THE UNIVERSITY OF SYDNEY

Tutorial
ELEC3506/9506
Communication Networks

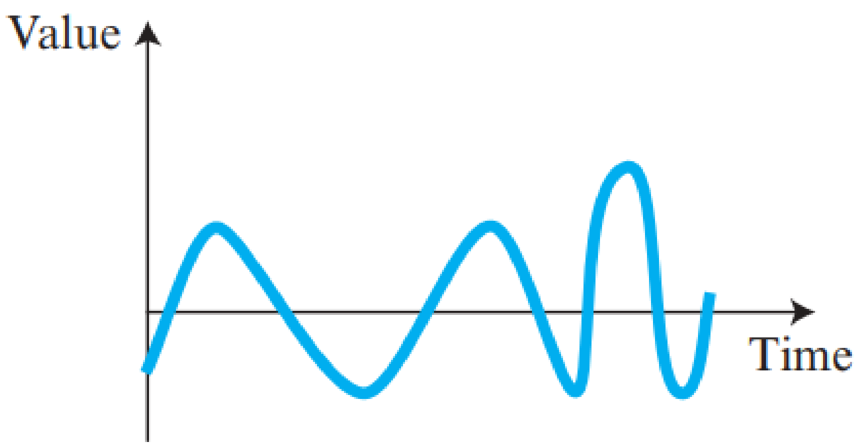
School of Electrical and Information Engineering
The University of Sydney

Dr. Shuvashis Saha
shuvashis.saha@sydney.edu.au

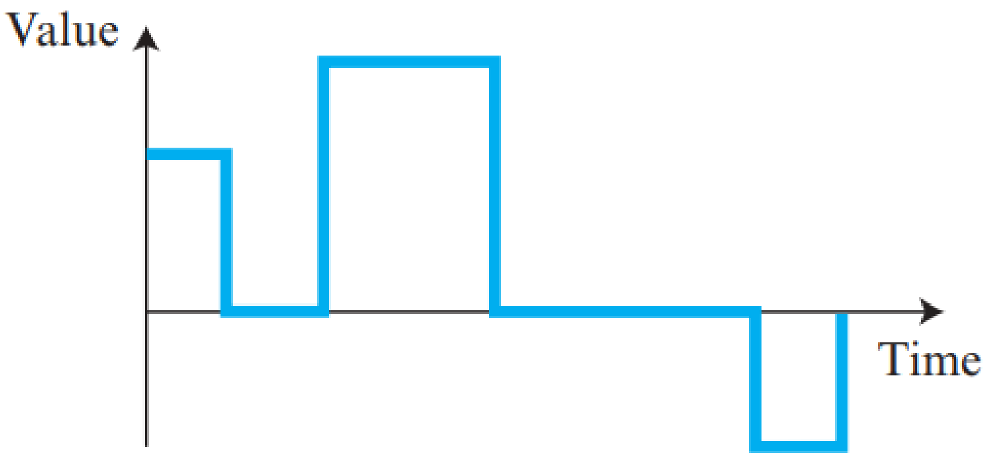
Tutorial 02 – Week 03

Data and Signals

- Data Types: Analog vs. Digital
  - Analog Data: Refers to information that is continuous in nature and can take on any value within a given range.
  - Digital Data: Refers to information that exists in discrete states, taking on specific, distinct values.



a. Analog signal



b. Digital signal

Q1. Distinguish between a Signal Element and a Data Element.

Data Element

- It refers to the smallest entity (that is, bit) that expresses some information.
- Data elements are **what we need to send**
- Data elements are being carried

Signal Element

- It refers to the shortest unit of digital signal. Each signal element carries one or more data elements
- Signal elements are **what we can send**
- Signal elements are the carriers

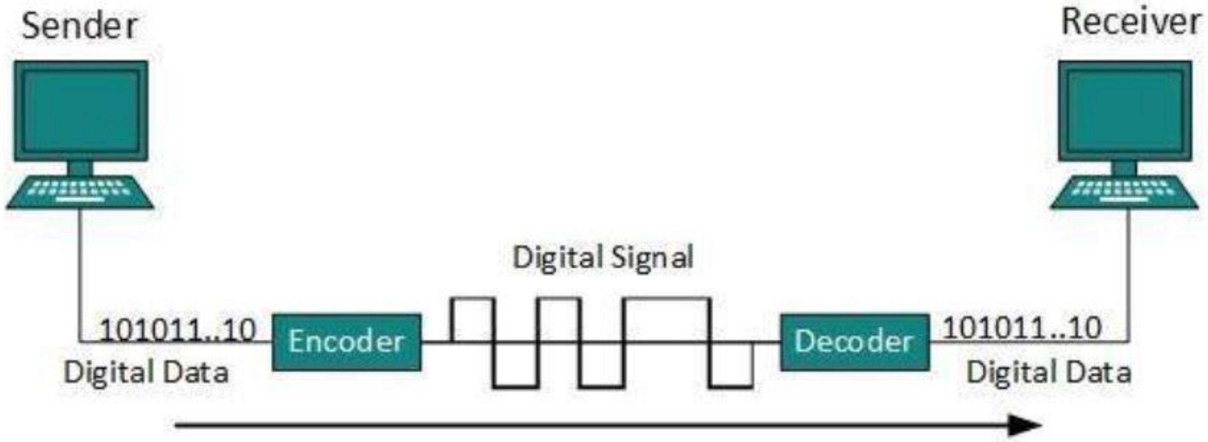


Fig 2.1: At the sender, digital data are encoded into a digital signal. at the receiver, the digital signal data are recreated by decoding the digital signal.

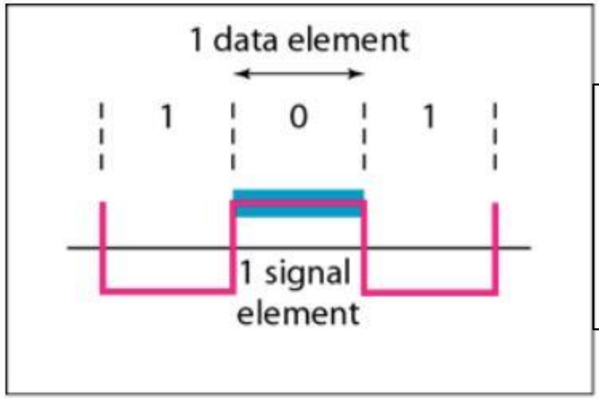
A single binary 1 or 0 is a data element.

A digital signal is a sequence of discrete, discontinuous voltage pulses. Each pulse is a signal element.

Q1. Distinguish between a Signal Element and a Data Element.

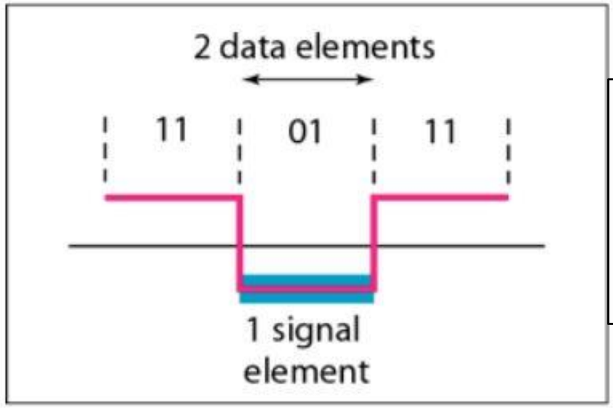
- The ratio (r) of number of data elements to number of signal element indicates the number of data elements carried by a signal element.

$$r = \frac{number\ of\ data\ elements}{number\ of\ signal\ element}$$



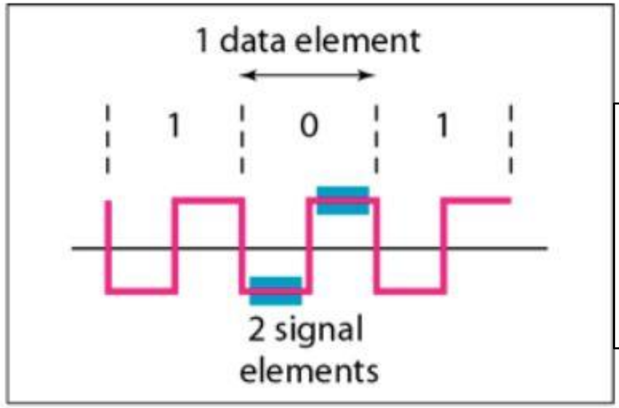
One data element per one signal element

$$r = \frac{1}{1} = 1$$



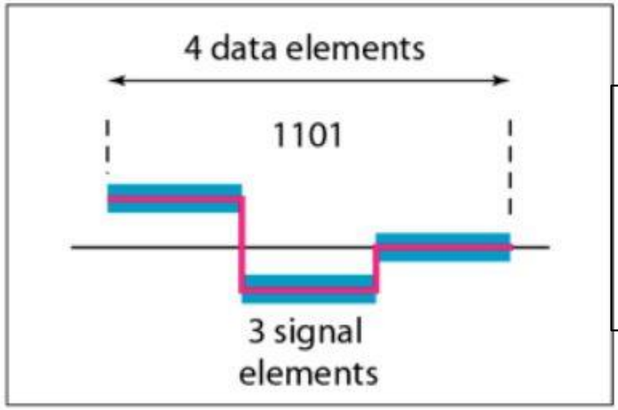
Two data element per one signal Element

$$r = \frac{2}{1} = 2$$



One data element per two signal Elements

$$r = \frac{1}{2}$$



Four data elements per three signal Element

$$r = \frac{4}{3}$$

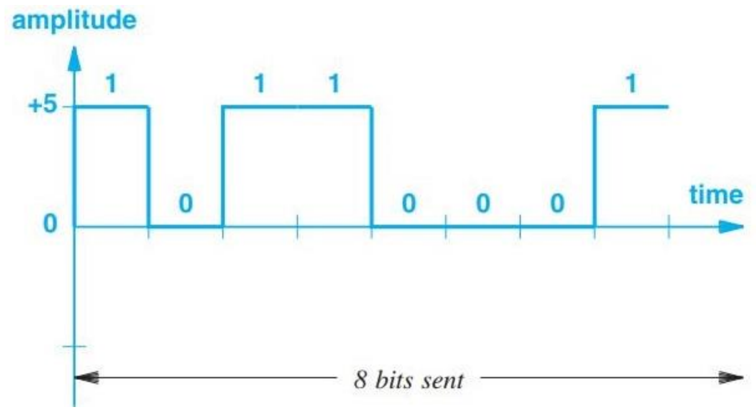
Q2. Distinguish between data rate and signal rate.

