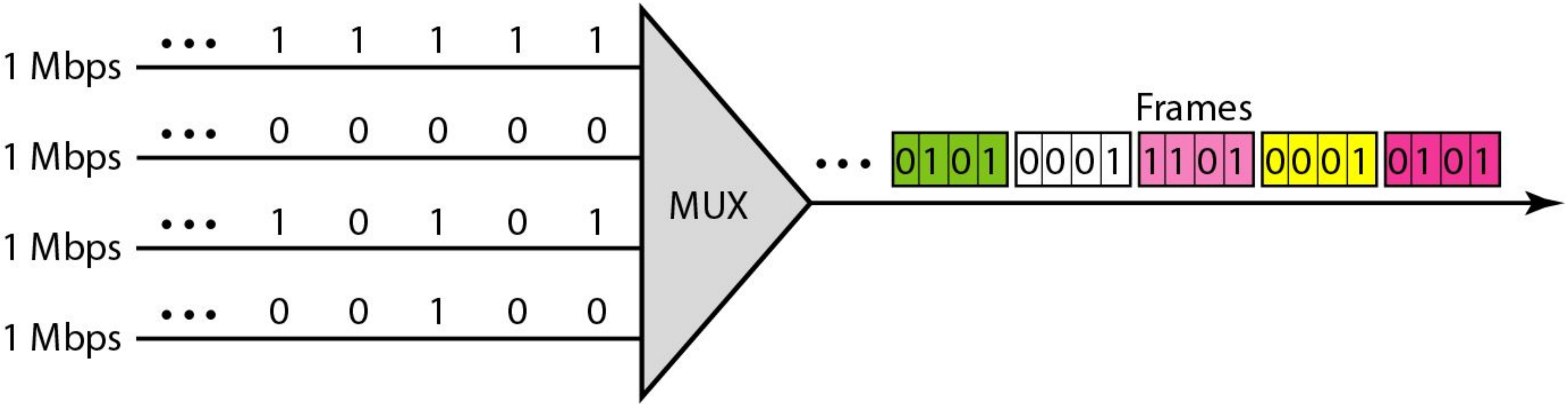


Figure 6.14 shows synchronous TDM with 4 1Mbps data stream inputs and one data stream for the output. The unit of data is 1 bit. Find (a) the input bit duration, (b) the output bit duration, (c) the output bit rate, and (d) the output frame rate.

Solution: Example-02

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

b. *The output bit duration is one-fourth of the input bit duration, or ¼ μs.*

c. *The output bit rate is the inverse of the output bit duration or 1/(4μs) 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.*

d. *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, we can verify the result of the previous question by multiplying the frame rate by the number of bits per frame.*

Example-03

Four 1-kbps connections are multiplexed together. A unit is 1 bit. Find (a) the duration of 1 bit before multiplexing, (b) the transmission rate of the link, (c) the duration of a time slot, and (d) the duration of a frame.

Solution

We can answer the questions as follows:

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

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

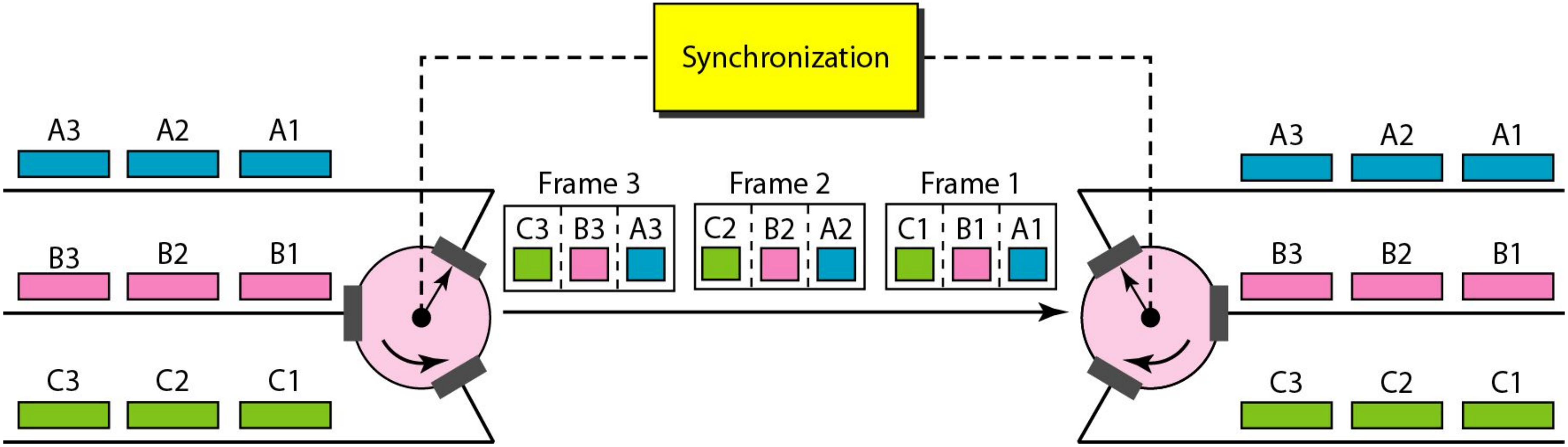
Example-03

c. *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.*

d. *The duration of a frame is always the same as the duration of a unit before multiplexing, or 1 ms. We can also calculate this in another way. Each frame in this case has four time slots. So the duration of a frame is 4 times 250 μs, or 1 ms.*

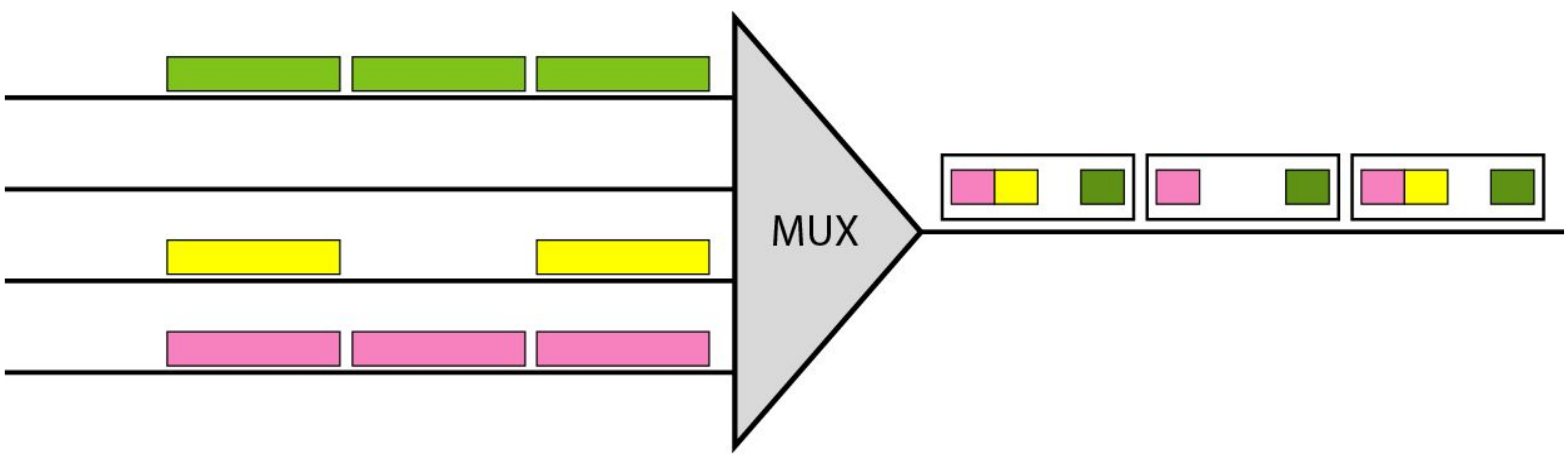
Interleaving

- 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.



Empty Slots

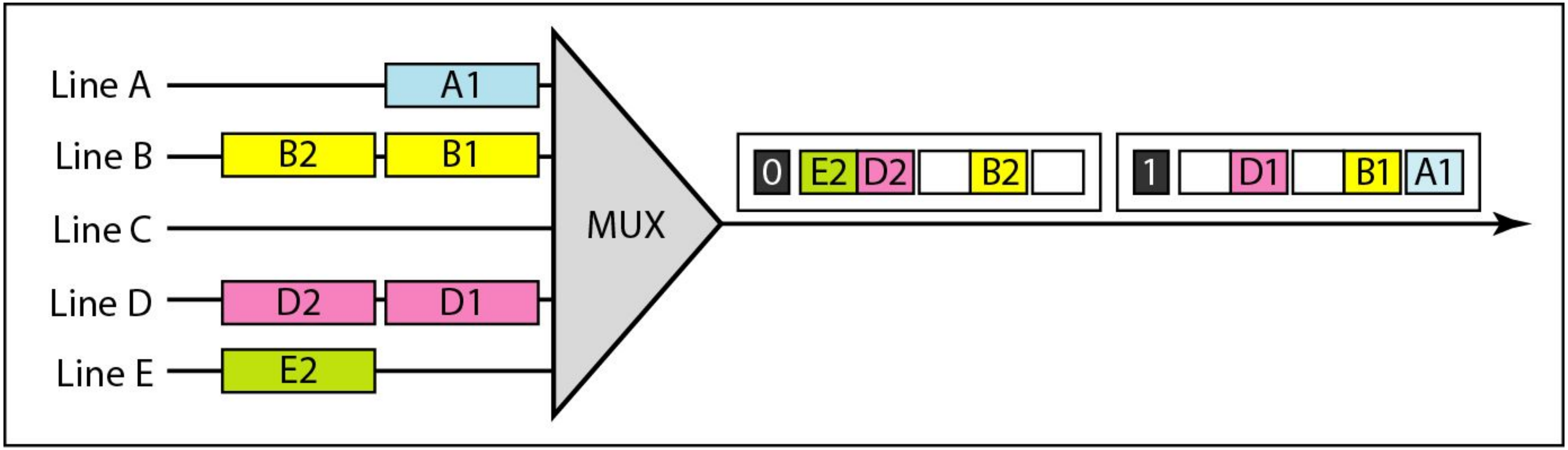
- If a source does not have data to send, the corresponding slot in the output frame is empty.
- The first output frame has three slots filled, the second frame has two slots filled, and the third frame has three slots filled. No frame is full.
- Statistical TDM can be used to improve the efficiency by removing the empty slots from the frame.



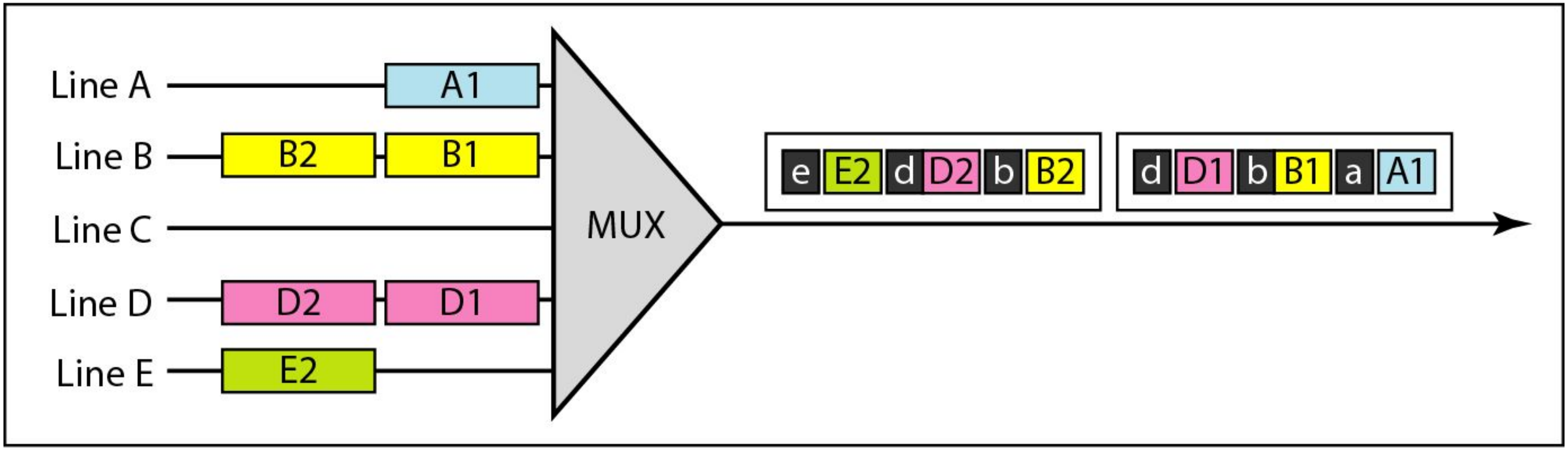
Statistical Time-Division Multiplexing

- In synchronous TDM, each input has a reserved slot in the output frame.
- This can be inefficient if input lines have no data to send.
- In statistical TDM, slots are dynamically allocated to improve bandwidth efficiency.
- Only when an input line has a slot's worth of data to send 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.

STDM



a. Synchronous TDM



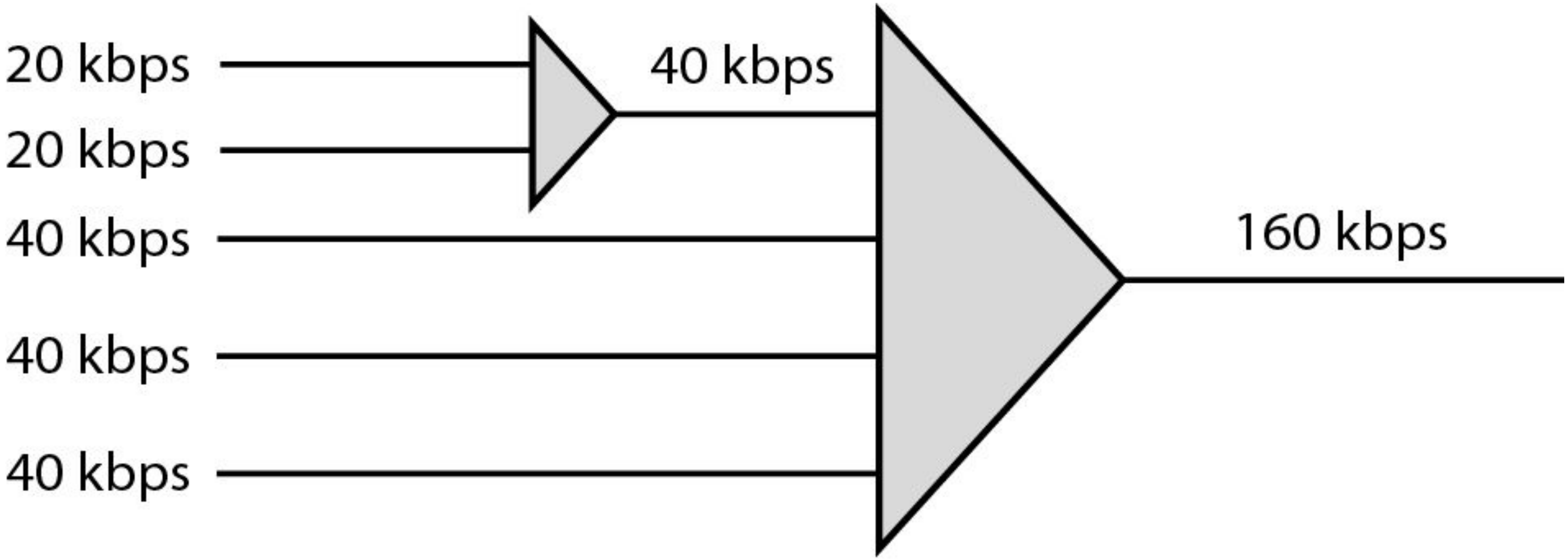
b. Statistical TDM

Data Rate Management

- One problem with the TDM is how to handle a disparity in the input data rates.
- So far in our discussion, we assumed that the data rates of all input lines were the same.
- However, If the data rates are not the same, three strategies, or a combination of them, can be used.
- Three strategies are:
  - Multilevel multiplexing
  - Multiple-slot allocation
  - Pulse stuffing.

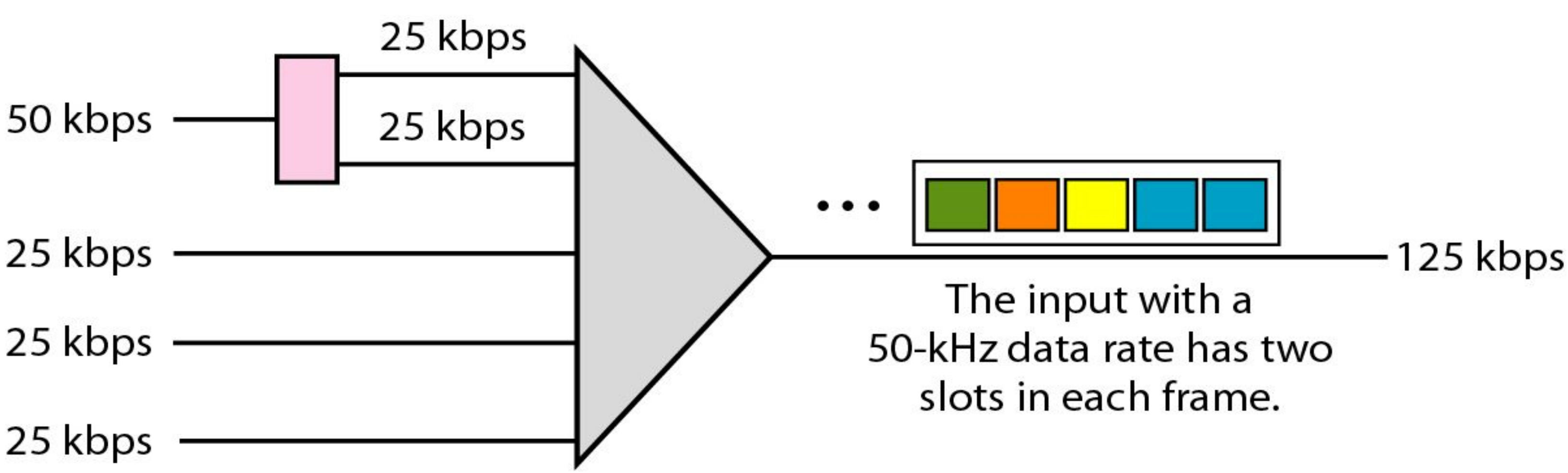
Multilevel Multiplexing

- Multilevel multiplexing is a technique used when the data rate of an input line is a multiple of others.
- 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.