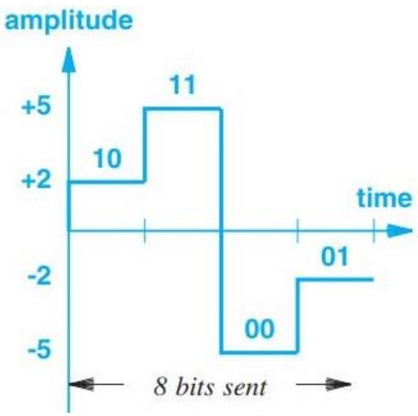
Data Rate

- Data rate defines the number of data elements (bit) sent in 1 sec .
- The unit is bits per second (bps).
- The data rate is sometimes called the bit rate
- The speed of transmission increases with the increase in data rate.

Signal Rate

- The signal rate is the number of signal elements sent in 1 sec .
- The unit is baud.
- The signal rate is sometimes called pulse rate, the modulation rate, or the baud rate.
- An increase in signal rate increases the demand of bandwidth.

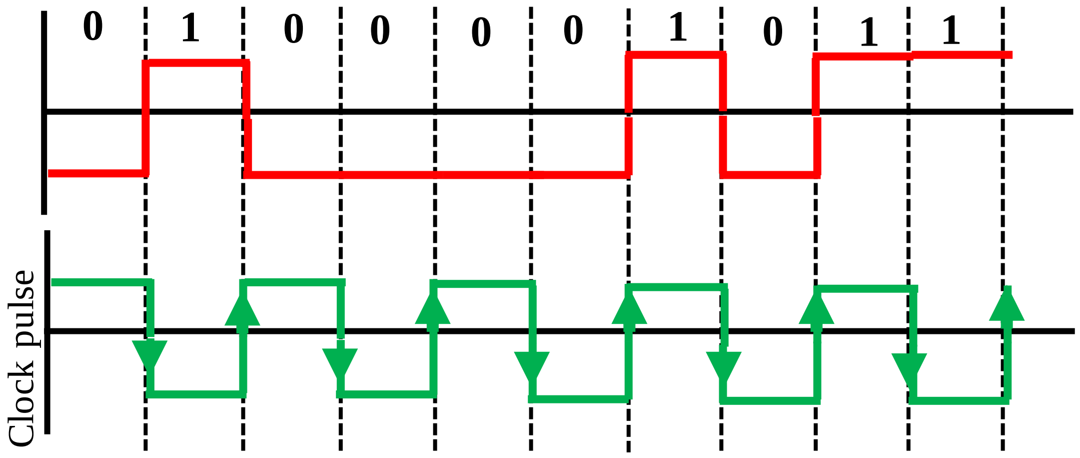


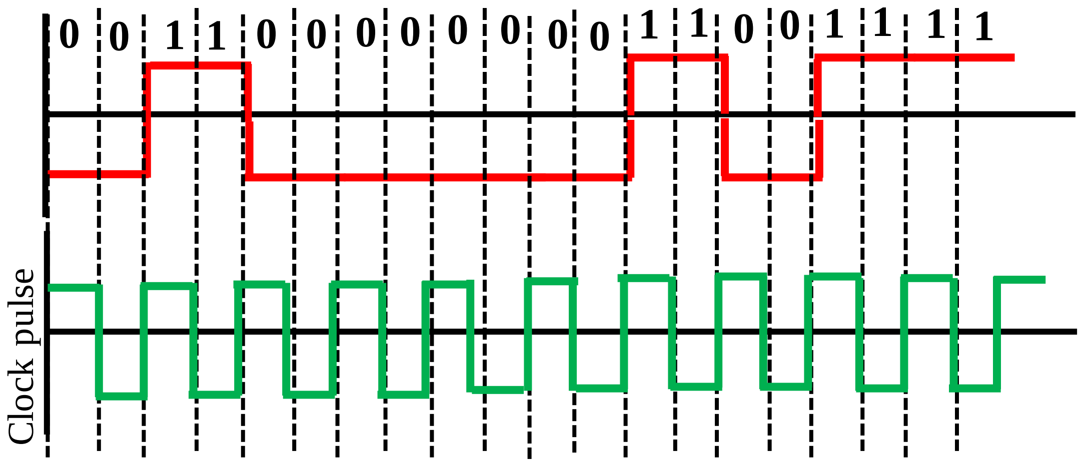


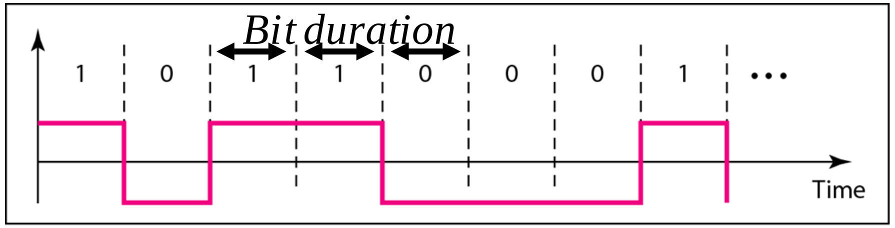
- [ ] The time is divided into eight segments, with one bit being sent during each segment.

- [ ] For lower Baud rate we can transmit same amount of data with reduce time.

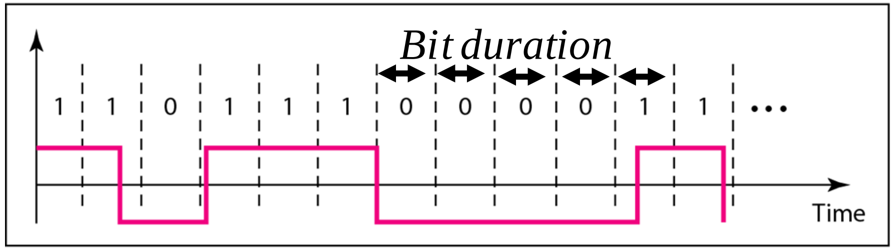
Q3. Define the characteristics of a self synchronizing signal.







a. Sent



b. Received

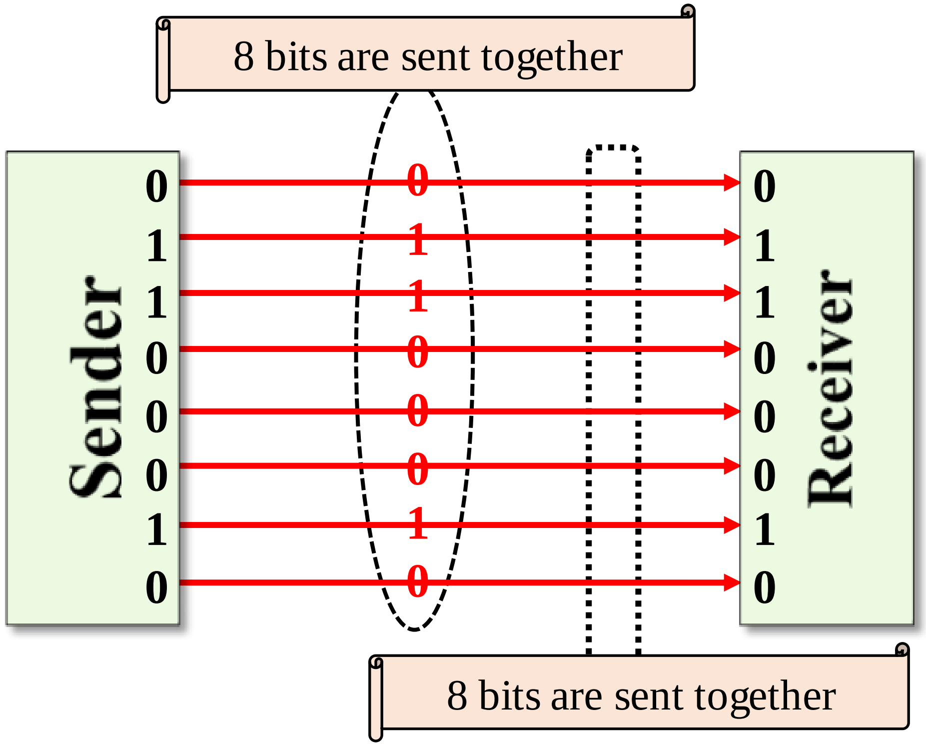
Self-synchronization: To correctly interpret the signals received from the sender, the receiver's bit intervals must correspond exactly to the sender's bit intervals.

- ➢ If the receiver clock is faster or slower, the bit intervals are not matched, and the receiver might misinterpret the signals.