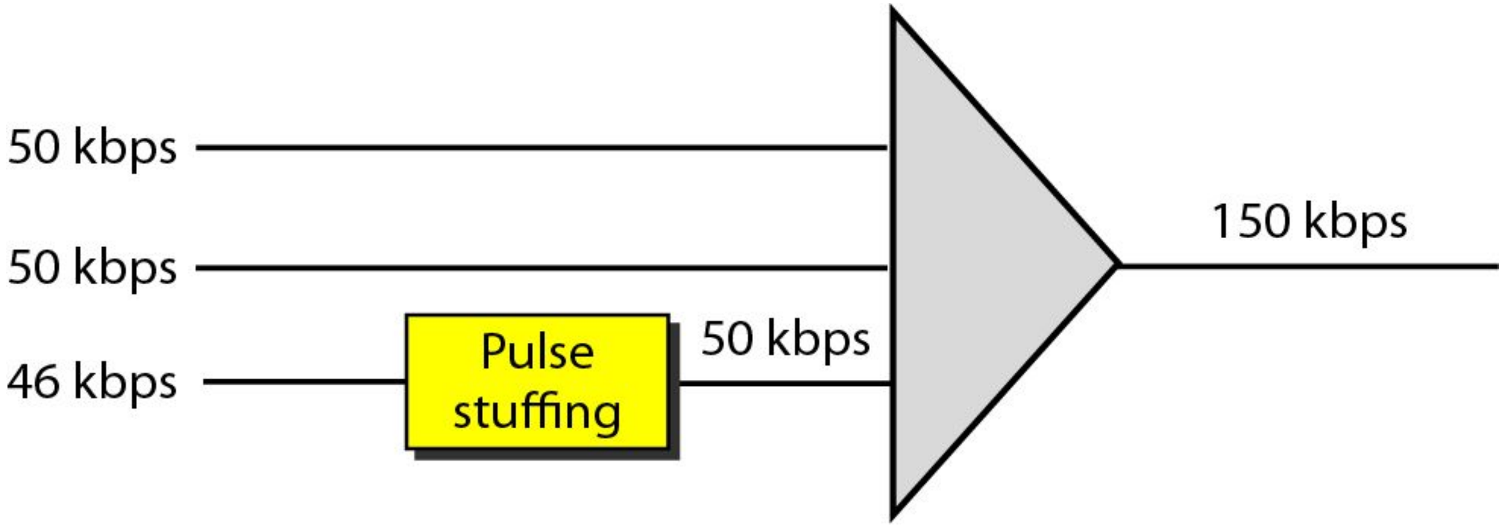
Multiple Slot Allocation

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



Pulse Stuffing

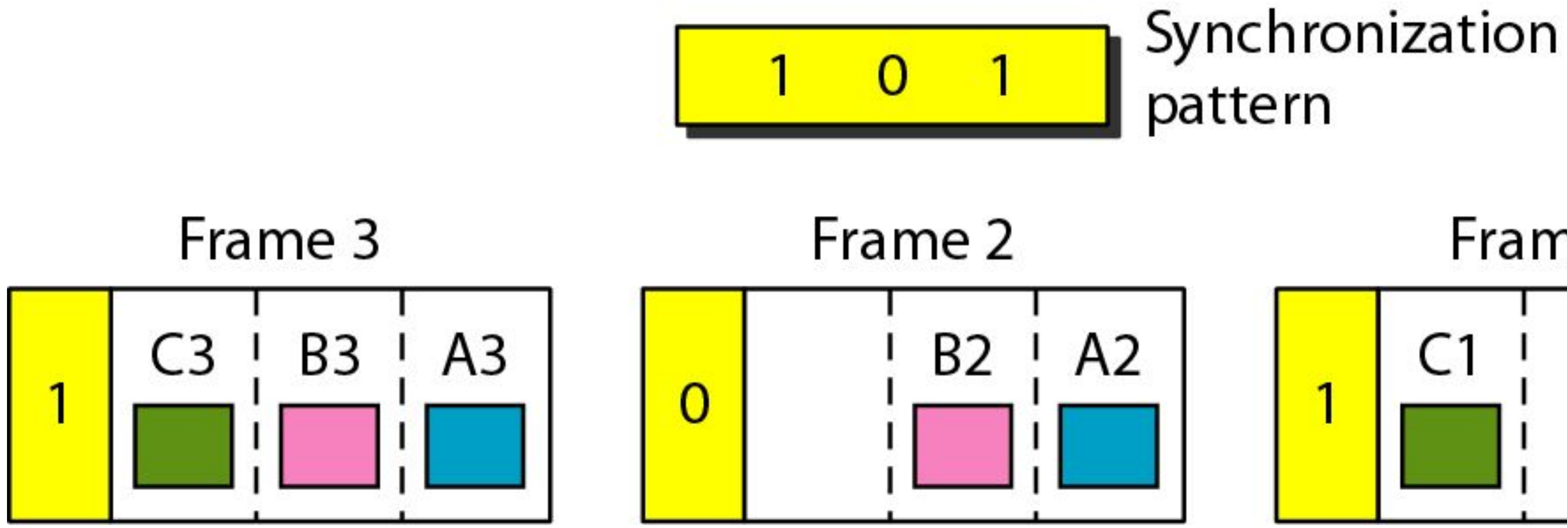
- Sometimes the bit rates of sources are not multiple integers of each other. Therefore, neither of the above two techniques can be applied.
- One solution is to make the highest input data rate the dominant data rate and then add dummy bits to the input lines with lower rates.
- This technique is called pulse stuffing, bit padding, or bit stuffing.



Frame Synchronizing

- The implementation of TDM is not as simple as FDM.
- Synchronization between the multiplexer and demultiplexer is a major issue.
- 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 framing bits allows the demultiplexer to synchronize with the incoming stream so that it can separate the time slots accurately.
- In most cases, synchronization information consists of 1 bit per frame, alternating between 0 and 1

Framing Synchronization



Example-01

We have four sources, each creating 250 8-bit characters per second. If the interleaved unit is a character and 1 synchronizing bit is added to each frame, find (a) the data rate of each source, (b) the duration of each character in each source, (c) the frame rate, (d) the duration of each frame, (e) the number of bits in each frame, and (f) the data rate of the link.

Solution

We can answer the questions as follows:

a. The data rate of each source is $250 \times 8 = 2000$ bps = 2 kbps.

Example-01 (Cont..)

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

c. *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.*

d. *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.*

e. *Each frame carries 4 characters and 1 extra synchronizing bit. This means that each frame is* $4 \times 8 + 1 = 33$ *bits.*

Example-02

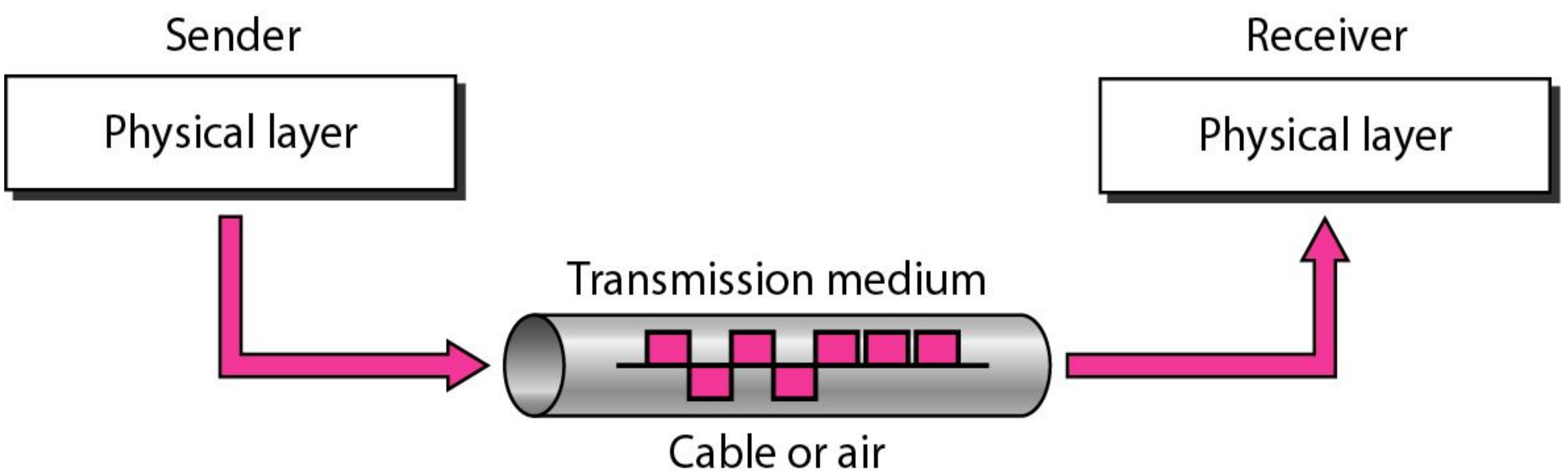
Two channels, one with a bit rate of 100 kbps and another with a bit rate of 200 kbps, are to be multiplexed. How this can be achieved? What is the frame rate? What is the frame duration? What is the bit rate of the link?

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 bit rate is 100,000 frames/s × 3 bits per frame, or 300 kbps.

Transmission Media

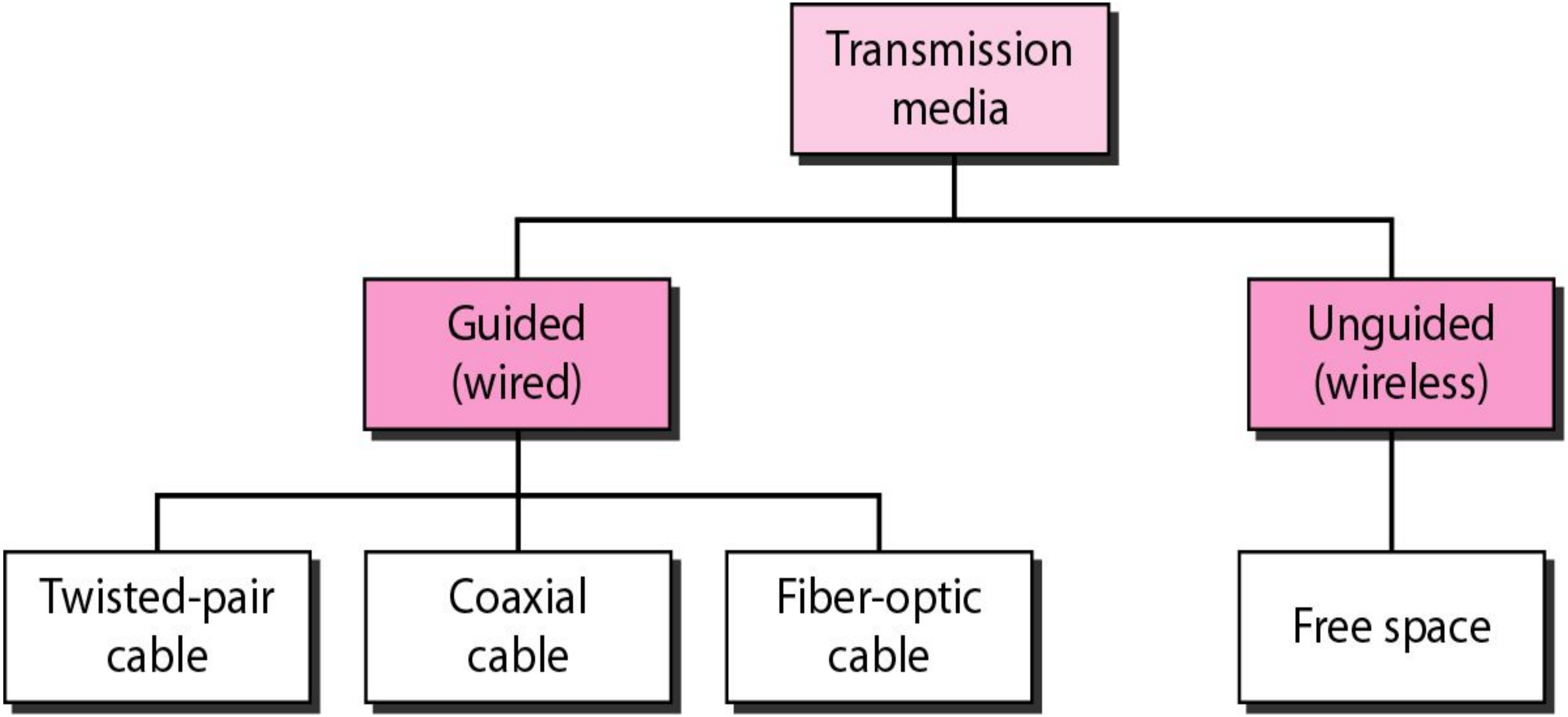
- Transmission media are actually located below the physical layer and are directly controlled by the physical layer.
- The following figure shows the position of transmission media in relation to the physical layer.
- A transmission medium can be broadly defined as anything that can carry information from a source to a destination.



Introduction

- computers and other telecommunication devices use signals to represent data.
- These signals are transmitted from one device to another in the form of electromagnetic energy, which is propagated through transmission media.
- In telecommunications, transmission media can be divided into two broad categories: Guided and Unguided.
- Guided media include twisted-pair cable, coaxial cable, and fiber-optic cable. Unguided medium is free space.

Classes of transmission media



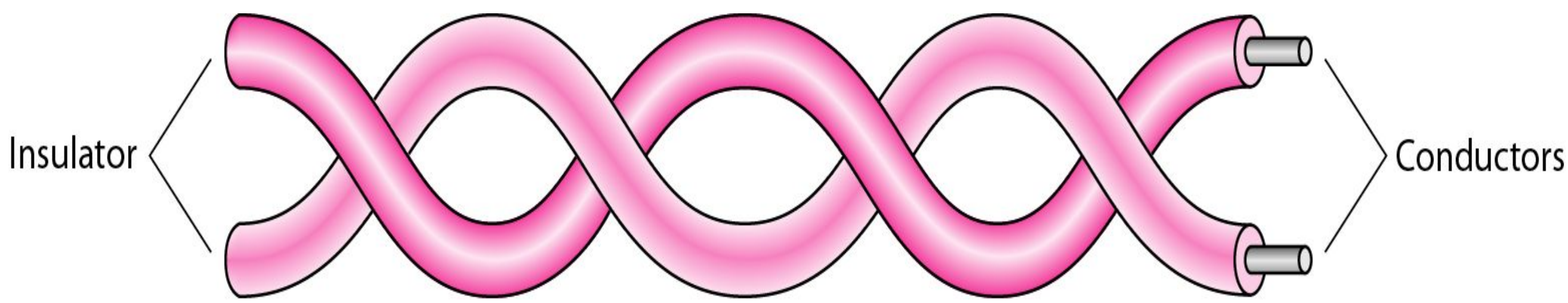
Guided Media

Guided media, which are those that provide a conduit from one device to another, include twisted-pair cable, coaxial cable, and fiber-optic cable.

- Twisted-pair and coaxial cable use metallic (copper) conductors that accept and transport signals in the form of electric current.
- Optical fiber is a cable that accepts and transports signals in the form of light.

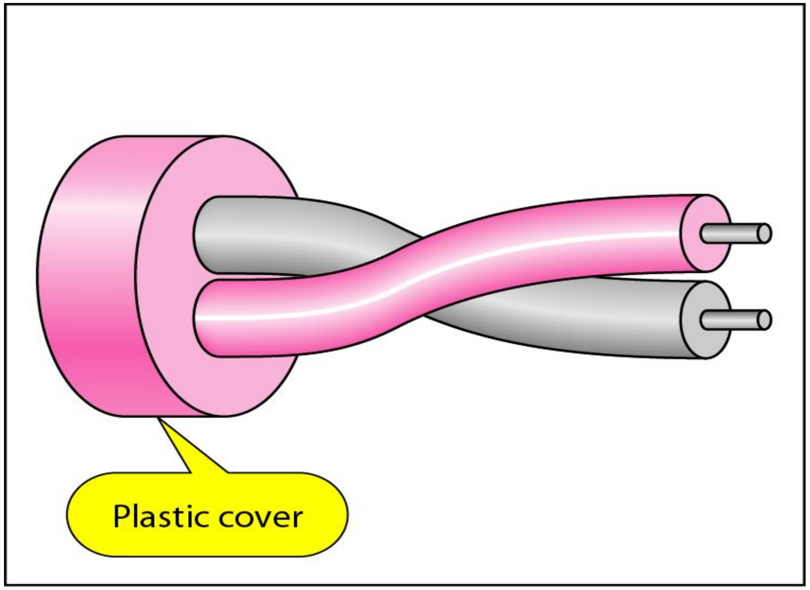
Twisted-Pair Cable

- A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together.
- One of the wires is used to carry signals to the receiver, and the other is used only as a ground reference.
- Additionally Interference (noise) and crosstalk may affect both wires and create unwanted signals.
- Number of twists per unit of length (e.g., inch) has some effect on the quality of the cable.

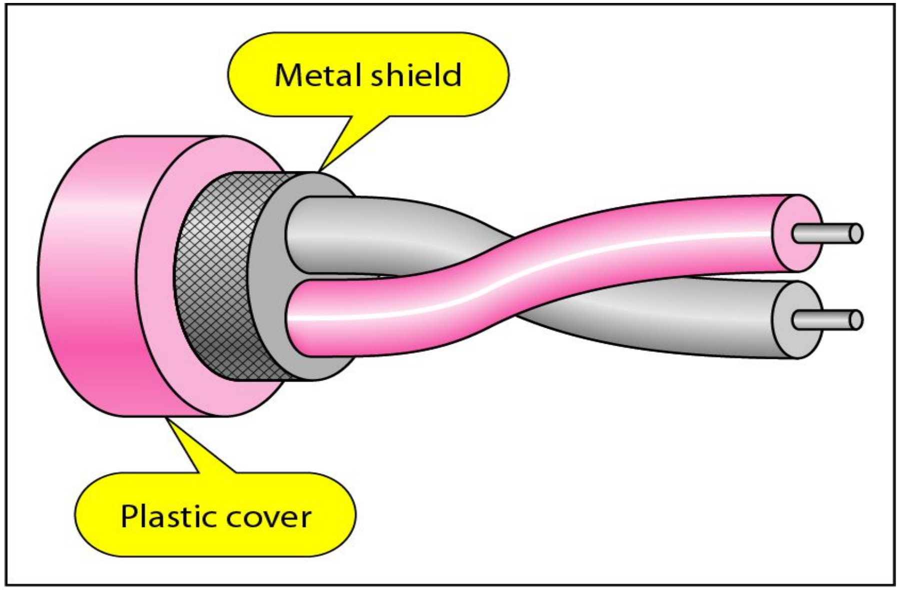


Unshielded Versus Shielded Twisted-Pair Cable

- Most common TPC used in communication is UTP.
- IBM has also produced a version of TPC for its use called shielded twisted-pair (STP).
- STP cable has a metal foil or braided mesh covering that encases each pair of insulated conductors.
- Although metal casing improves the quality of cable by preventing noise or crosstalk, But its expensive.