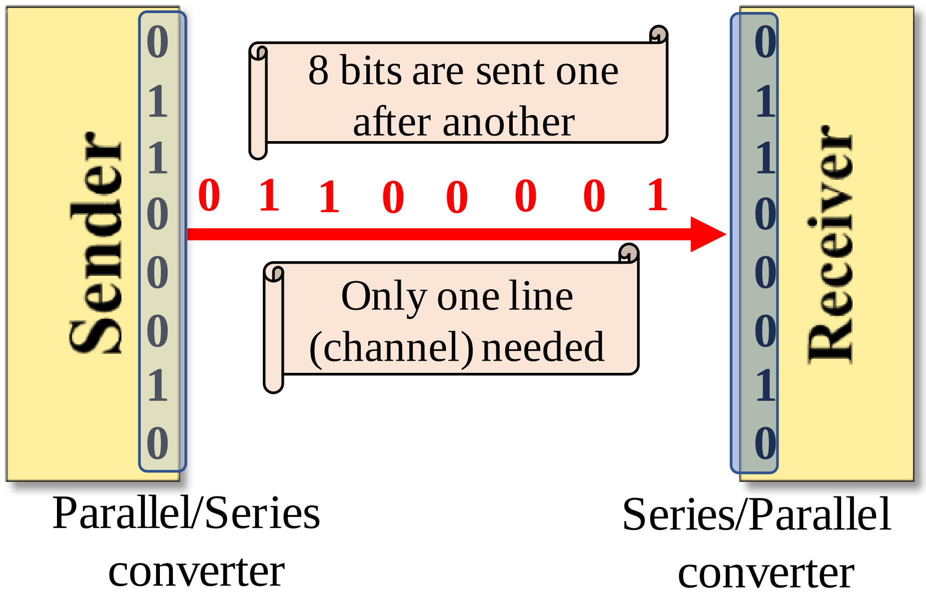
❑ A self-synchronizing digital signal includes timing information in the data being transmitted.

Q4. What are the differences between parallel and serial transmission?

- The transmission of binary data across a link can be accomplished in either **parallel or serial mode**.
- In parallel mode, multiple bits are sent with each clock tick.
- In serial mode, 1 bit is sent with each clock tick.



Parallel data transmission



Series data transmission

Q4. What are the differences between parallel and serial transmission?

Parallel transmission

- The stream of bits is divided into groups and one group is sent per each clock pulse.
- It is a faster mode of transmission, as several bits can be transmitted at a time.
- To send n bits at a time, it requires *n* communication channel between communicating devices. As a result, cost is increased
- No such converters are required.

Serial transmission

- The data is transmitted by sending one bit per each clock pulse.
- It is a slower mode of transmission, as only one bit can be transmitted at a time.
- It requires only one communication channel between communicating devices; thus, it is a cheaper mode
- As communication within devices is parallel, both sender and receiver require converter at the interface between the device and the communication channel.

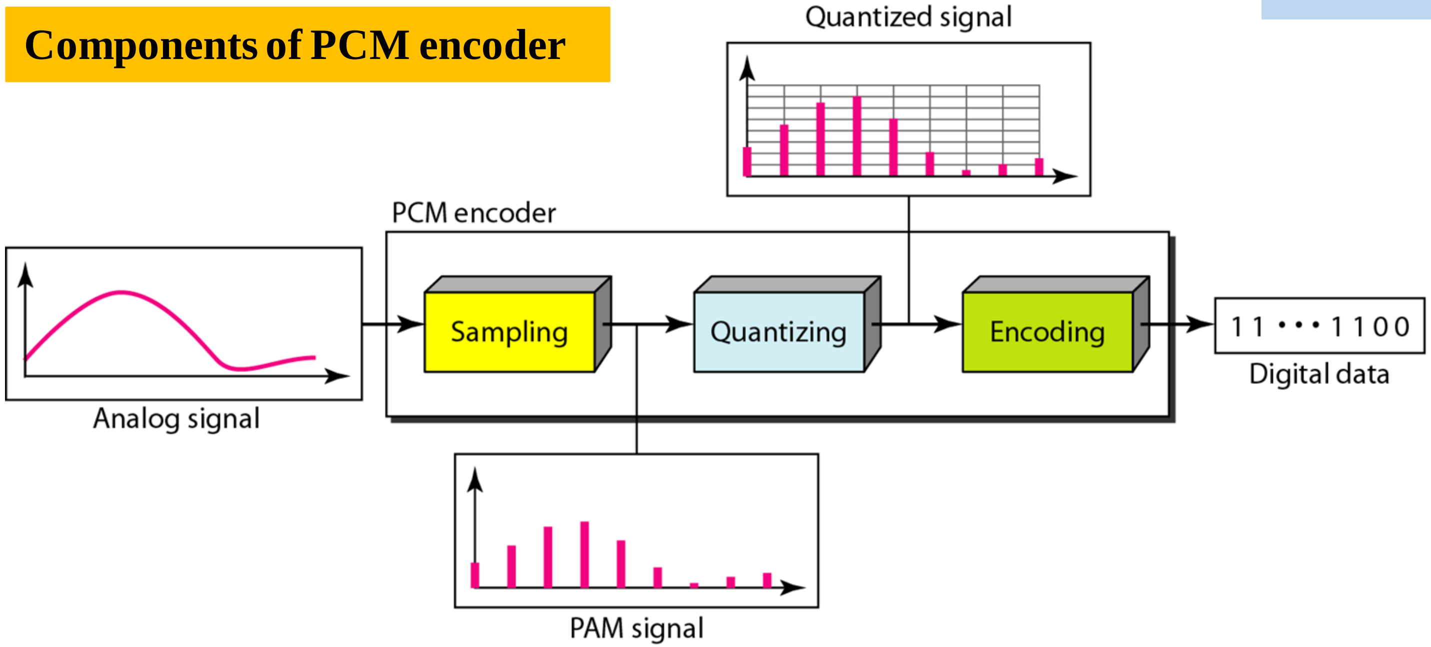
Q5. Discuss the steps of PCM.

- Pulse code modulation is the most common technique to change an analog signal to digital data.

A PCM encoder has three processes

1. The analog signal is sampled.
2. The sampled signal is quantized.
3. The quantized values are encoded as streams of bits.

Components of PCM encoder



Sampling process is used to convert continuous time signal to discrete time signals.

Quantization is the process of rounding off the amplitudes of flat top samples to a manageable no. of levels.

After quantization, encoding is done in which each sample is converted to *m*-bit codeword.

Q5. Discuss the steps of PCM.

Sampling

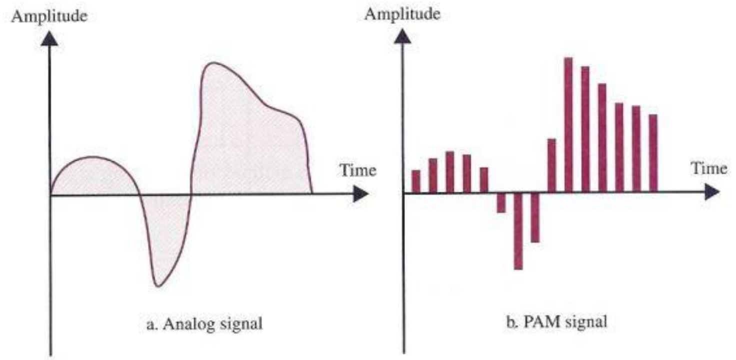
- This takes an analogue signal and measures the signal at equal intervals, called sampling.
- Only transforms the signal to a series of pulses not a full digital signal (PAM Signal).

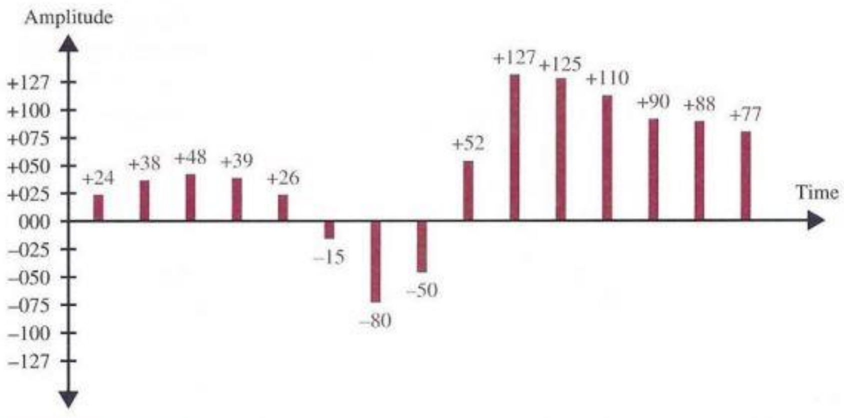
Quantization

- The sampled PAM pulses may have non-integral values of amplitude which cannot be encoded directly.
- Quantization assigns values in a specific range to sampled instances.

Encoding

- The third step is to encode the quantized values to a stream of bits.
- Each value is translated to its seven-bit binary equivalent, and the eighth bit indicates the sign.





+024	00011000	–015	10001111	+125	01111101
+038	00100110	–080	11010000	+110	01101110
+048	00110000	–050	10110010	+090	01011010
+039	00100111	+052	00110110	+088	01011000
+026	00011010	+127	01111111	+077	01001101

Sign bit
+ is 0 – is 1

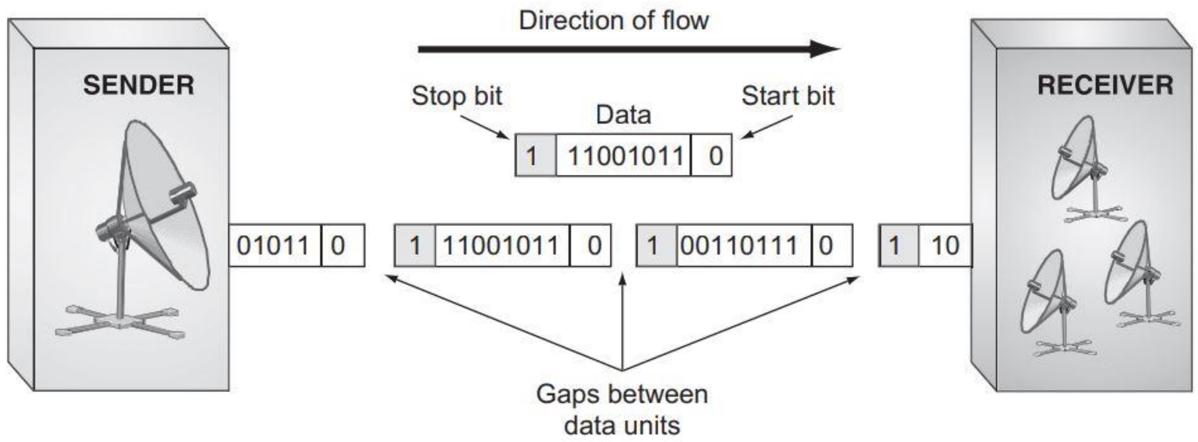
Q6. List different techniques of serial transmission and explain their difference?