a. UTP



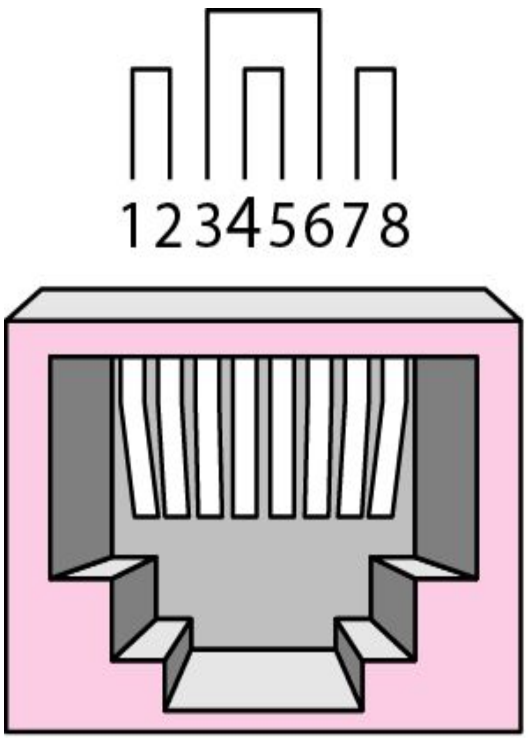
b. STP

Categories of unshielded twisted-pair cables

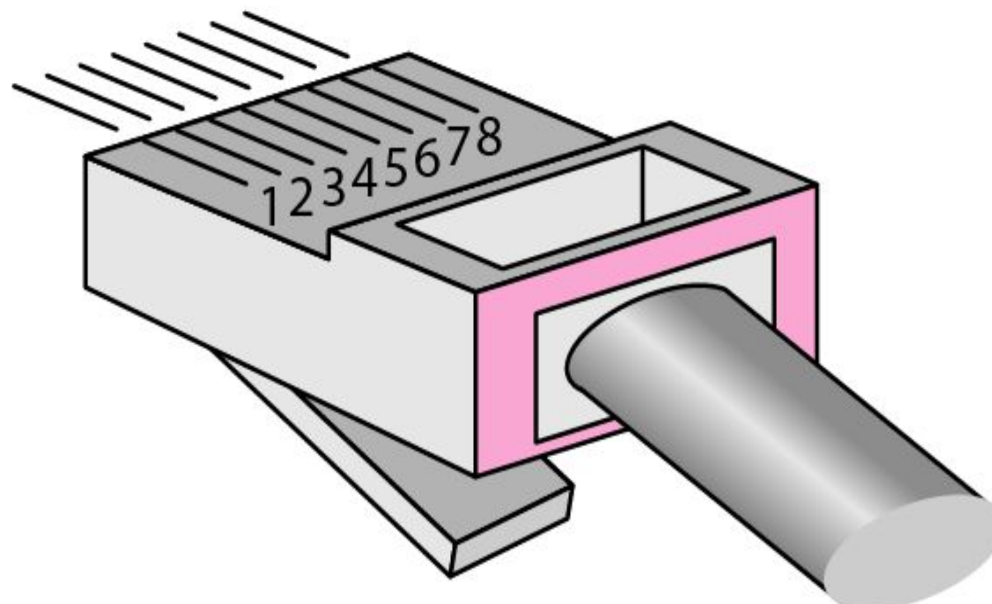
Category	*Specification*	*Data Rate (Mbps)*	*Use*
1	Unshielded twisted-pair used in telephone	< 0.1	Telephone
2	Unshielded twisted-pair originally used in T-lines	2	T-1 lines
3	Improved CAT 2 used in LANs	10	LANs
4	Improved CAT 3 used in Token Ring networks	20	LANs
5	Cable wire is normally 24 AWG with a jacket and outside sheath	100	LANs
5E	An extension to category 5 that includes extra features to minimize the crosstalk and electromagnetic interference	125	LANs
6	A new category with matched components coming from the same manufacturer. The cable must be tested at a 200-Mbps data rate.	200	LANs
7	Sometimes called SSTP (shielded screen twisted-pair). Each pair is individually wrapped in a helical metallic foil followed by a metallic foil shield in addition to the outside sheath. The shield decreases the effect of crosstalk and increases the data rate.	600	LANs

Connectors

- The most common UTP connector is RJ45 (RJ stands for registered jack).
- The RJ45 is a keyed connector, meaning the connector can be inserted in only one way.



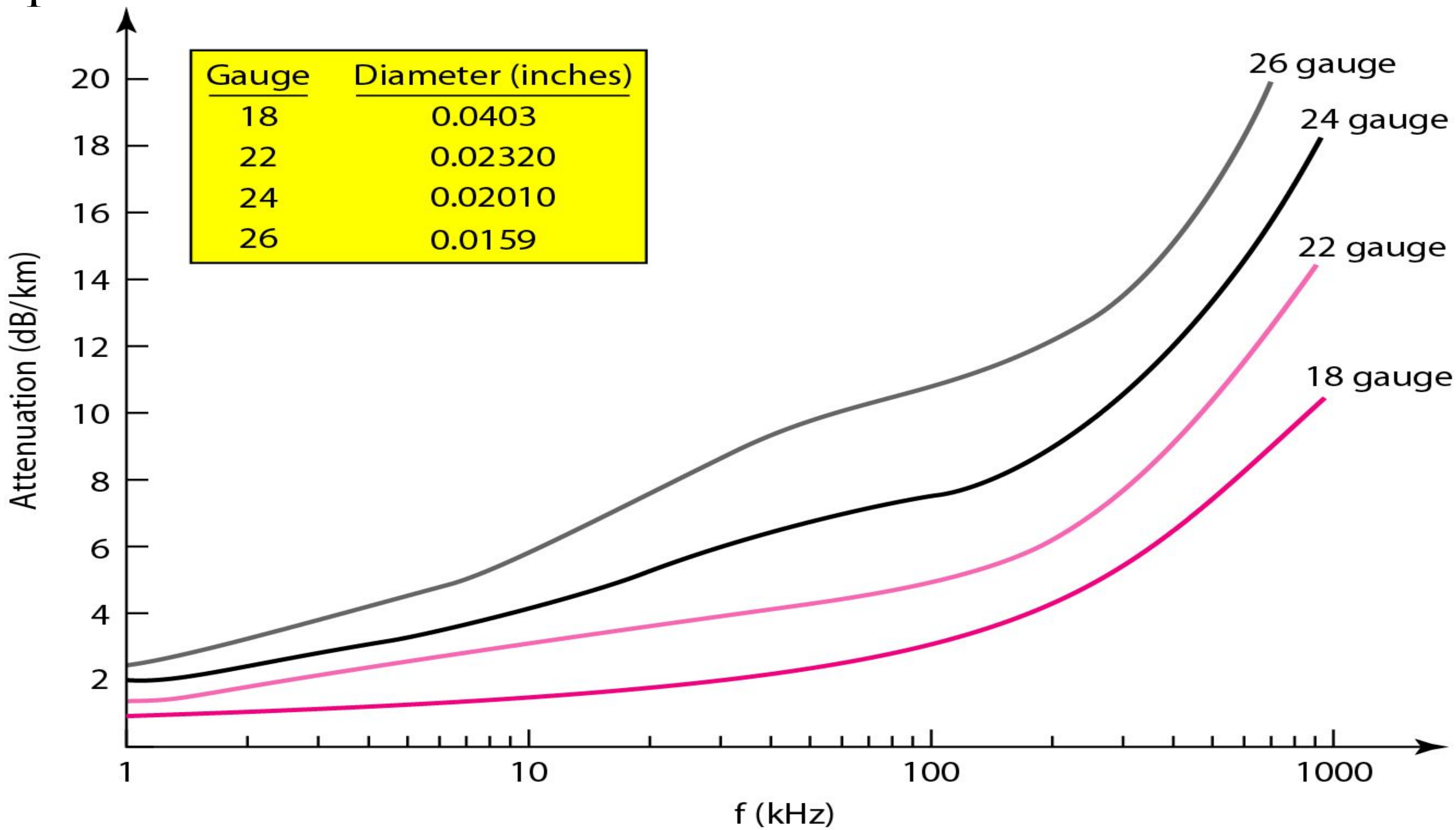
RJ-45 Female



RJ-45 Male

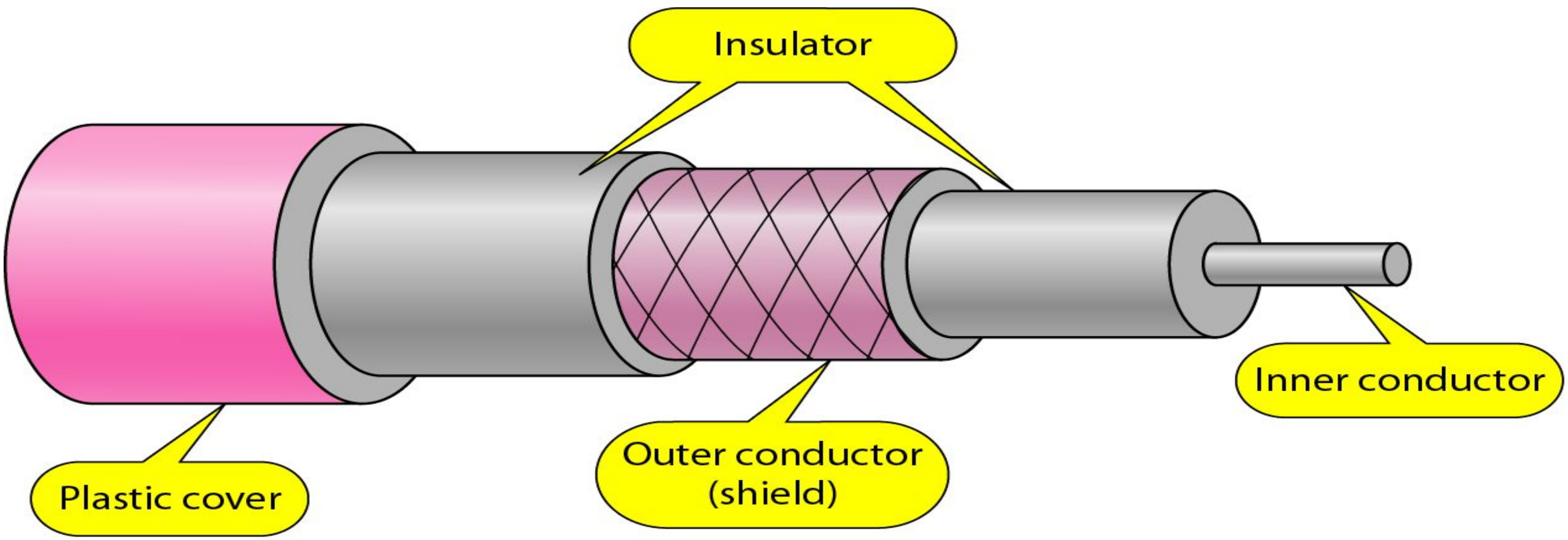
Performance

- One way to measure the performance of twisted-pair cable is to compare attenuation versus frequency and distance.
- A twisted-pair cable can pass a wide range of frequencies.
- With increasing frequency, the attenuation sharply increases with frequencies above 100 kHz.



Coaxial Cable

- Coaxial cable carries signals of higher frequency ranges than twisted pair cable, in part because the two media are constructed quite differently.
- coax has a central core conductor of solid or stranded wire (usually copper) enclosed in an insulating sheath.
- The outer metallic wrapping serves both as a shield against noise and as the second conductor, which completes the circuit.



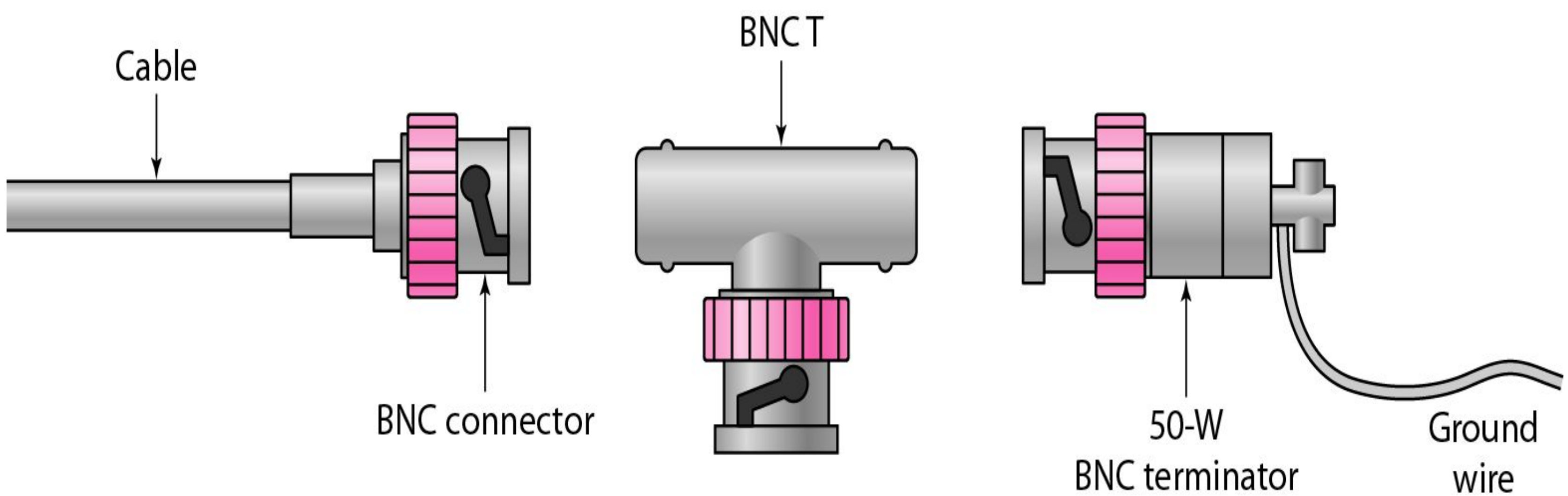
Coaxial Cable Standards

- Coaxial cables are categorized by their radio government (RG) ratings.
- Each RG number denotes a unique set of physical specifications, including the wire gauge of the inner conductor, the thickness and type of the inner insulator, size and type of the outer case.

Category	*Impedance*	*Use*
RG-59	75 Ω	Cable TV
RG-58	50 Ω	Thin Ethernet
RG-11	50 Ω	Thick Ethernet

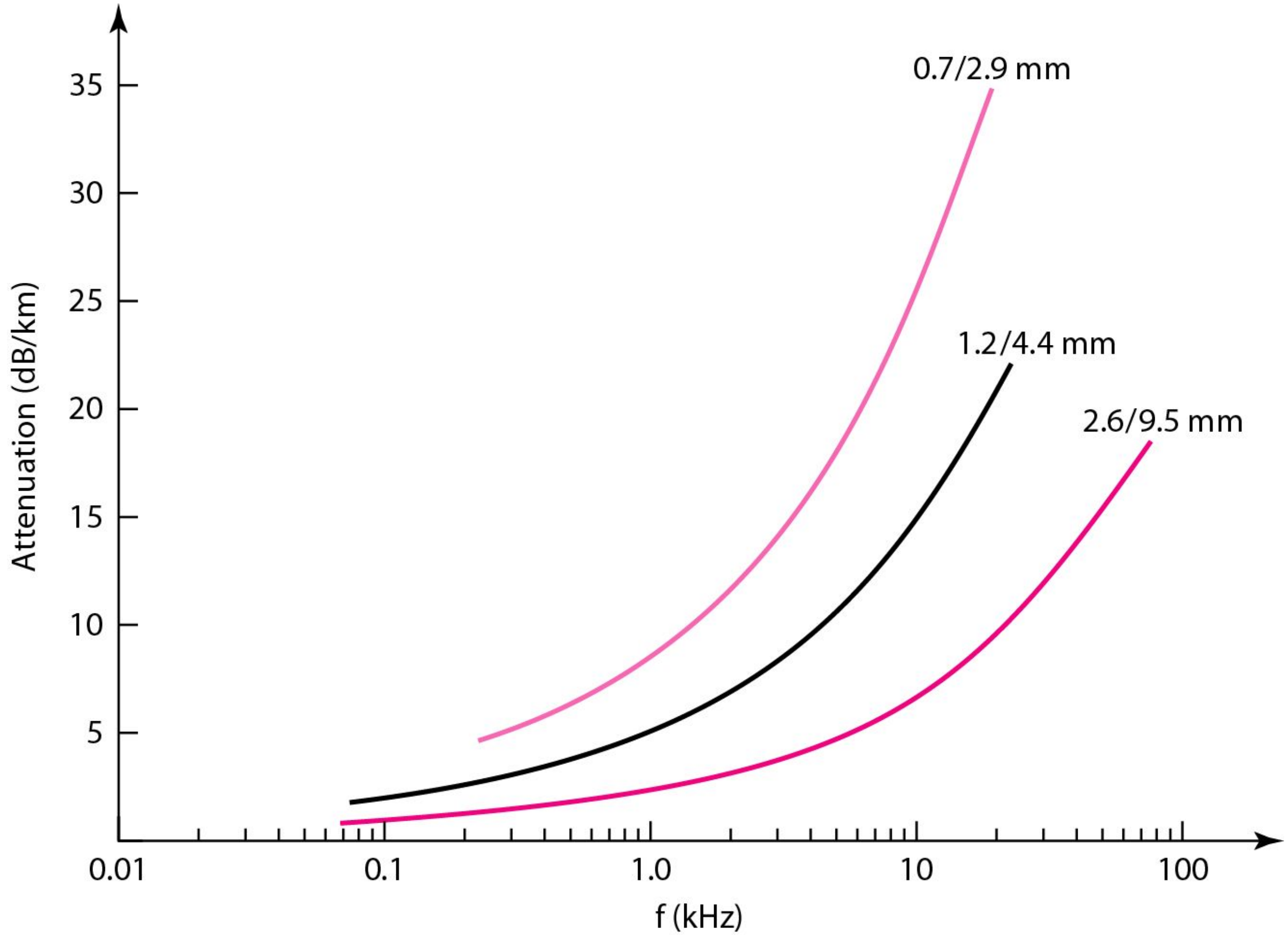
Coaxial Cable Connectors

- The most common type of connector used today is the Bayone-Neill-Concelman (BNC), connector.
- The following figure shows the 3 types of connectors: the BNC connector, the BNC T connector, and the BNC terminator.
- The BNC connector is used to connect the end of the cable to a device, such as a TV set.
- The BNC T connector is used in Ethernet networks.
- The BNC terminator is used at the end of the cable to prevent the reflection of the signal.



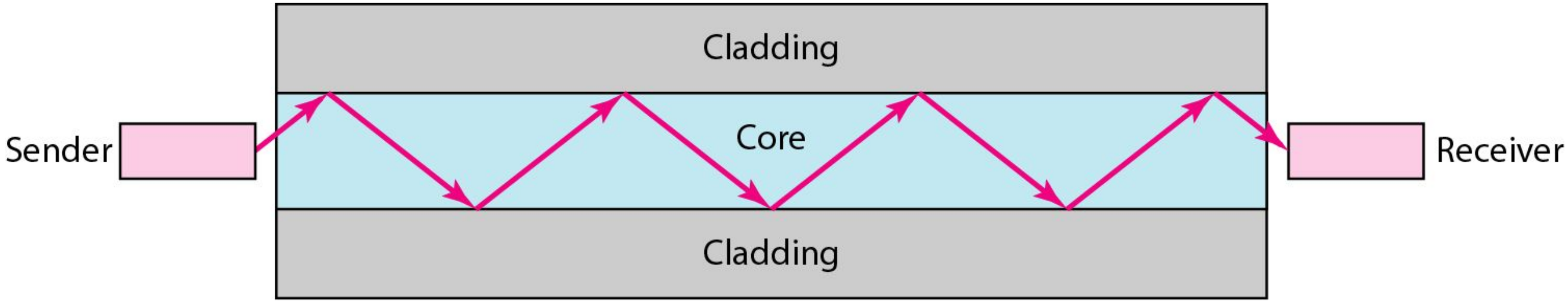
Performance

- Attenuation is much higher in coaxial cables than in twisted-pair cable.
- Coaxial cable has a much higher bandwidth, the signal weakens rapidly and requires the frequent use of repeaters.

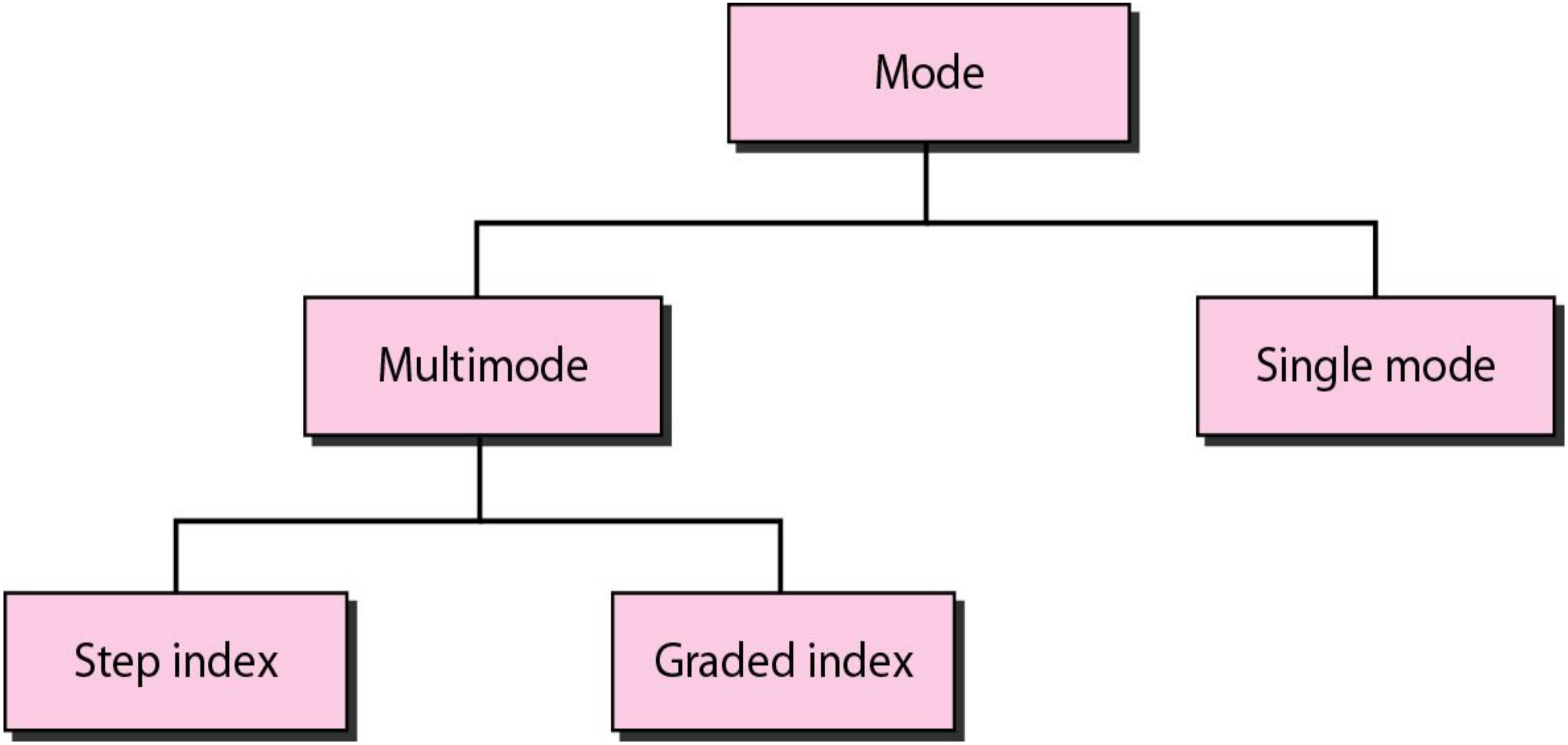


Fiber-Optic Cable

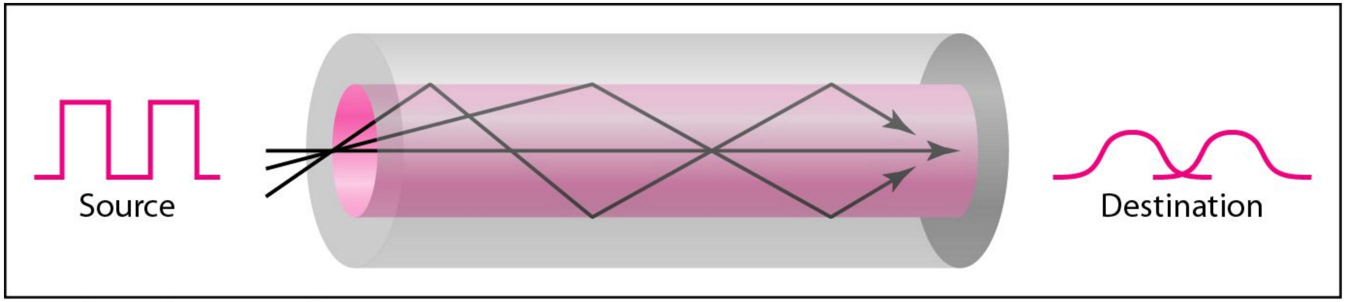
- A fiber-optic cable is made of glass or plastic and transmits signals in the form of light.
- Optical fibers use reflection to guide light through a channel.
- A glass or plastic core is surrounded by a cladding of less dense glass or plastic.
- A beam of light moving through the core is reflected off the cladding instead of being refracted into it.



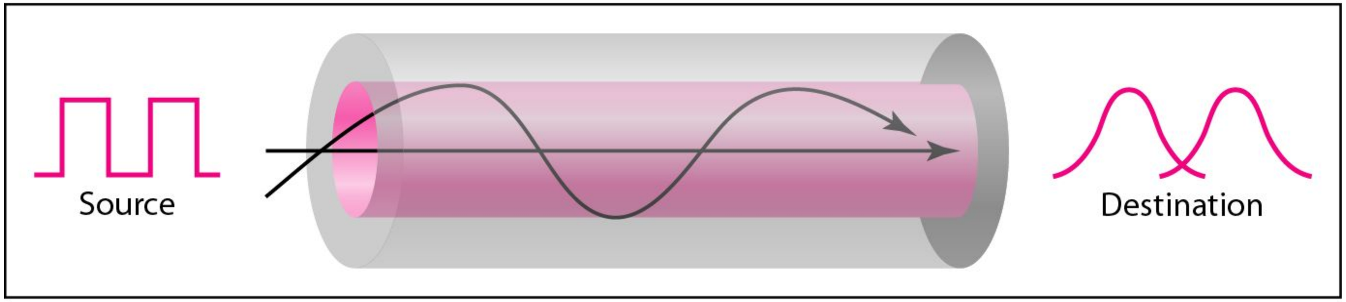
Propagation Modes



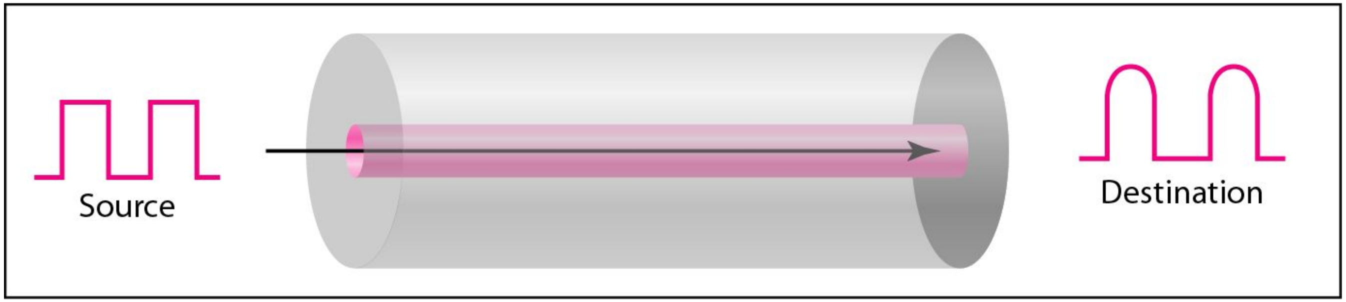
Modes



a. Multimode, step index



b. Multimode, graded index

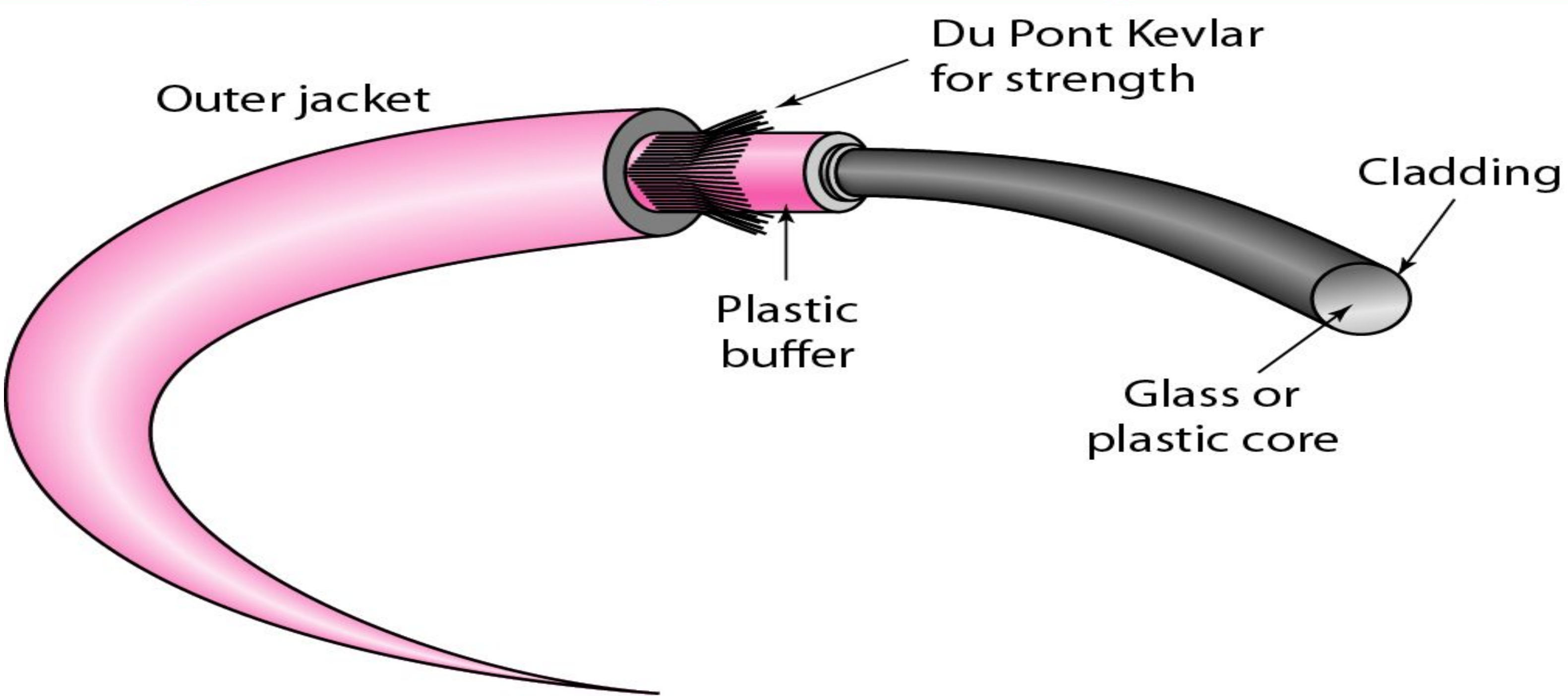


c. Single mode

Fiber sizes

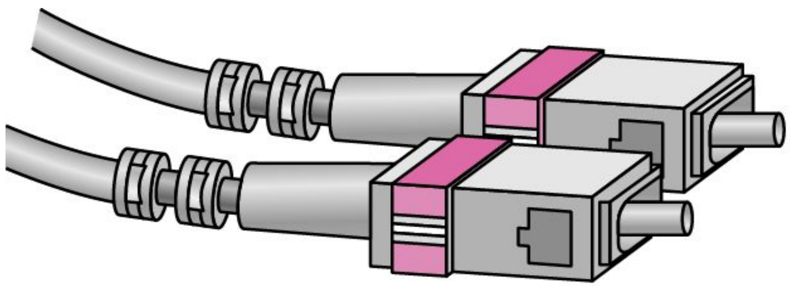
- Optical fibers are defined by the ratio of the diameter of their core to the diameter of their cladding, both expressed in micrometers.

Type	*Core (µm)*	*Cladding (µm)*	*Mode*
50/125	50.0	125	Multimode, graded index
62.5/125	62.5	125	Multimode, graded index
100/125	100.0	125	Multimode, graded index
7/125	7.0	125	Single mode

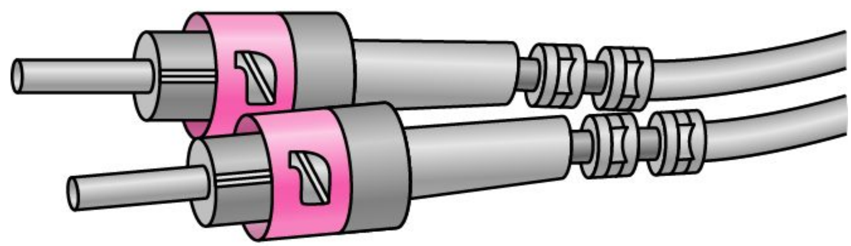


Fiber-Optic Cable Connectors

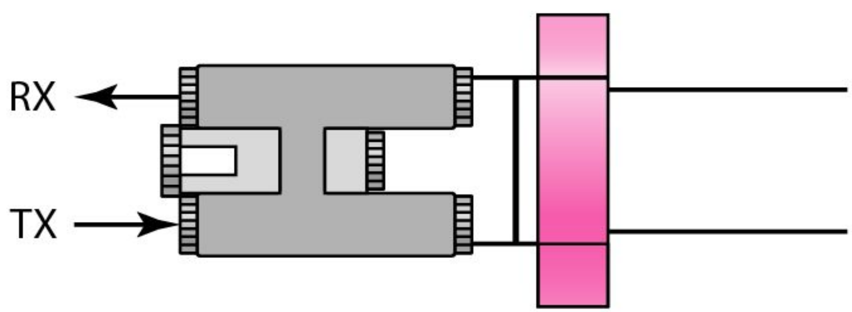
- The subscriber channel (SC) connector is used for cable TV. It uses a push/pull locking system.
- The straight-tip (ST) connector is used for connecting cable to networking devices.
- MT-RJ is a connector that is the same size as RJ45.



SC connector



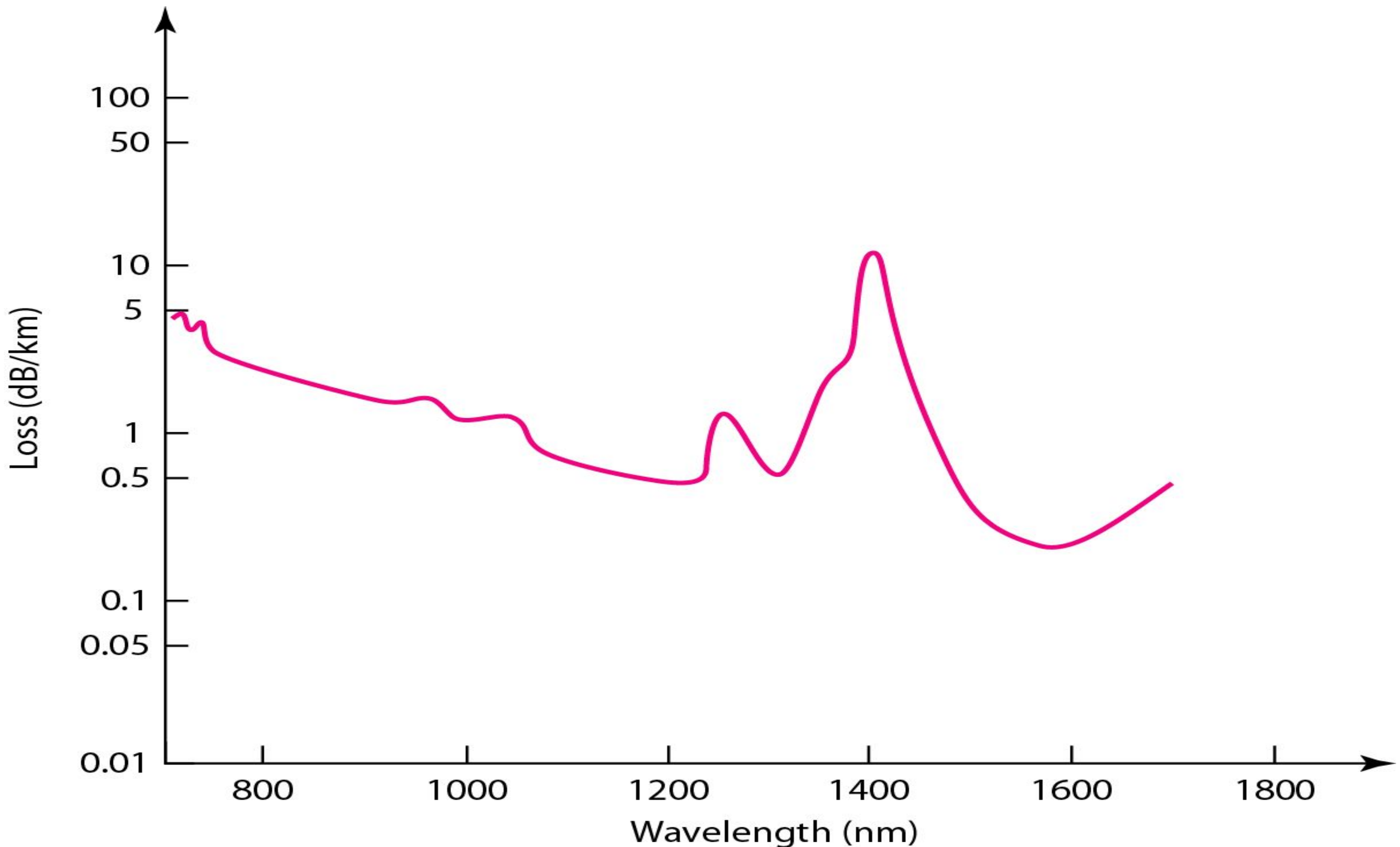
ST connector



MT-RJ connector

Performance

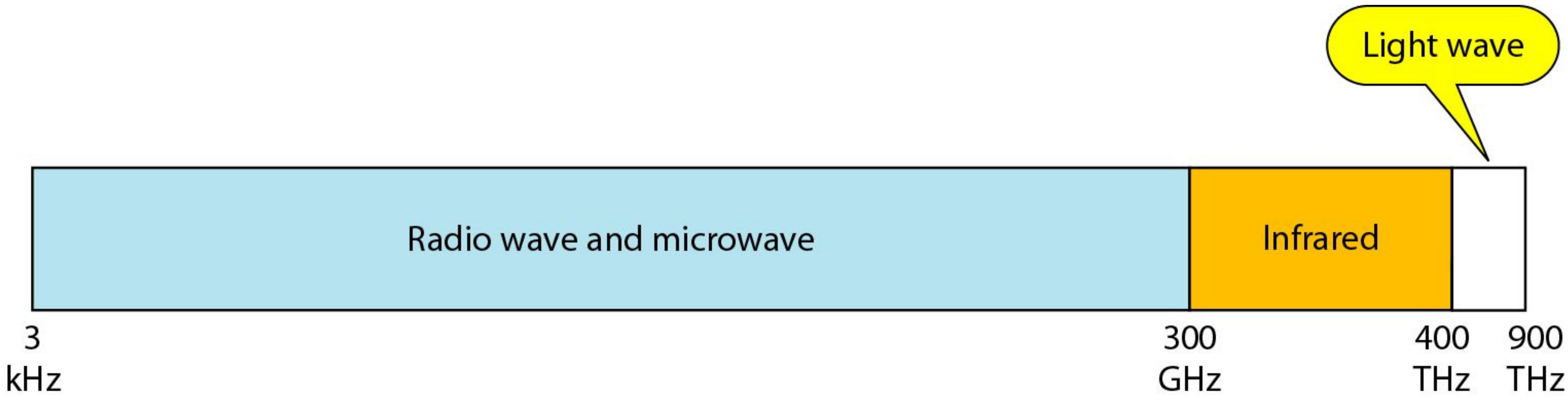
- Attenuation is flatter than in the case of twisted-pair cable and coaxial cable.
- The performance is such that we need fewer (actually 10 times less) repeaters when we use fiber-optic cable.