- Serial mode transmission can be classified into three types, namely

1) Asynchronous serial data transmission mode
2) Synchronous serial data transmission mode
3) Isochronous serial data transmission mode

Q6. List different techniques of serial transmission and explain their difference?

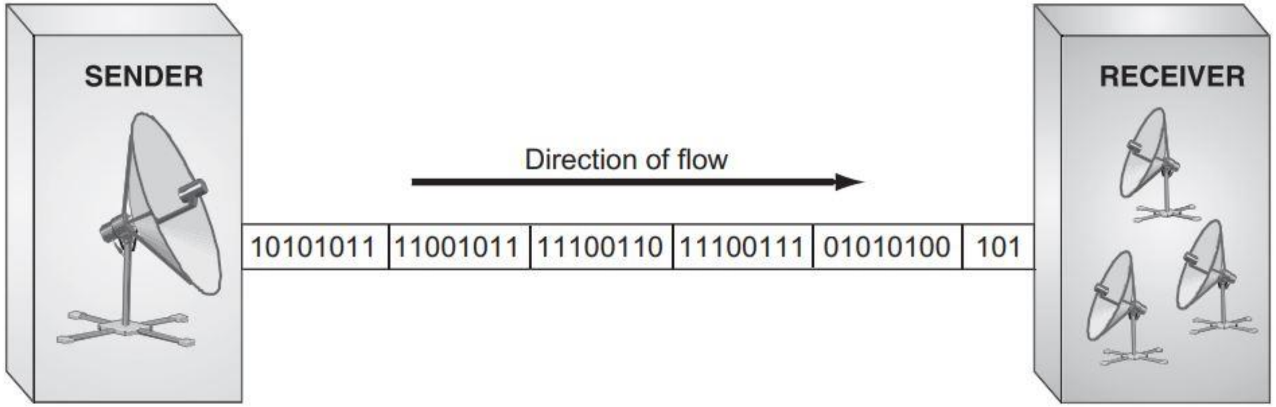
Asynchronous serial data transmission mode



- In this transmission, the entire bit stream is divided into groups of 8 bits (that is, one byte) each.
- Each byte is treated independently and transmitted whenever ready regardless of the timer.
- To let the receiver, know about the arrival and end of a byte, a start and stop bit is used, respectively. Usually, **Start bit = 0** and **Stop bit = 1**.
- Some synchronization is needed during the transmission of bits within a byte.
- To achieve this synchronization, the receiver starts the timer after finding the start bit and counts the number of bits until it finds the stop bit.
- Asynchronous transmission is slow as it adds extra bits.
- It is a cheaper and effective mode of transmission

Q6. List different techniques of serial transmission and explain their difference?

Synchronous serial data transmission mode



- In synchronous transmission, we send bits one after another without start or stop bits or gaps. It is the responsibility of the receiver to group the bits.
- Multiple bytes are combined to form frames.
- At the receiver's end, the receiver keeps counting the bit and separates them into byte groups for decoding.
- Synchronous transmission is fast as compared to asynchronous transmission.
- This transmission cannot be used for real-time applications such as television broadcasting.

Q6. List different techniques of serial transmission and explain their difference?

Isochronous serial data transmission mode

- In real-time audio and video, in which uneven delays between frames are not acceptable, **synchronous transmission fails**.
- TV images are broadcast at the rate of 30 images per second; they must be viewed at the same rate.
- If each image is sent by using one or more frames, there should be no delays between frames.
- For this type of application, synchronization between characters is not enough; the entire stream of bits must be synchronized.
- The **isochronous** transmission guarantees that the data arrive at a fixed rate.

Q7. Which characteristics of an analog signal are changed to represent the digital signal in each of the following digital-to-analog conversion?
a) ASK ; b) FSK ; c) PSK ; d) QAM

Amplitude Shift Keying (ASK): It involves changing the **amplitude** of the carrier signal without changing its frequency and phase.

Frequency Shift Keying (FSK): In this technique, the **frequency** of the carrier signal is changed without changing its amplitude and phase.

Phase Shift Keying (PSK): In this technique, the **phase** of the carrier signal is changed without changing its amplitude and frequency.

Quadrature Amplitude Modulation (QAM): QAM technique combines the idea of ASK and PSK. That is, instead of changing only one attribute of a carrier, two attributes including **amplitude** and **phase** of the carrier signal are changed.

THE UNIVERSITY OF SYDNEY

Q8. Which of the above four are most susceptible to noise? Explain your answer
a) ASK ; b) FSK ; c) PSK ; d) QAM

- Though Amplitude Shift Keying (ASK) is the simplest technique, it is highly susceptible to noise and thus is an inefficient modulation technique

- The term noise refers to unintentional voltages introduced on to a line by various phenomena (heat or crosstalk).
- These unintentional voltages combine with the **signal to change the amplitude**.

- In ASK, the criterion for bit detection is the amplitude of the signal; in PSK, it is the phase. Noise can change the amplitude easier than it can change the phase.

Q9. What is the number of bits per baud for the following techniques?

a) **ASK with four different amplitudes**

b) **FSK with 8 different frequencies**

c) **PSK with four different phases**

- We use the formula $r = \log_2 L$ to calculate the value of r for each case.

where r is the number of data elements carried in one signal element and L is the type of signal element, not the level.

a) The number of bits per baud for ASK with four different amplitudes;

$$r = \log_2 L = \log_2(4) = 2$$

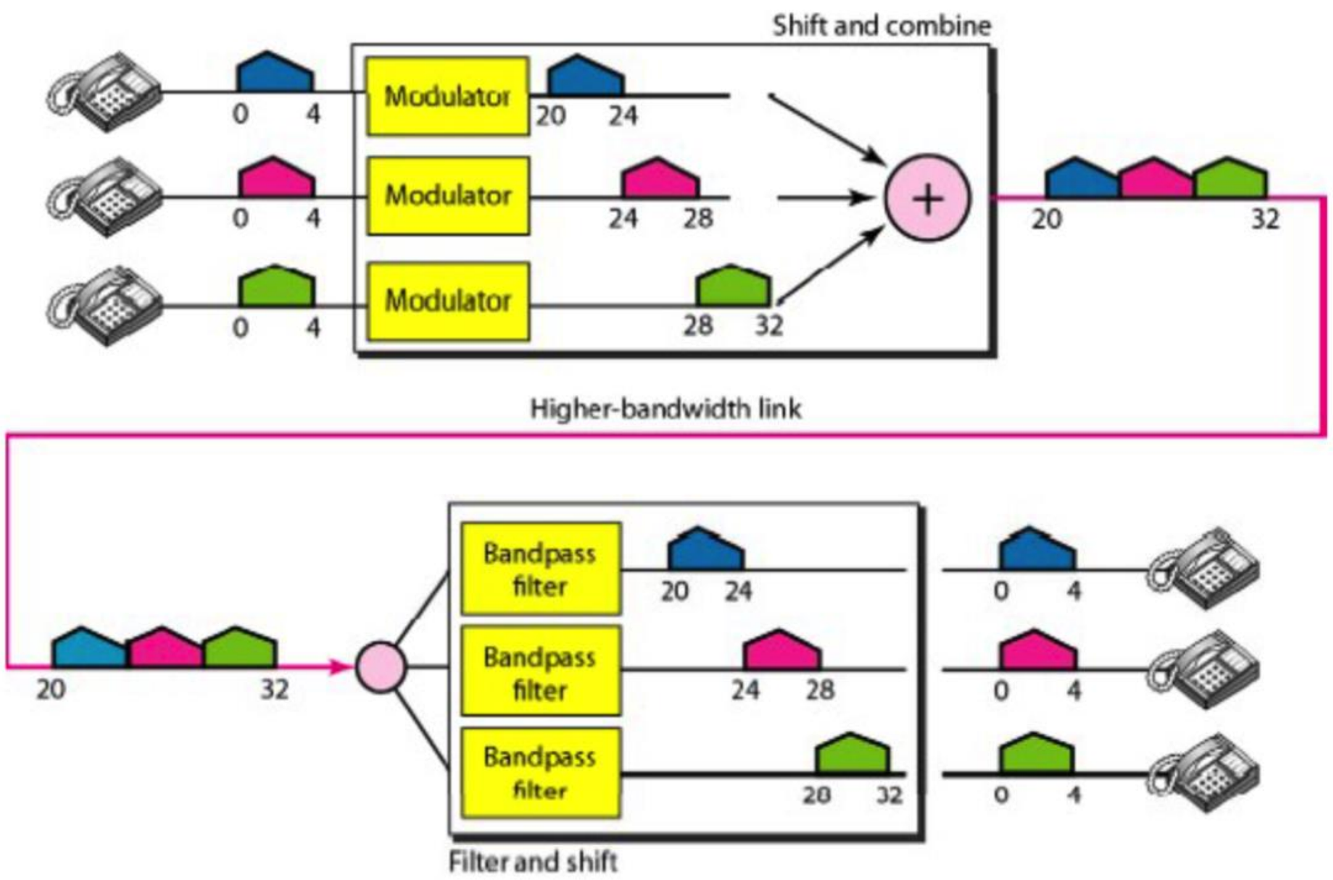
b) The number of bits per baud for FSK with 8 different frequencies;

$$r = \log_2 L = \log_2(8) = 3$$

c) The number of bits per baud for PSK with four different phases;

$$r = \log_2 L = \log_2(4) = 2$$

Q10. Assume that a voice channel occupies a bandwidth of 4kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32kHz. Show the configuration, using the frequency domain. Assume that there are no guard bands.