UNGUIDED MEDIA: WIRELESS

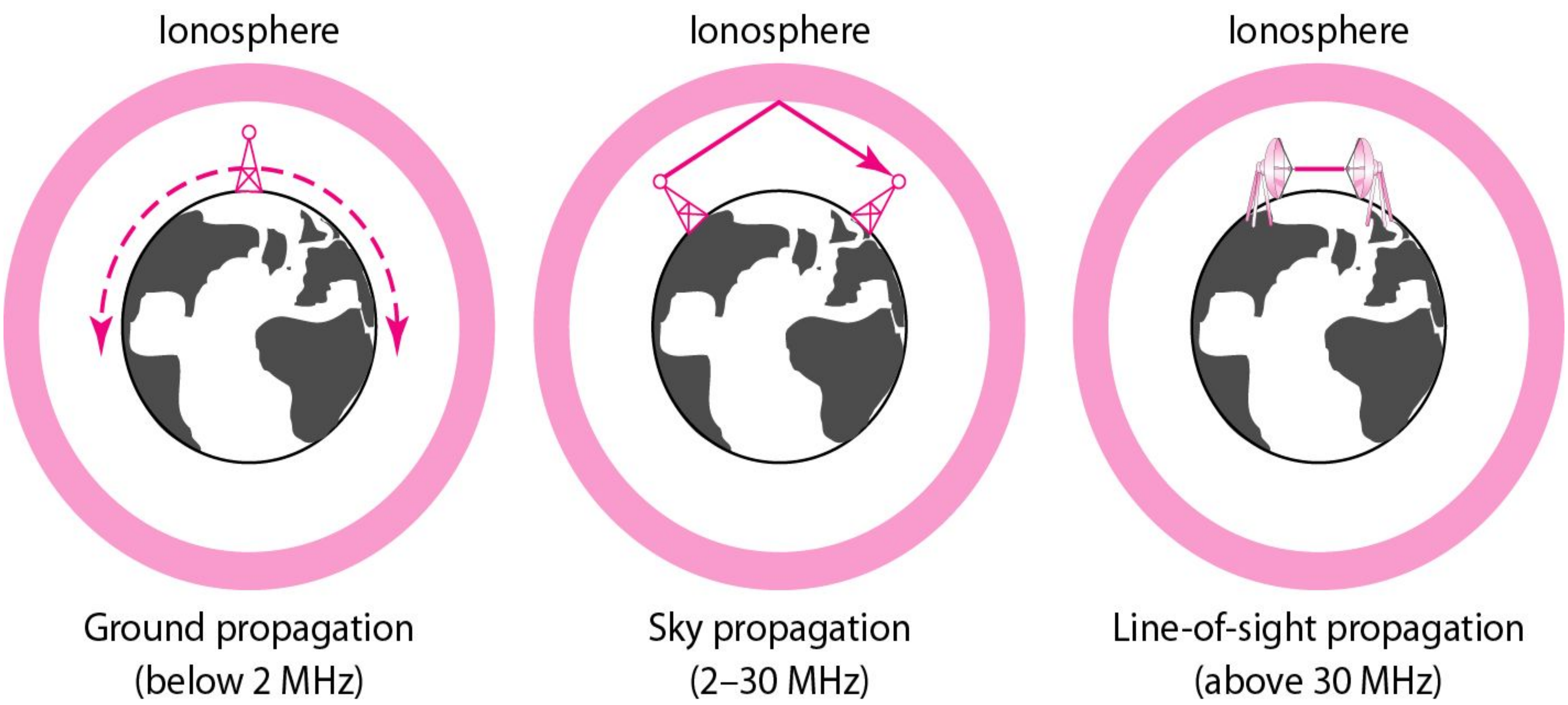
Unguided media transport electromagnetic waves without using a physical conductor. This type of communication is often referred to as wireless communication.

- Signals are normally broadcast through free space and anyone who has a device capable of receiving them.



Propagation method

- Unguided signals can travel from the source to destination in several ways: ground propagation, sky propagation, and line-of-sight propagation.



Propagation methods

- In ground propagation, radio waves travel through the lowest portion of the atmosphere.
- These low-frequency signals emanate in all directions from the transmitting antenna and follow the curvature of the planet.
- Distance depends on the amount of power in the signal: The greater the power, the greater the distance.
- In sky propagation, higher-frequency radio waves radiate upward into the ionosphere (the layer of atmosphere where particles exist as ions).
- They are reflected back to earth. This type of transmission allows for greater distances with lower output power.
- In line-or-sight propagation, very high-frequency signals are transmitted in straight lines directly from antenna facing each others.

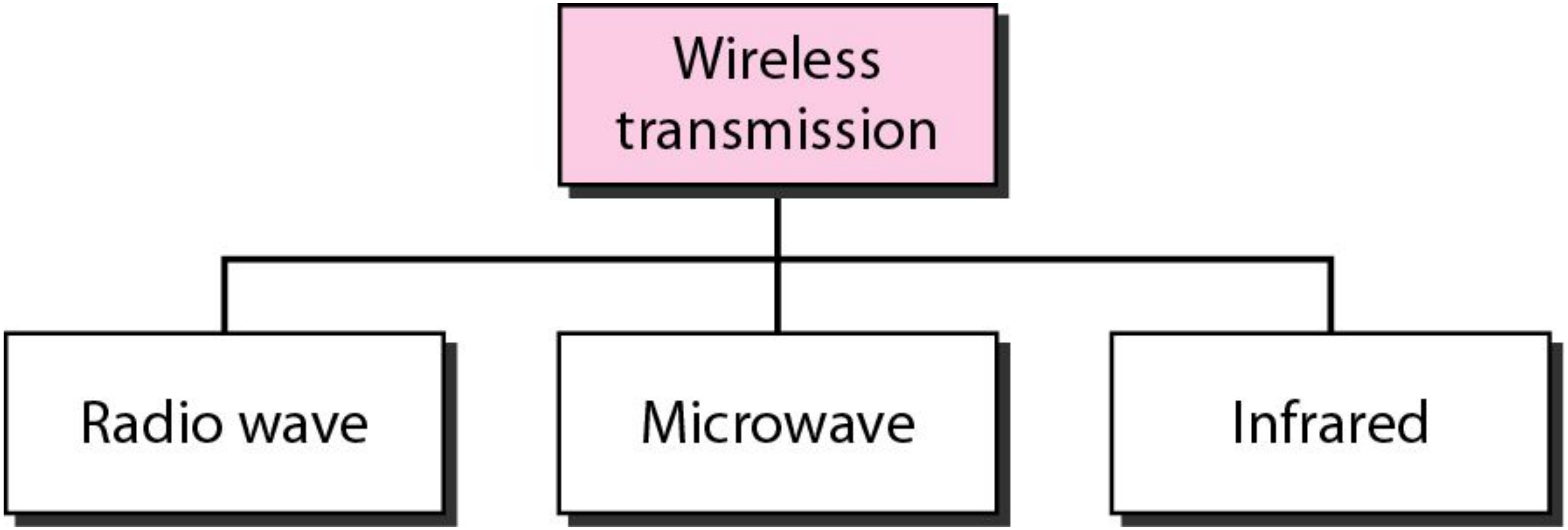
Bands

- Electromagnetic spectrum defined as radio waves and microwaves is divided into eight ranges, called bands.

Band	*Range*	*Propagation*	*Application*
VLF (very low frequency)	3–30 kHz	Ground	Long-range radio navigation
LF (low frequency)	30–300 kHz	Ground	Radio beacons and navigational locators
MF (middle frequency)	300 kHz–3 MHz	Sky	AM radio
HF (high frequency)	3–30 MHz	Sky	Citizens band (CB), ship/aircraft communication
VHF (very high frequency)	30–300 MHz	Sky and line-of-sight	VHF TV, FM radio
UHF (ultrahigh frequency)	300 MHz–3 GHz	Line-of-sight	UHF TV, cellular phones, paging, satellite
SHF (superhigh frequency)	3–30 GHz	Line-of-sight	Satellite communication
EHF (extremely high frequency)	30–300 GHz	Line-of-sight	Radar, satellite

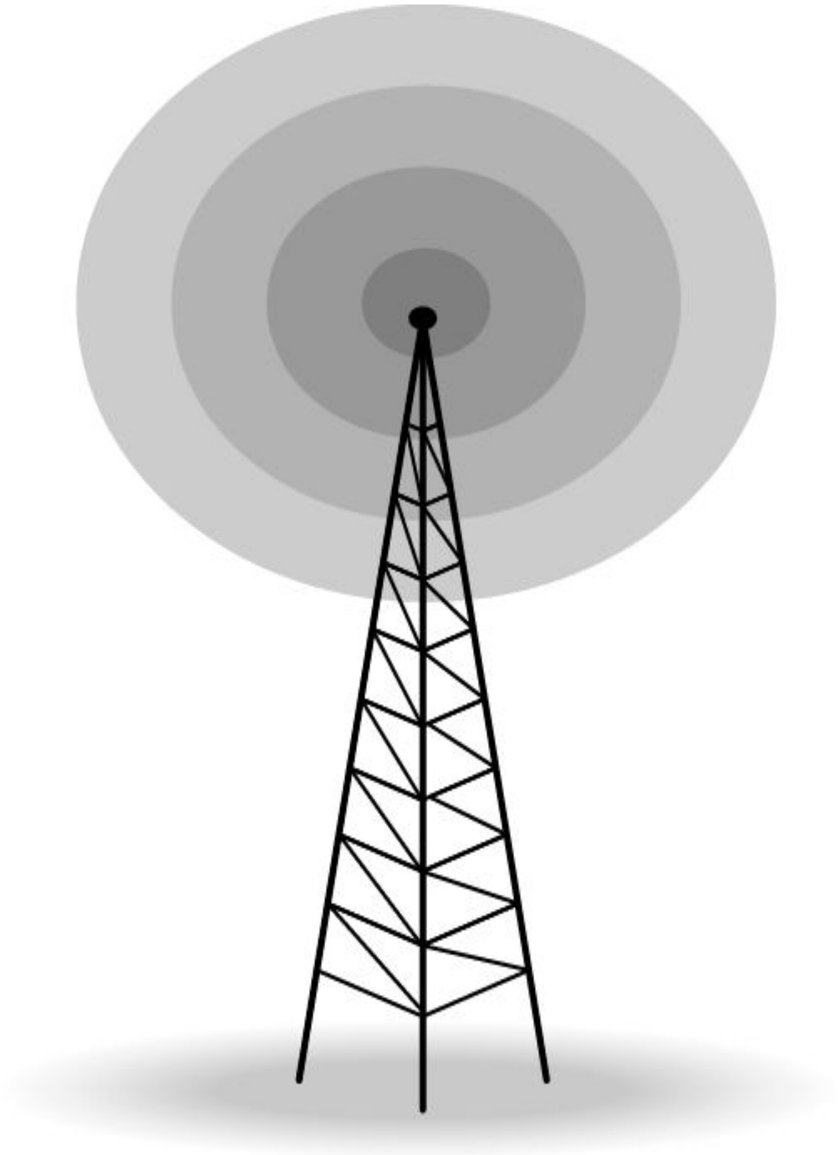
Wireless transmission

- Wireless transmission can be divided into three broad groups: radio waves, microwaves, and infrared waves.



Radio Waves

Radio waves are used for multicast communications, such as radio and television, and paging systems. They can penetrate through walls. Highly regulated. Use omni directional antennas



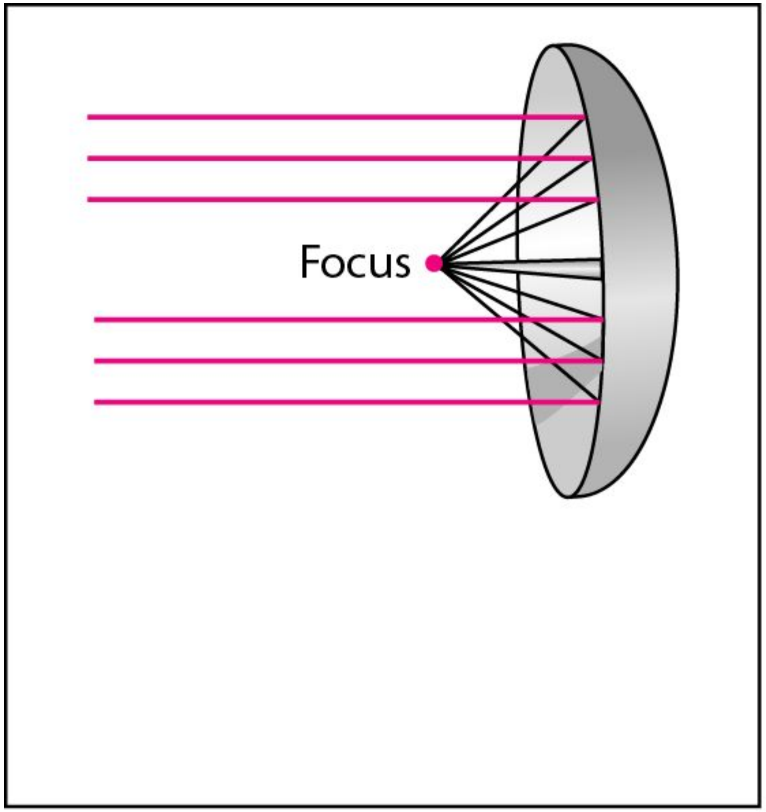
Micro Waves

Microwaves are used for unicast communication such as cellular telephones, satellite networks, and wireless LANs.

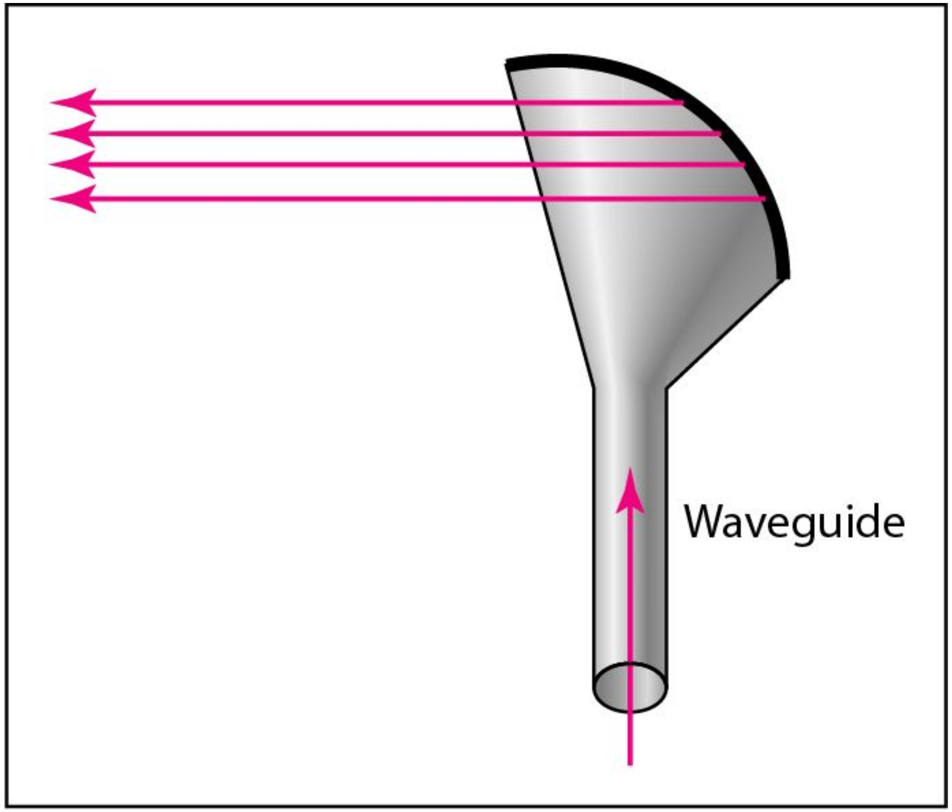
Higher frequency ranges cannot penetrate walls.

Use directional antennas - point to point line of sight communications.

Unidirectional antennas



a. Dish antenna



b. Horn antenna

Infrared signals can be used for short-range communication in a closed area using line-of-sight propagation.

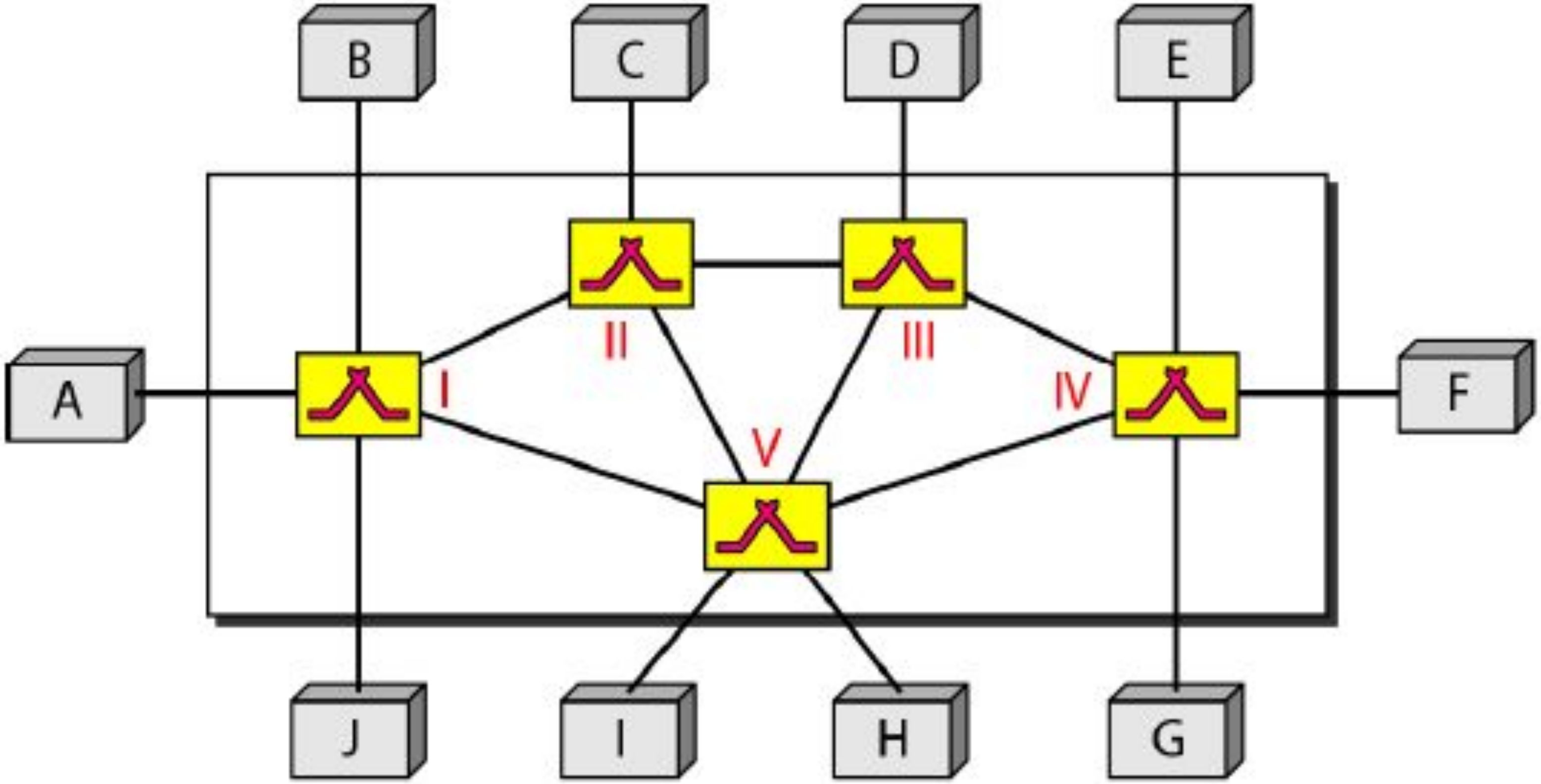
Wireless Channels

- Are subject to a lot more errors than guided media channels.
- Interference is one cause for errors, can be circumvented with high SNR.
- The higher the SNR the less capacity is available for transmission due to the broadcast nature of the channel.
- Channel also subject to fading and no coverage holes.

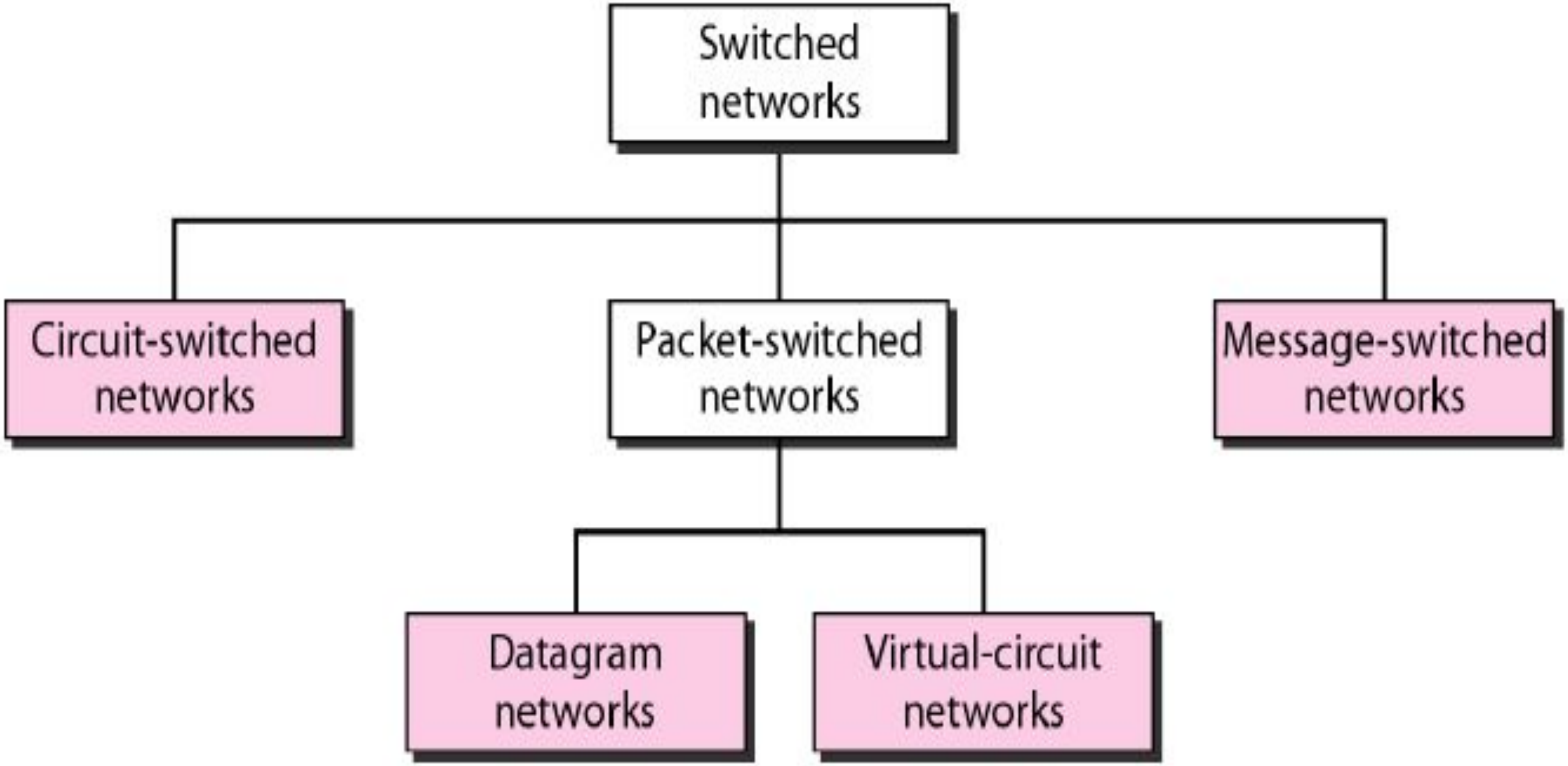
Switching

- A network is a set of connected devices.
- Whenever we have multiple devices, we have the problem of how to connect them to make one-to-one communication possible.
- One solution is to make a point-to-point connection between each pair of devices (a mesh topology) or between a central device and every other device (a star topology).
- These methods, however, are impractical and wasteful when applied to very large networks.
- A better solution is switching. A switched network consists of a series of interlinked nodes, called switches.
- Switches are devices capable of creating temporary connections between two or more devices linked to the switch.

Switched Network



Categories of Networks



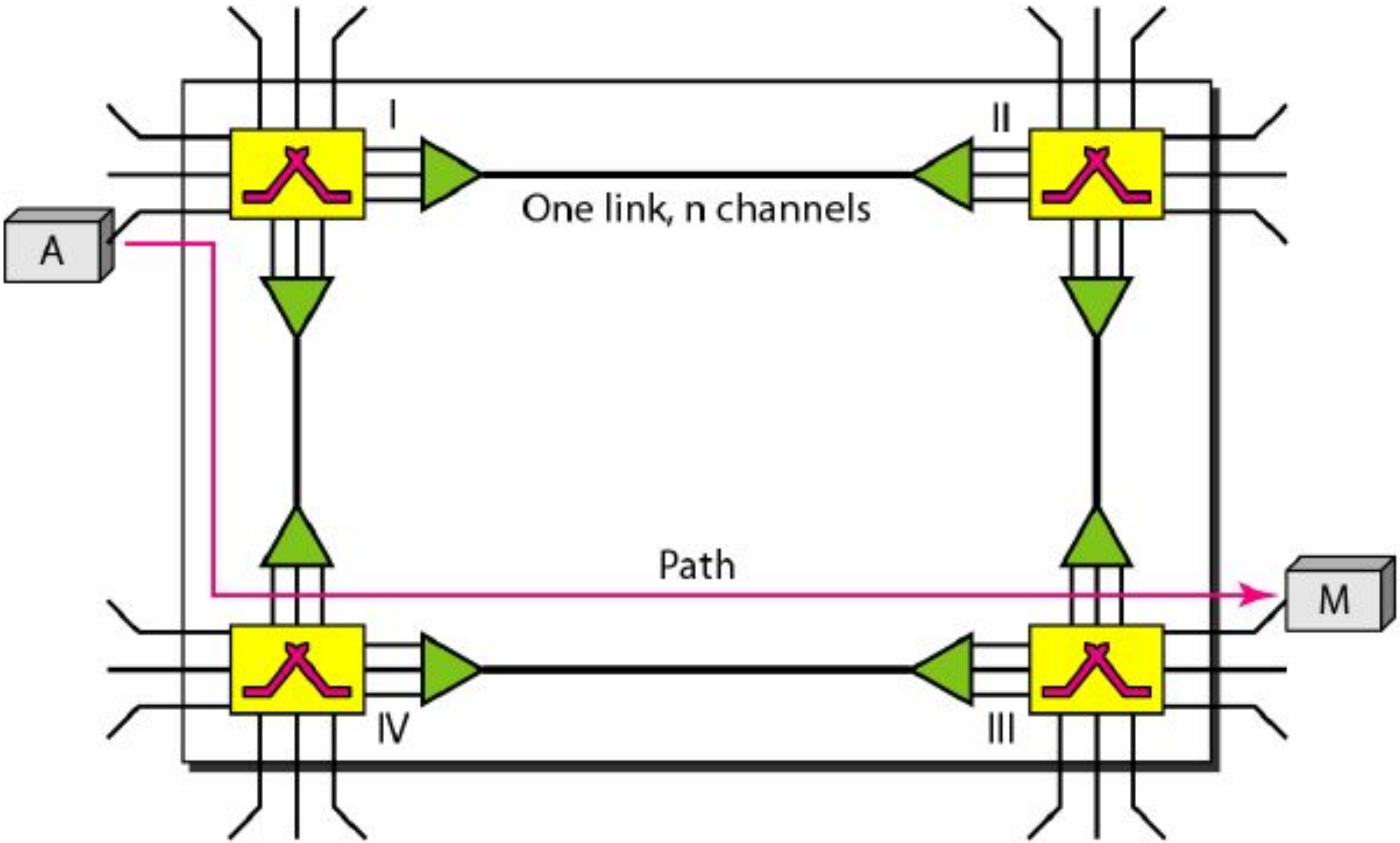
Circuit Switched Networks

A circuit-switched network consists of a set of switches connected by physical links. A connection between two stations is a dedicated path made of one or more links. However, each connection uses only one dedicated channel on each link. Each link is normally divided into n channels by using FDM or TDM.

Note

A circuit-switched network is made of a set of switches connected by physical links, in which each link is divided into *n* channels.

Trivial Circuit Switched Network



Note

In circuit switching, the resources need to be reserved during the setup phase; the resources remain dedicated for the entire duration of data transfer until the teardown phase.

Emphasizes on CSN

- Circuit switching takes place at the physical layer.
- The stations must make a reservation for the resources to be used during the communication.
- The data are a continuous flow sent by the source station and received by the destination station.
- There is no addressing involved during data transfer, there is end-to end addressing used during the setup phase.
- Few Example – Self Study

CSN phases

- Three Phases:
  - Setup phase- Reservation of resources.
  - Data Transfer Phase- Two parties transfer data
  - Teardown Phase- Signal sent to each switch to release the resources.
- Efficiency: CSN are not as efficient as the other two types of networks because resources are allocated during the entire duration of the connection. These resources are unavailable to other connections.
- Delay: Delay is minimum.

PSN- Datagram Networks

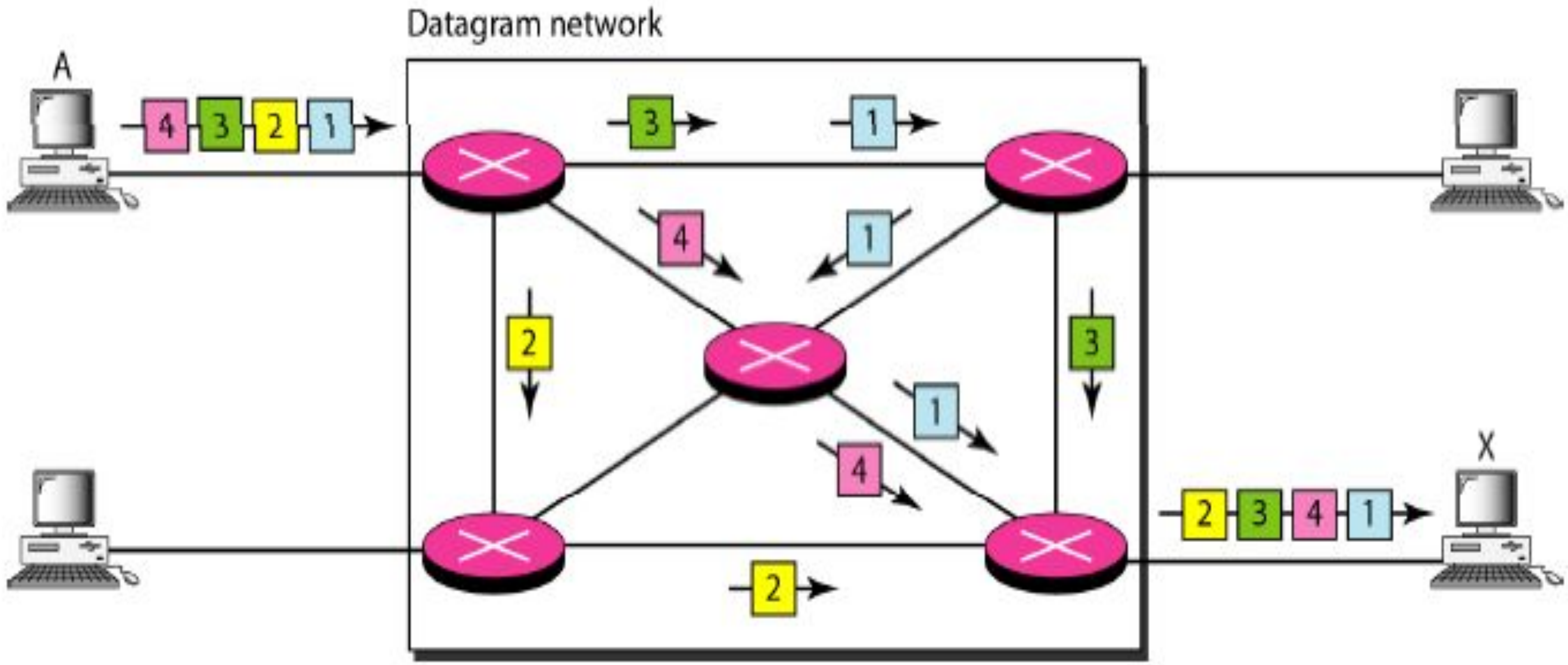
In data communications, we need to send messages from one end system to another. If the message is going to pass through a packet-switched network, it needs to be divided into packets of fixed or variable size. The size of the packet is determined by the network and the governing protocol.

Note

In a packet-switched network, there is no resource reservation; resources are allocated on demand.

Datagram Switched Network

- Also called as connectionless network.
- There are no connection setup, tear down process.



Emphasizes on DSN

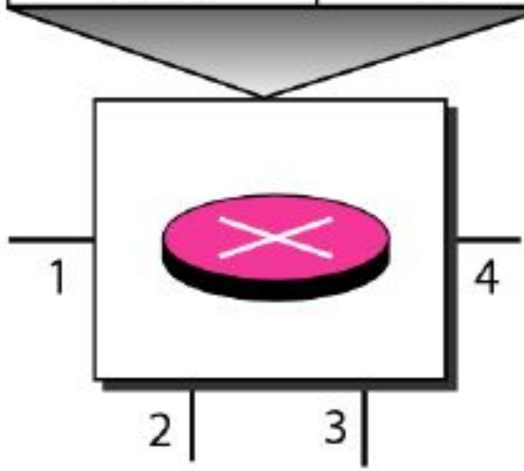
- Datagram switching is normally done at the network layer.
- The allocation is done on a first come, first-served basis.
- When a switch receives a packet, no matter what is the source or destination, the packet must wait if there are other packets being processed.
- Each packet is treated independently of all others and may take different route.
- it is the responsibility of an upper-layer protocol to reorder the datagrams or ask for lost datagrams before passing them on to the application.
- The switches in a datagram network are traditionally referred to as routers.

Routing Table

- Each switch (or packet switch) has a routing table which is based on the destination address.
- The routing tables are dynamic and are updated periodically.
- The destination addresses and the corresponding forwarding output ports are recorded in the tables.
- In CSN each entry is created when the setup phase is completed and deleted when the teardown phase is over.

Routing Table

Destination address	Output port
1232	1
4150	2
⋮	⋮
9130	3

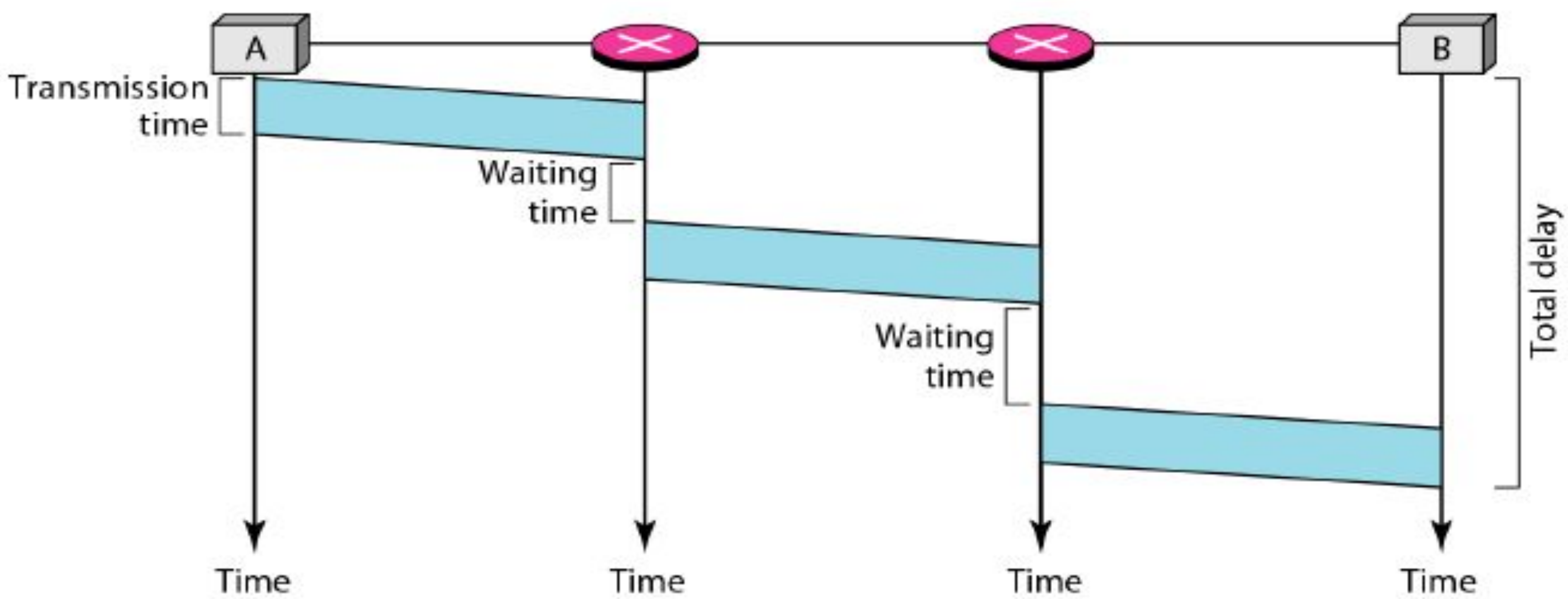


Note

A switch in a datagram network uses a routing table that is based on the destination address.