Voice Channels Specification: Each voice channel occupies a bandwidth of **4 kHz**.

Total Bandwidth Available: The link has a total bandwidth of **12 kHz** (from 20 kHz to 32 kHz).

Combining the Channels: We need to assign each 4 kHz voice channel to a specific part of the 12 kHz link bandwidth.

- **Channel 1**: Assigned to the frequency range from 20 kHz to 24 kHz.
- **Channel 2**: Assigned to the frequency range from 24 kHz to 28 kHz.
- **Channel 3**: Assigned to the frequency range from 28 kHz to 32 kHz.

Q11. Five channels, each with a 100kHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10kHz between the channels to prevent interference?

- **Channel Bandwidth**: Each channel has a bandwidth of 100 kHz.
- **Number of Channels**: There are 5 channels to be multiplexed together.
- **Guard Band**: There is a need for a guard band of 10 kHz between each pair of adjacent channels to prevent interference.

- For 5 channels, the total bandwidth occupied by the channels alone is:

$$\mathbf{5\times100\ kHz= 500\ kHz}$$

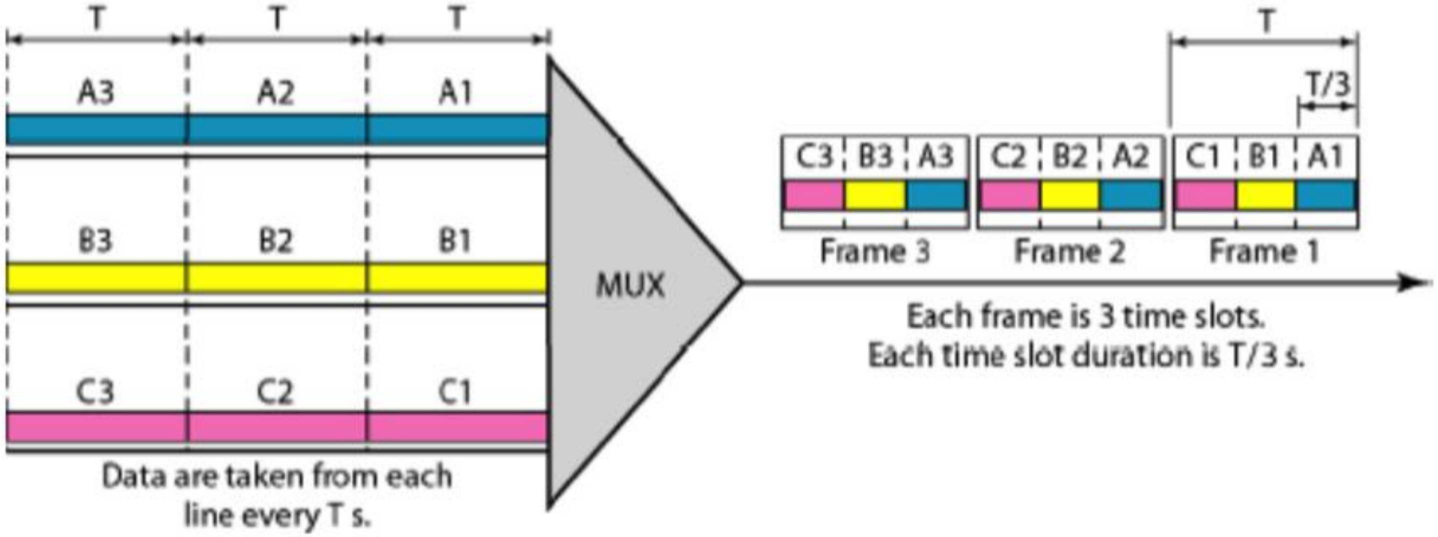
- The total bandwidth occupied by the guard bands is:

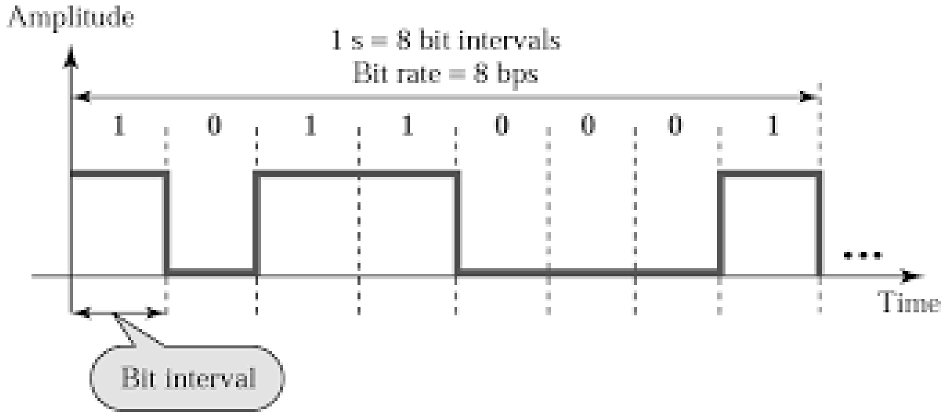
$$\mathbf{4\times10\ kHz = 40\ kHz}$$

Total Bandwidth :

$$\mathbf{(100 \times 5) + (4 \times 10) = 540\ kHz}$$

Q12. From the below figure, the data rate for each input connection is 3 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?

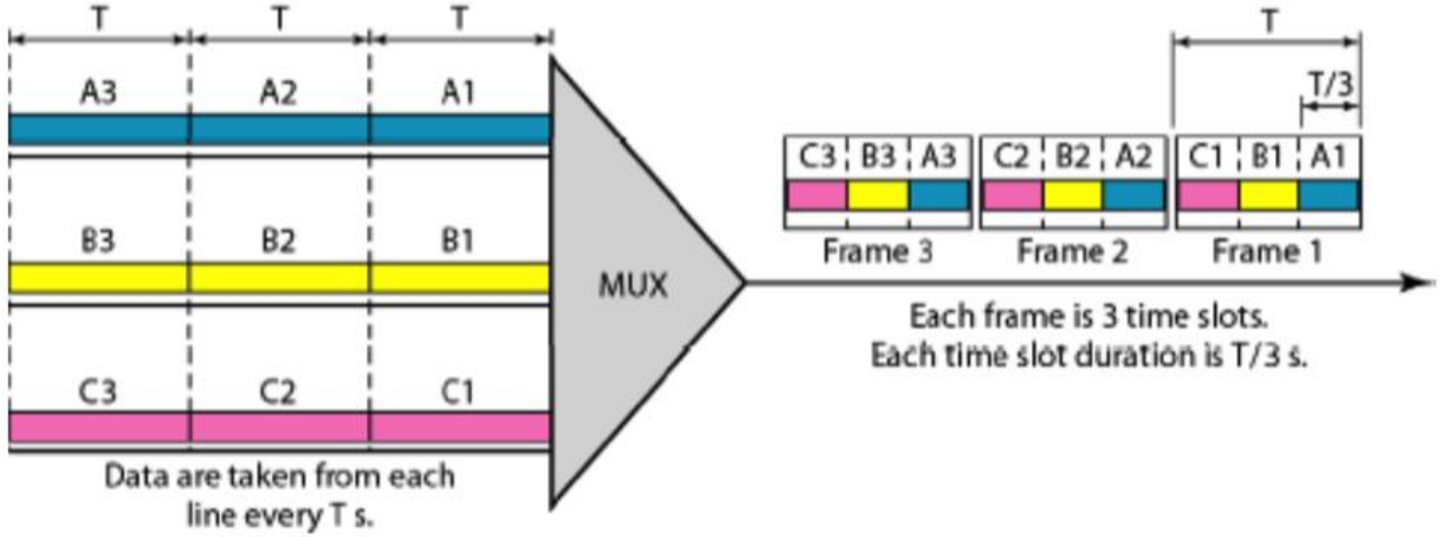




a) The data rate of each input connection is 3kbps.

- This means that the **bit duration is 1/3000s**.
- The duration of the **input time slot is 1/3000s**.
- The duration of the input time slot is same as **bit duration → 1/3000s**.

Q12. From the below figure, the data rate for each input connection is 3 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?



b) The duration of each output slot is one-third of the input time slot

→ **1/9000s.**

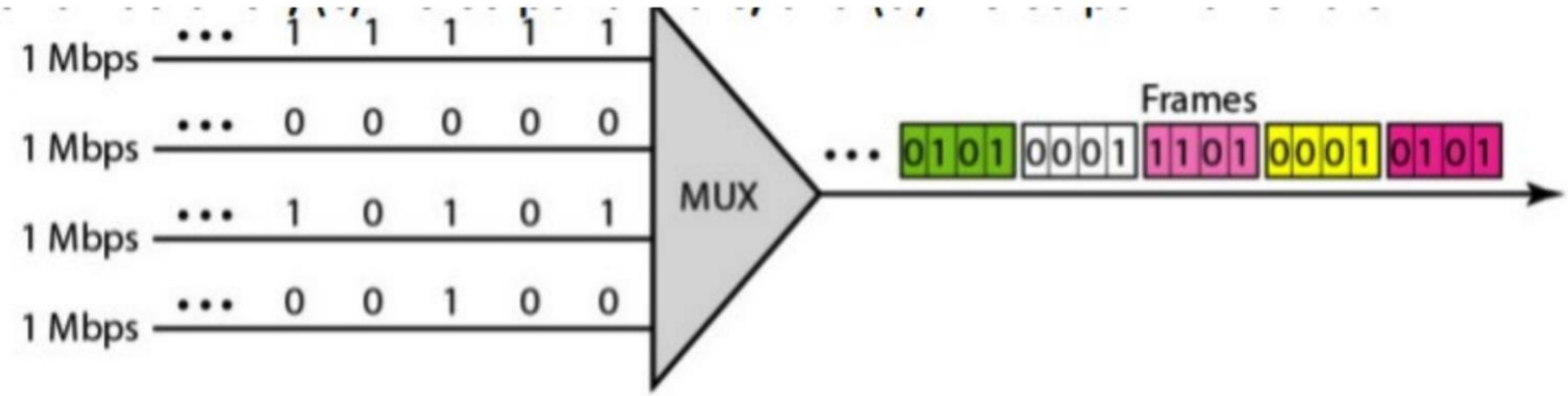
c) Each frame carries three output slots.

- So the duration of the frame is

3 x (1/9000s) = 1/3000s

THE UNIVERSITY OF SYDNEY

Q13. The figure below 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 (a) the input bit duration, (b) the output bit duration, (c) the output bit rate, and (d) the output frame rate.



a) **The input bit duration** is the reciprocal of the input bit rate.

- Input bit duration

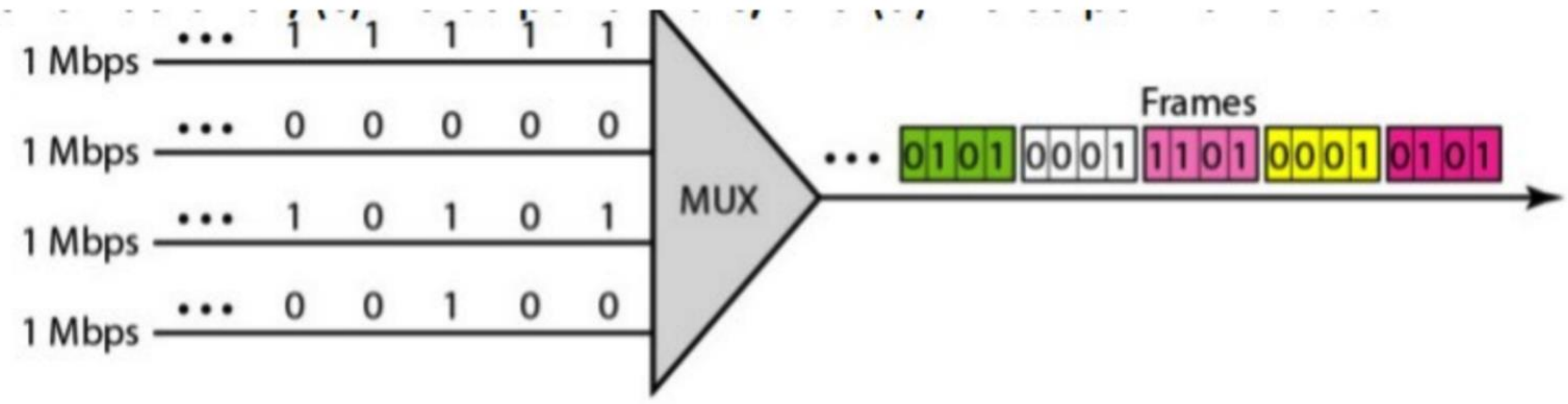
  = 1 / 1 Mbps
- **1 microsecond (μs)**

b) **Output Bit Duration**:

- Since one bit from each of the four input data streams is combined into a single output bit, the output bit duration is one-fourth of the input bit duration.
- **Output bit duration** = 1 μs / 4 = **0.25 μs**

THE UNIVERSITY OF SYDNEY

Q13. The figure below 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 (a) the input bit duration, (b) the output bit duration, (c) the output bit rate, and (d) the output frame rate.



c) Output Bit Rate:

- The output bit rate is the reciprocal of the output bit duration.
- Output bit rate = 1 / 0.25 μs = 4 Mbps
- Alternatively, it's the sum of the input bit rates: 1 Mbps * 4 = 4 Mbps.

d) Output Frame Rate:

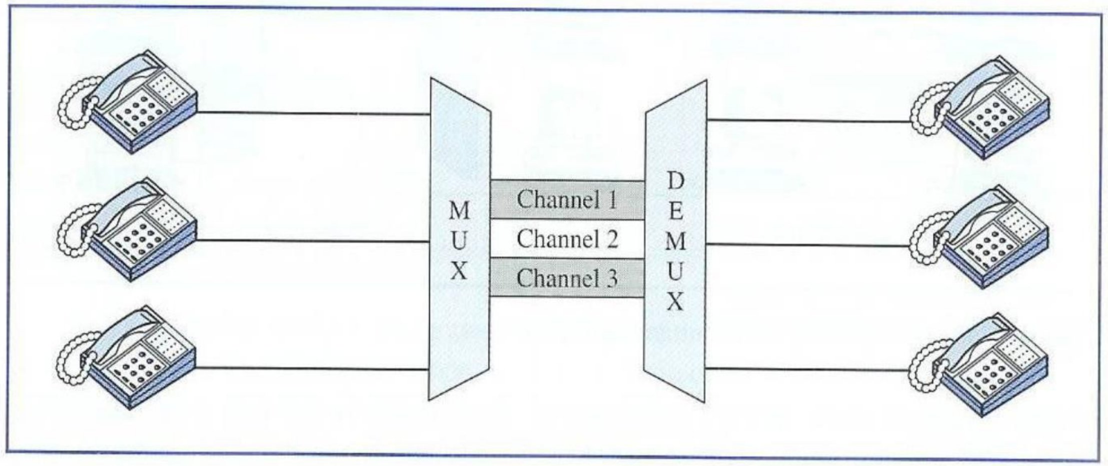
- In TDM, the frame rate is equal to the bit rate of any of the input channels.
- 4Mbps / 4 = 1 Mbps.

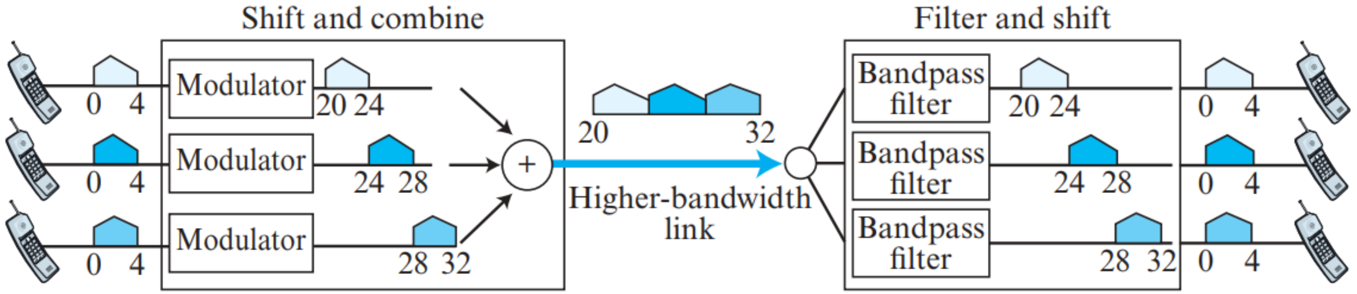
Q14. List the main multiplexing techniques discussed in the lecture.

- ❑ Frequency Division Multiplexing (FDM)
- ❑ Synchronous Time Division Multiplexing (Sync TDM)
- ❑ Asynchronous Time Division Multiplexing (Async TDM) → Also known as statistical TDM

Frequency Division Multiplexing (FDM)

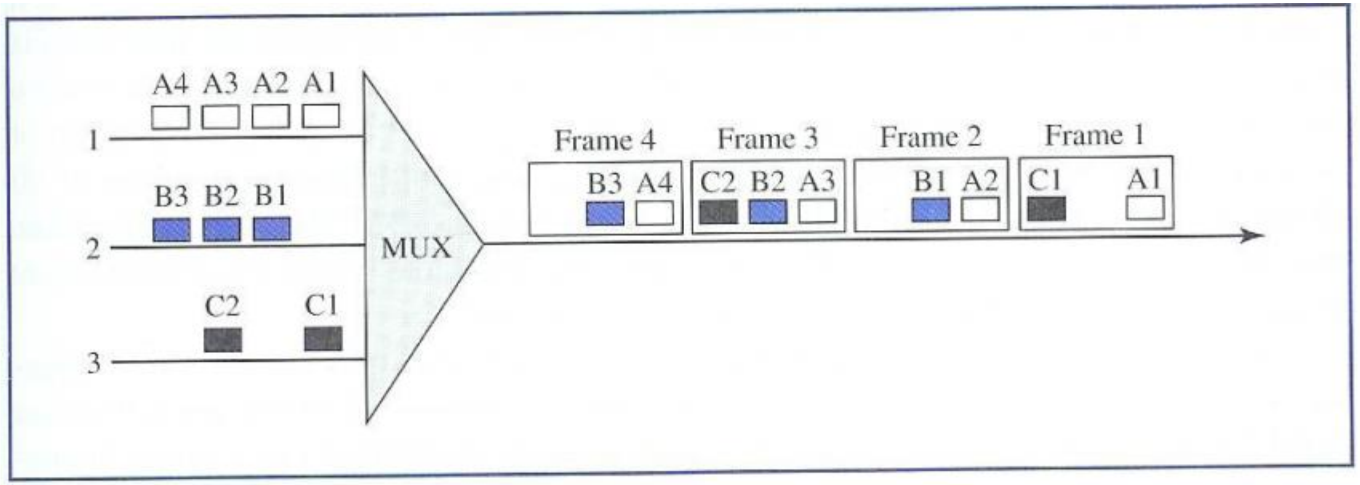
- Signals are combined in the frequency domain
- Can only be applied when the bandwidth link is greater than the combined bandwidth of the transmitted signals
- Channels/Frequencies must be separated by using guard bands to prevent signals from overlapping

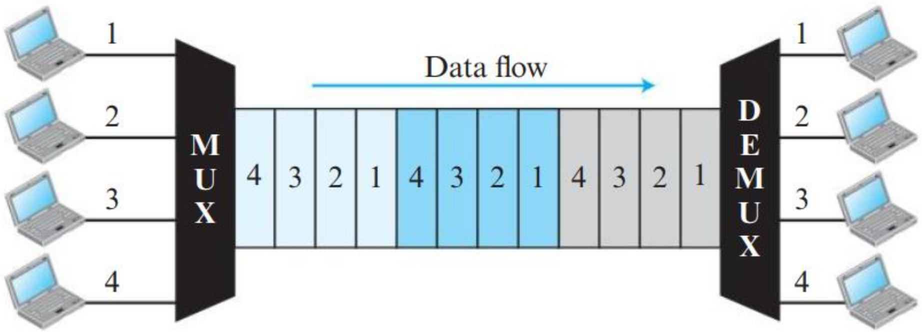




Q14. List the main multiplexing techniques discussed in the lecture.