Performance of DSN

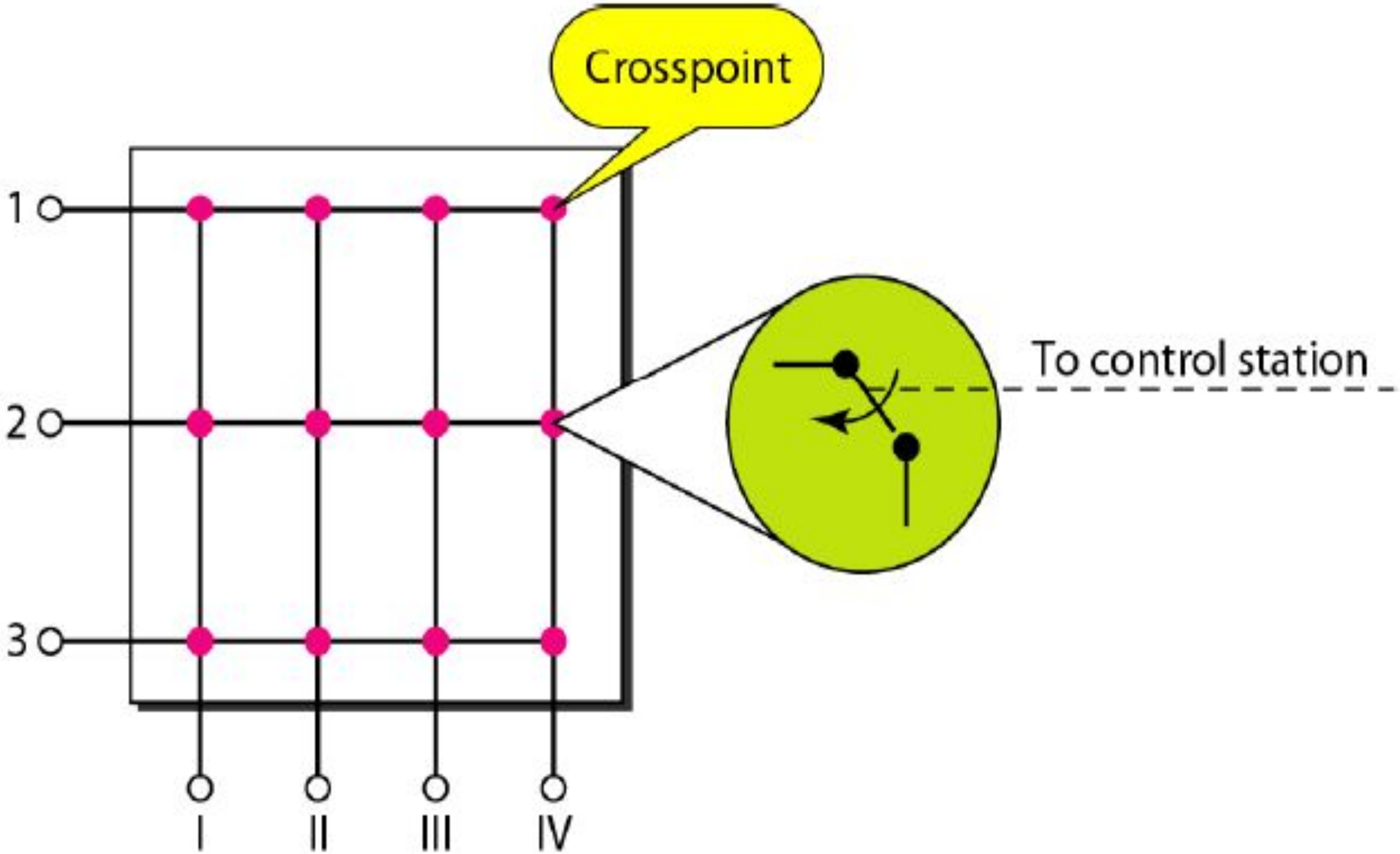
- Efficiency: The efficiency of a datagram network is better than that of a CSN. Resources are allocated only when there are packets to be transferred.
- Delay: There may be greater delay in a datagram network than in a virtual-circuit network. Extra delay added coz of each packet may experience a wait at a switch before it is forwarded.



Structure of a Switch

- We use switches in circuit-switched and packet switched networks.
- Structure of Circuit Switch: Uses 2 technologies- Space division and Time division switch.
- Space-Division Switch: The paths in the circuit are separated from one another spatially.
- Currently used in both analog and digital networks.
- *Crossbar Switch: A crossbar switch connects n inputs to m outputs in a grid, using electronic micro switches (transistors) at each cross point.*
- To connect n inputs to m outputs using a crossbar switch requires n x m crosspoints.
- Crossbar is inefficient, coz of most of the crossbars are idle.

Crossbar Switch



Multistage Switch

- The solution to the limitations of the crossbar switch is the multistage switch.
- which combines crossbar switches in several (normally three) stages.
- In a single crossbar switch, only one row or column (one path) is active for any connection. So we need N x N crosspoints.
- If we can allow multiple paths inside the switch, we can decrease the number of crosspoints.

Three-Multistage switch

1. We divide the N input lines into groups, each of n lines. For each group, we use one crossbar of size n x k, where k is the number of crossbars in the middle stage. In other words, the first stage has N/n crossbars of n x k crosspoints.

2. We use k crossbars, each of size (N/n) x (N/n) in the middle stage.

3. We use N/n crossbars, each of size k x n at the third stage.

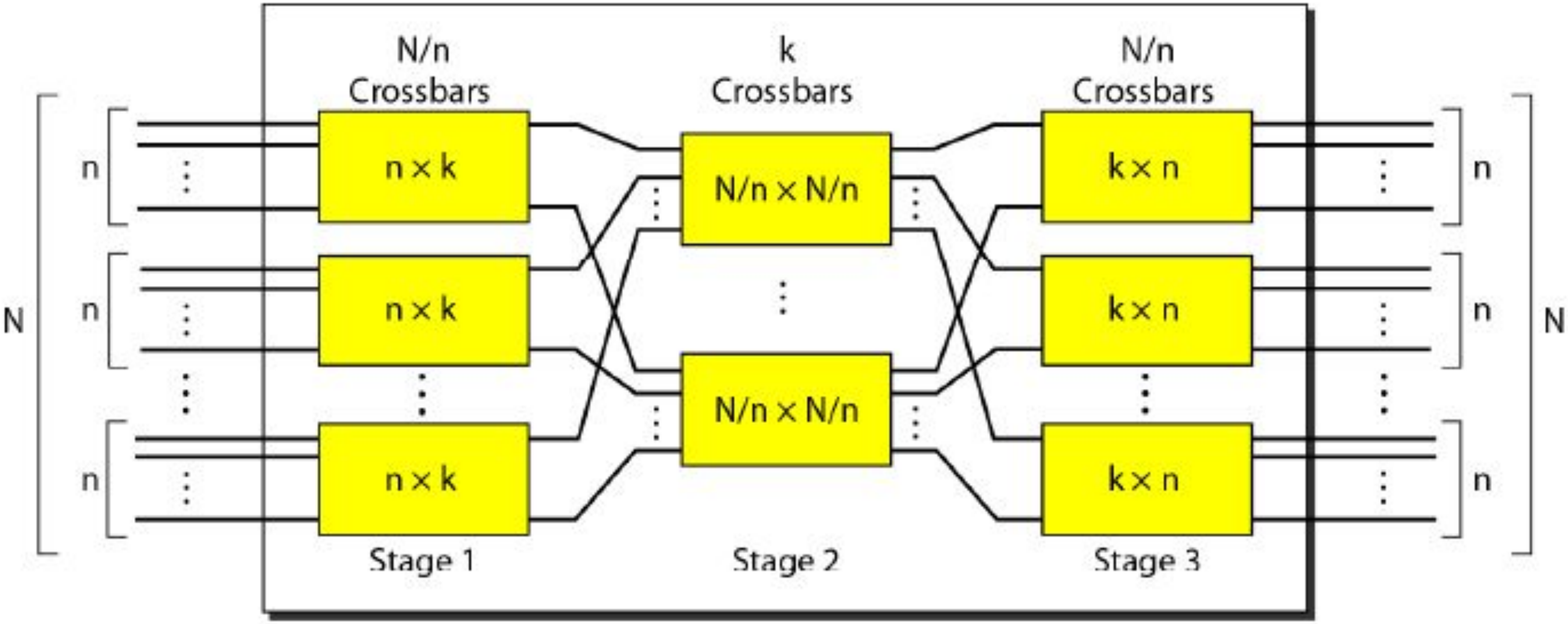
Note

In a three-stage switch, the total number of crosspoints is

$$2kN + k(N/n)^2$$

which is much smaller than the number of crosspoints in a single-stage switch (N^2).

Multistage Switch



Example

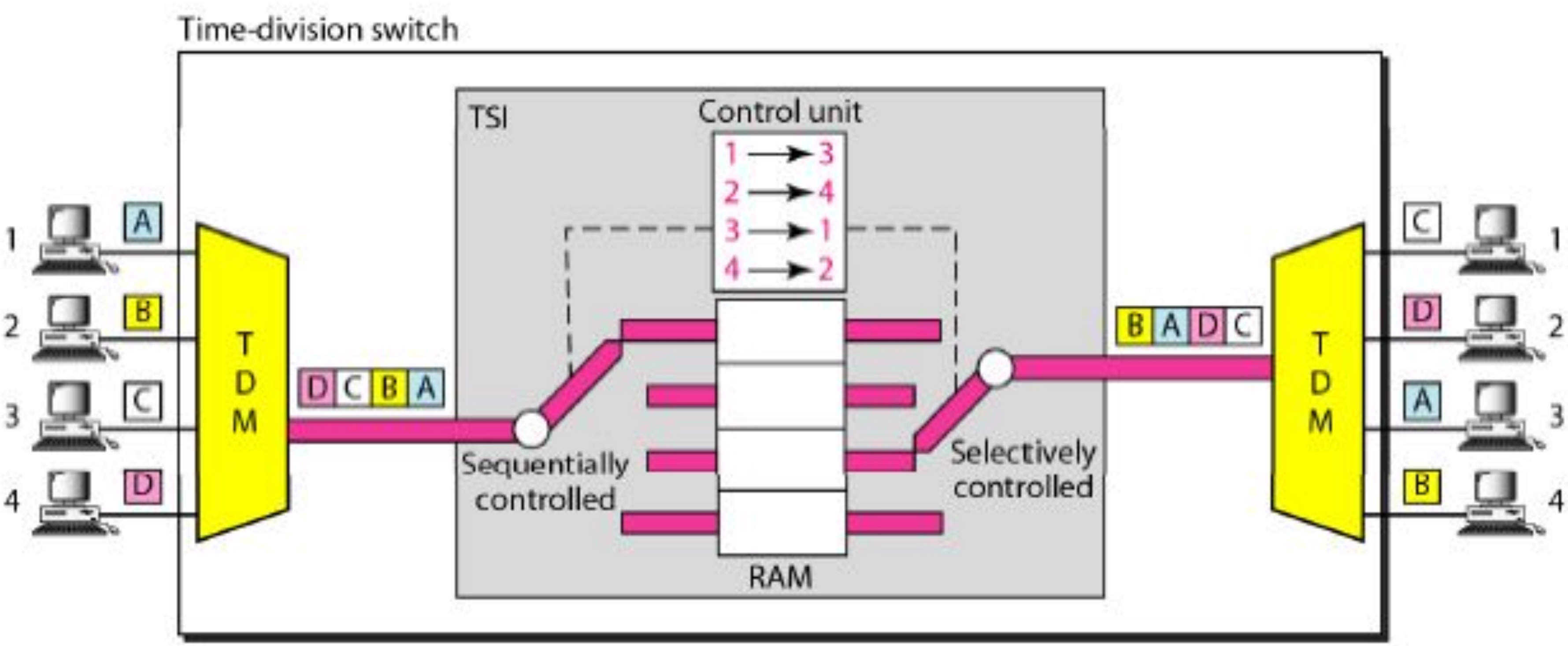
Design a three-stage, 200 × 200 switch (N = 200) with k = 4 and n = 20.

Solution

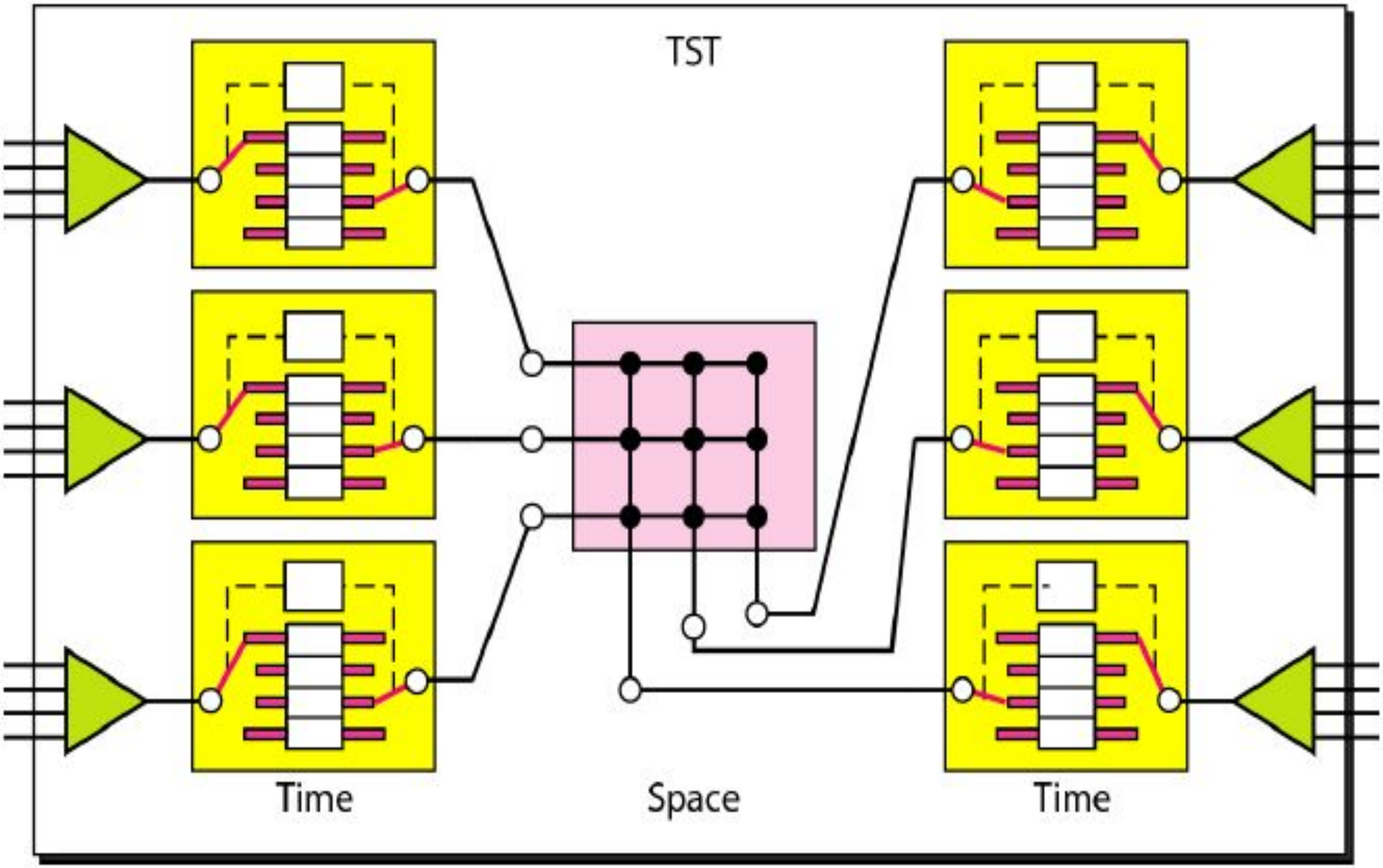
In the first stage we have N/n or 10 crossbars, each of size 20 × 4. In the second stage, we have 4 crossbars, each of size 10 × 10. In the third stage, we have 10 crossbars, each of size 4 × 20. The total number of crosspoints is $2kN + k(N/n)^2$*, or 2000 crosspoints. This is 5 percent of the number of crosspoints in a single-stage switch (200 × 200 = 40,000).*

Time Division Switch

- Time-division switching uses time-division multiplexing (TDM) inside a switch. The most popular technology is called the time-slot interchange (TSI).

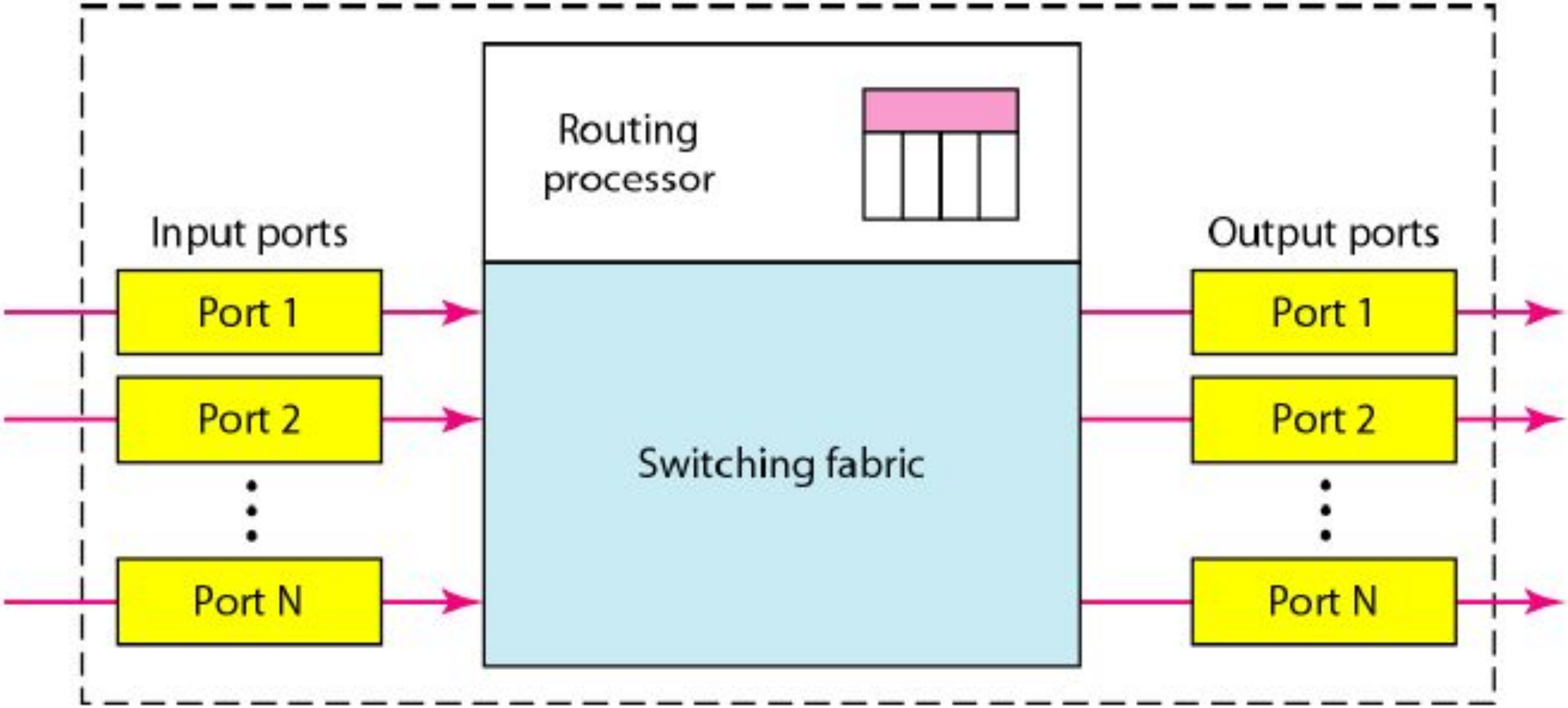


Time-Space-Time Division Switch



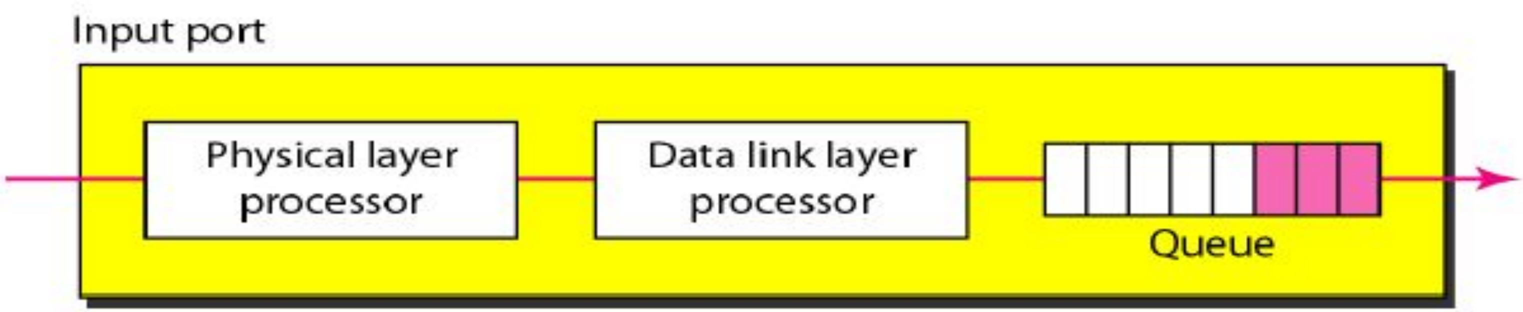
Structure of a packet switches

- Packet switch has four components: input ports, output ports, the routing processor, and the switching fabric.



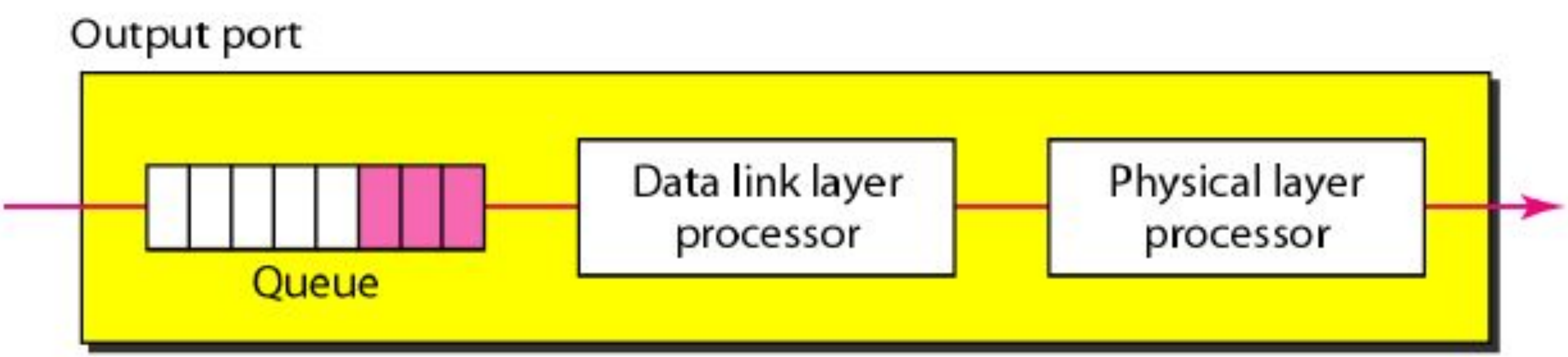
Components of packet switch

- Input ports: An input port performs the physical and data link functions of the packet switch.
- The bits are constructed from the received signal.
- The packet is decapsulated from the frame. Errors are detected and corrected.
- The packet is now ready to be routed by the network layer.
- In addition to a physical layer processor and a data link processor, the input port has buffers (queues) to hold the packet before it is directed to the switching fabric.



Components of packet switch

- Output Port: The output port performs the same functions as the input port, but in the reverse order.
- First the outgoing packets are queued, then the packet is encapsulated in a frame.
- Finally the physical layer functions are applied to the frame to create the signal to be sent on the line.



Components of packet switch

- Routing Processor: The routing processor performs the functions of the network layer.
- The destination address is used to find the address of the next hop and, at the same time, the output port number from which the packet is sent out.
- This activity is sometimes referred to as table lookup because the routing processor searches the routing table.
- In the newer packet switches, this function of the routing processor is being moved to the input ports to facilitate and expedite the process.

Components of packet switch

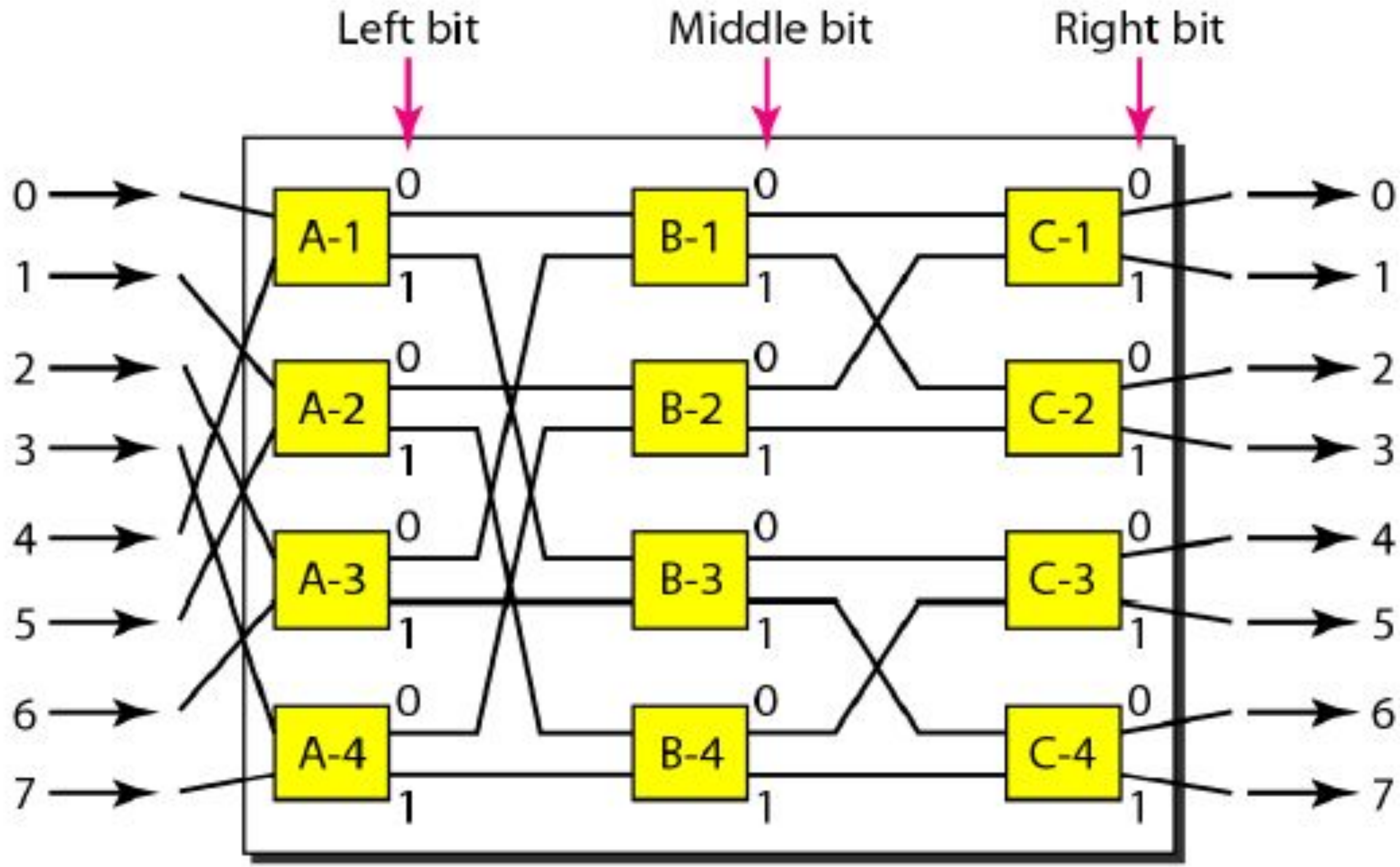
- Switching Fabrics: The most difficult task in a packet switch is to move the packet from the input queue to the output queue.
- Packet switch was actually a dedicated computer, the memory of the computer or a bus was used as the switching fabric.
- The input port stored the packet in memory; the output port retrieved the packet from memory.
- Today, packet switches are specialized mechanisms that use a variety of switching fabrics.
  - Crossbar switch
  - Banyan switch
  - Batcher-banyan switch

Banyan switch

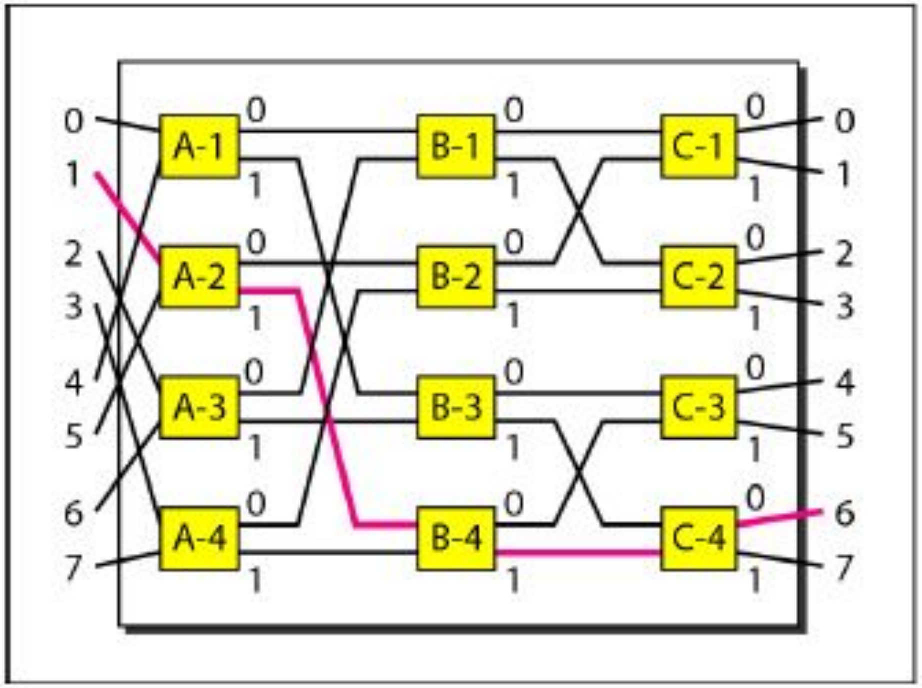
- A more realistic approach than the crossbar switch is the banyan switch.
- A banyan switch is a multistage switch with micro switches at each stage that route the packets based on the output port represented as a binary string.
- For n inputs and n outputs, we have $\log_2 n$ stages with n/2 micro switches at each stage.
- The first stage routes the packet based on the high-order bit of the binary string.
- The second stage routes the packet based on the second high-order bit, and so on.

Banyan Switch

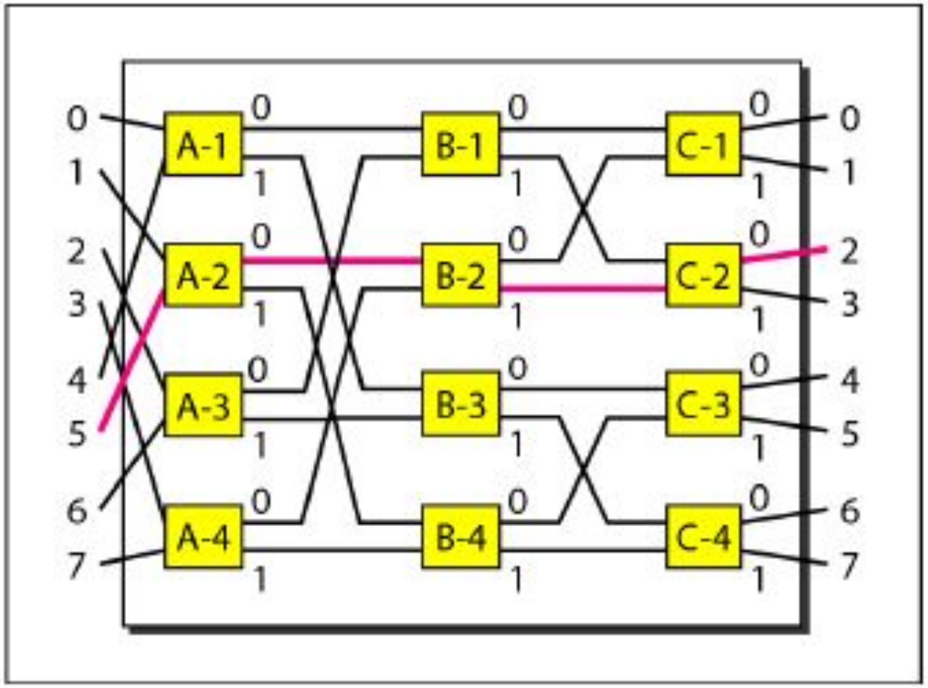
- banyan switch with eight inputs and eight outputs. The number of stages is $\log_2(8) = 3$.



Example- Routing in banyan switch



a. Input 1 sending a cell to output 6 (110)

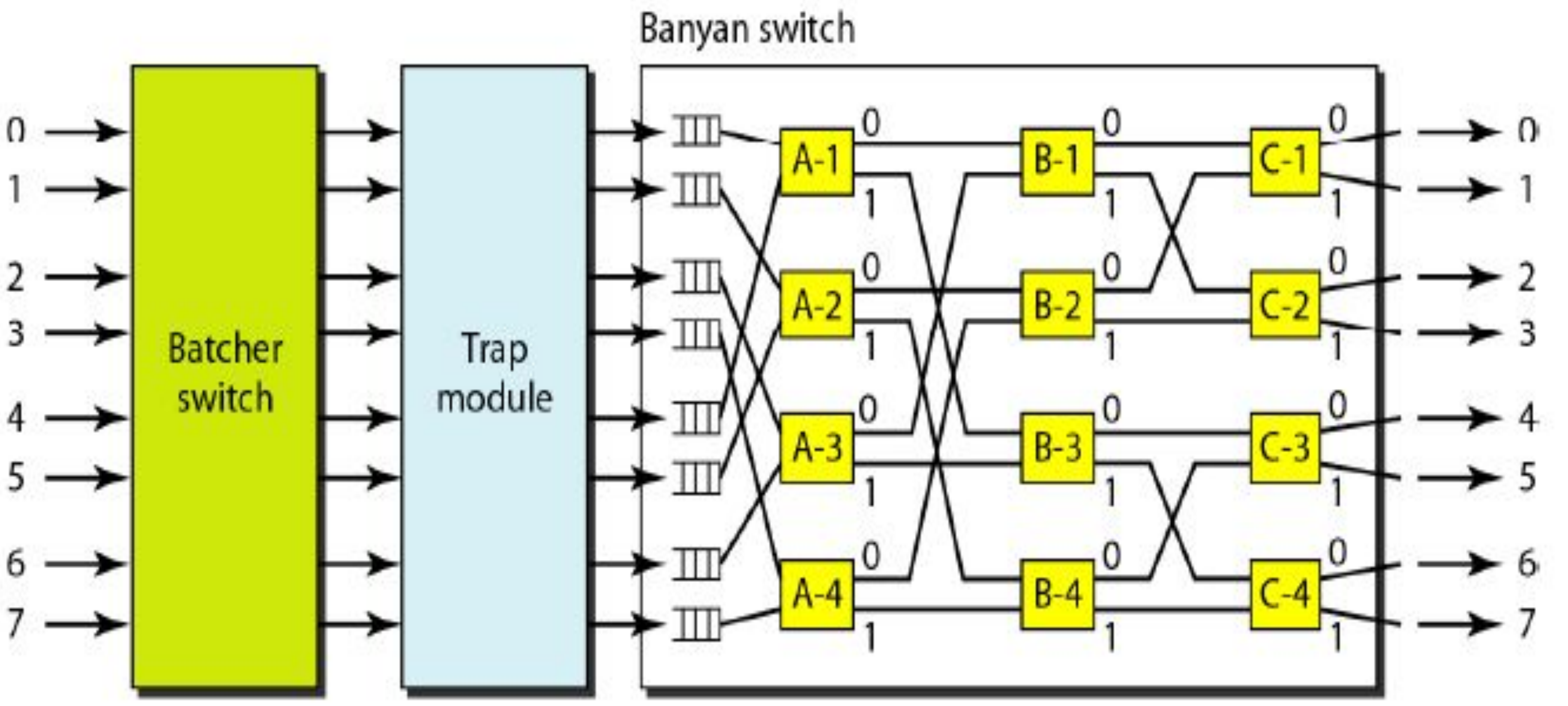


b. Input 5 sending a cell to output 2 (010)

Batcher-Banyan Switch

- The problem with the banyan switch is the possibility of internal collision even when two packets are not heading for the same output port.
- We can solve this problem by sorting the arriving packets based on their destination port.
- Batcher designed a switch that comes before the banyan switch and sorts the incoming packets according to their final destinations.
- Hardware module called a trap is added between the Batcher switch and the banyan switch.
- The trap module prevents duplicate packets (packets with the same output destination) from passing to the banyan switch simultaneously.
- Only one packet for each destination is allowed at each tick; if there is more than one, they wait for the next tick.

Batcher-Banyan Switch



End of Unit-03