- **Synchronous TDM**
  - The usage of a high capacity link is divided into time slots. Each device has a time slot.
  - Can only be used with a digital signal.
  - Also known as synchronous time division multiplexing

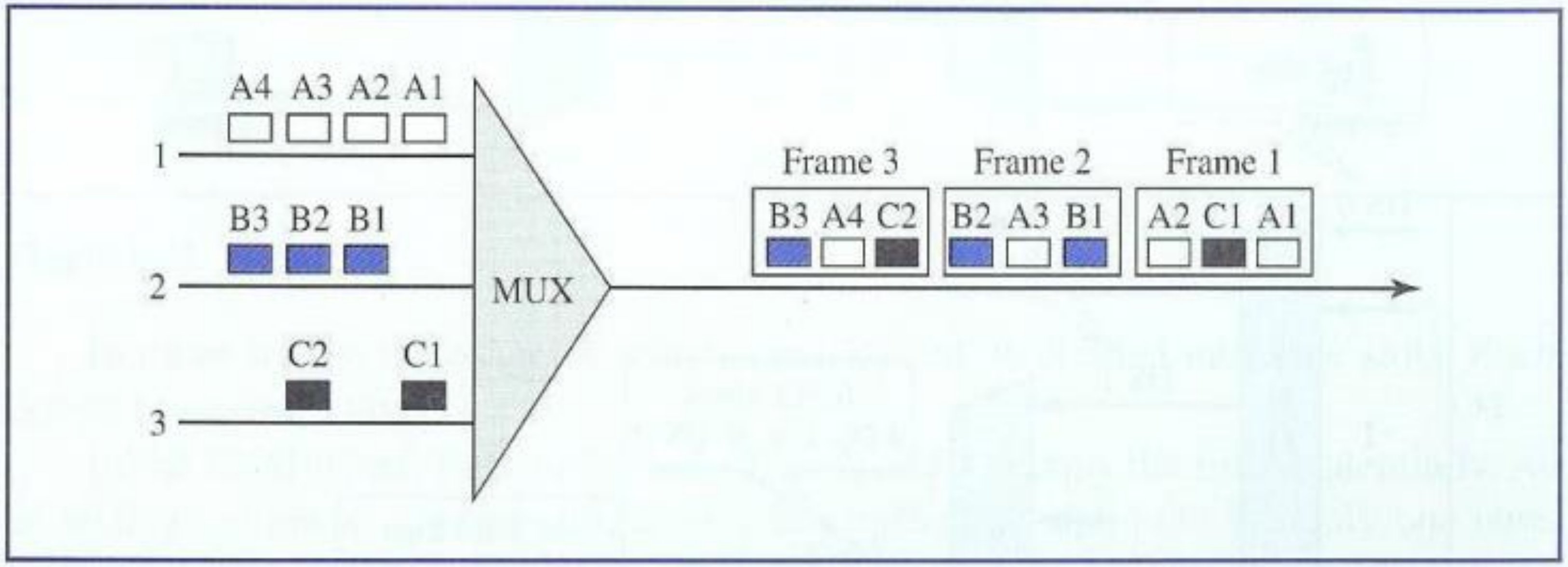




✓ **Synchronous TDM**: Fixed time slots, simpler implementation, potential bandwidth wastage, requires strict synchronization.

Q14. List the main multiplexing techniques discussed in the lecture.

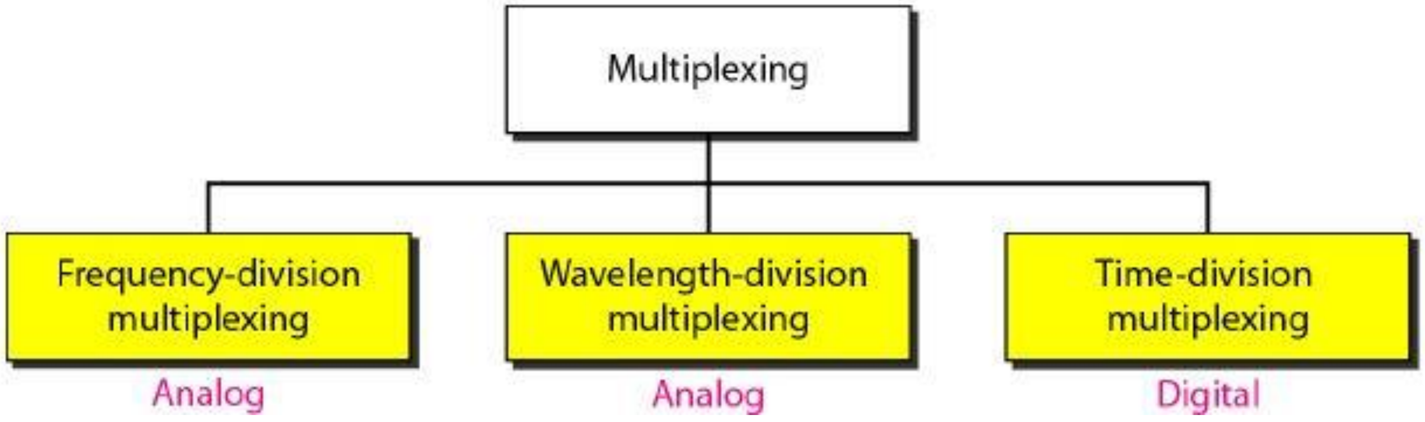
- **Statistical (Asynchronous) Time Division Multiplexing (STDM)**
  - STDM guaranties the full capacity of a Link
  - The STDM frame is constructed using a statistical analysis of the likelihood that input lines will be transmitting at any given time.
  - The multiplexer continuously scans the input lines until the frame is filled, and then proceeds to send the frame.



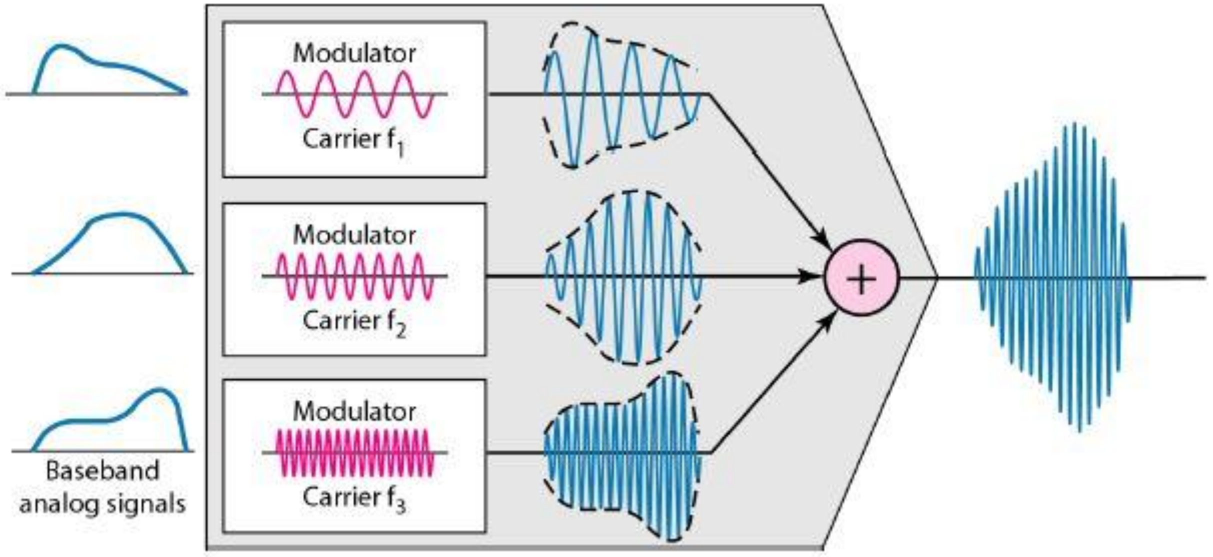
Asynchronous TDM

- Variable time slots,
- More complex implementation,
- **Efficient** bandwidth usage

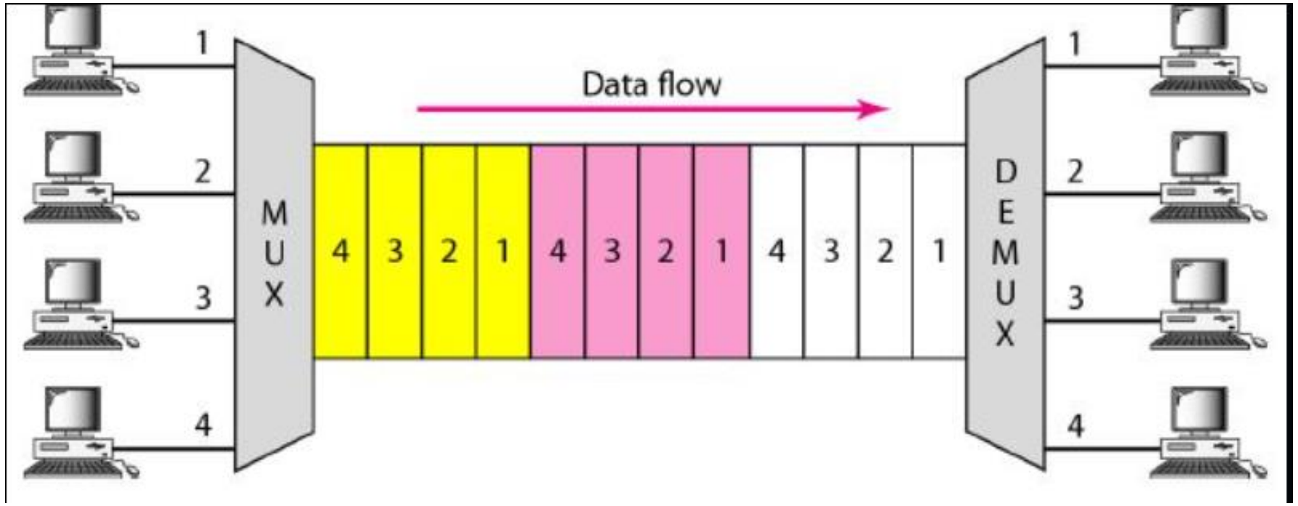
Q15. Which of them (Q14) are used for combining analog signal?



- **Frequency Division Multiplexing (FDM):** 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.



Q16. Which of them (Q14) are used for combining digital signal?



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

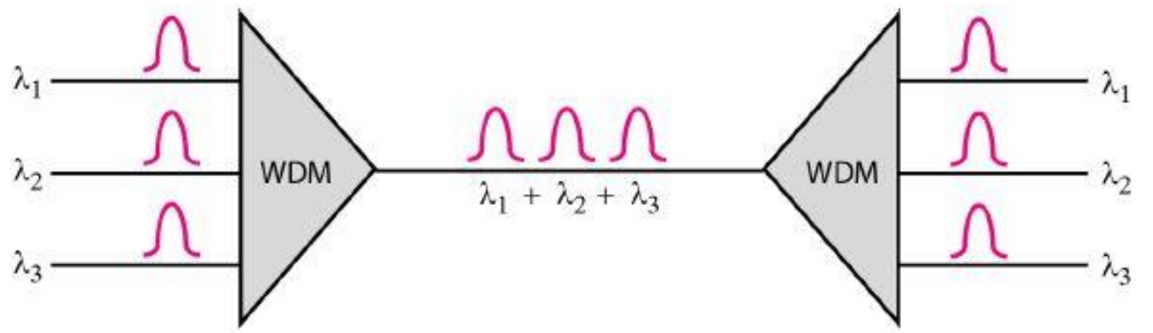
- Sync Time Division Multiplexing (Sync TDM)
- Async Time Division Multiplexing (Async TDM)

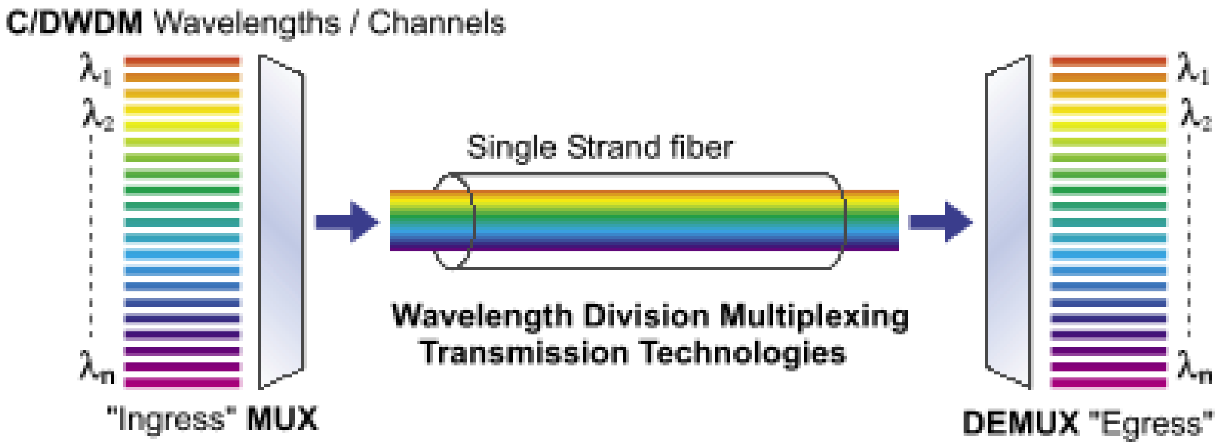
Q17. Which of the three multiplexing techniques is common for fiber optic links? Explain why.

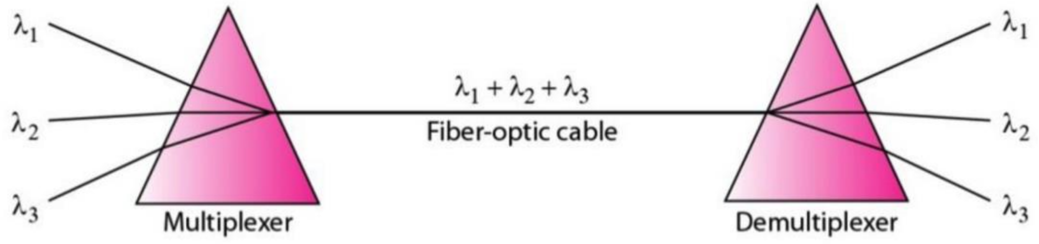
- ❑ Wavelength Division Multiplexing (WDM)
  - ❑ Used for analog signal

- ❑ Commonly used for fiber optics because:
  - ❑ WDM allows multiple data channels to be transmitted simultaneously over a single fiber optic cable, each using a different wavelength of light.
  - ❑ This significantly increases the overall data capacity of the link.

- High bandwidth
- Efficient
- Flexible
- Long-distance transmission







THE UNIVERSITY OF SYDNEY

Q18. Distinguish between Sync TDM vs statistical TDM

Synchronous TDM (Sync TDM)

- In Sync TDM, each input channel is assigned a fixed, predetermined time slot within the TDM frame, regardless of whether the channel has data to transmit or not.
- Since each channel has a dedicated time slot, the timing is predictable. The receiver knows exactly when to expect data from each channel.
- If a particular input channel has no data to send during its assigned time slot, the time slot remains empty, leading to potential wastage of bandwidth.
- Sync TDM is suitable for applications where data transmission is continuous and consistent, such as in voice communication systems.

Statistical TDM

- In Statistical TDM, time slots are dynamically allocated based on the statistical analysis of which input channels have data to send.
- Since time slots are only allocated when data is present, there is minimal wasted bandwidth, making Statistical TDM more efficient compared to Sync TDM.
- The timing for when a particular channel gets a time slot is not fixed. The receiver must use addressing or other methods to identify which channel's data is being transmitted.
- Statistical TDM is more suitable for data communication systems where transmission is bursty and unpredictable, such as in computer networks.

Q19. Assume that a voice channel occupies a bandwidth of 4 kHz. We need to multiplex 10 voice channels with guard bands of 500 Hz using FDM. Calculate required bandwidth

- Voice channel bandwidth = 4 kHz
- Number of channels = 10
- Guard band = 500 Hz

- Guard bands are required between each pair of adjacent channels.
- Since there are **10 channels, there will be 9 guard bands:**

9×500 Hz = 4.5 kHz

- Total Bandwidth for Voice Channels:
- The total bandwidth occupied by the 10 voice channels is:

$$\mathbf{10 \times 4\ \boldsymbol{kHz} = 40\ \boldsymbol{kHz}}$$

- Total bandwidth = (4 x 10) + (9 x 0.5) = 44.5 kHz

Q20. We need to transmit 100 digitized voice channels using a pass-band channel of 20 kHz. What should be the ratio of bits/Hz if we use no guard band?

- Number of channels = 100
- Passband channel = 20 kHz
- Bandwidth per channel = 20 kHz / 100 = 200 Hz

- Bandwidth for each digitized voice channel

  20 kHz/100 = 200 Hz

- Assume that the **sampling rate is 8kHz** and there are **8 bits/sample** (This is a common rate used in telephone communication).

- Thus, each digitized voice channel :

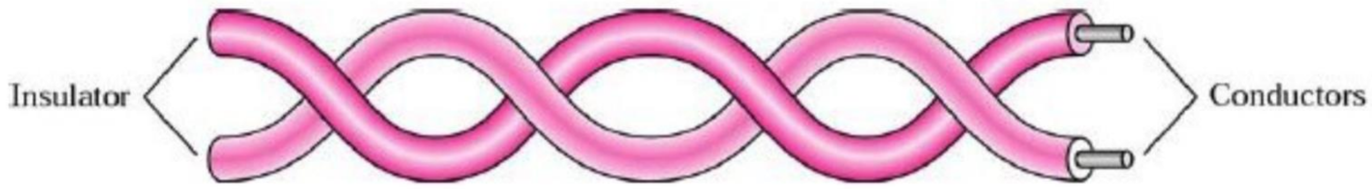
  8bit/sample * 8kHz = 64 kbps

- Therefore, the ratio of bits/s/Hz :

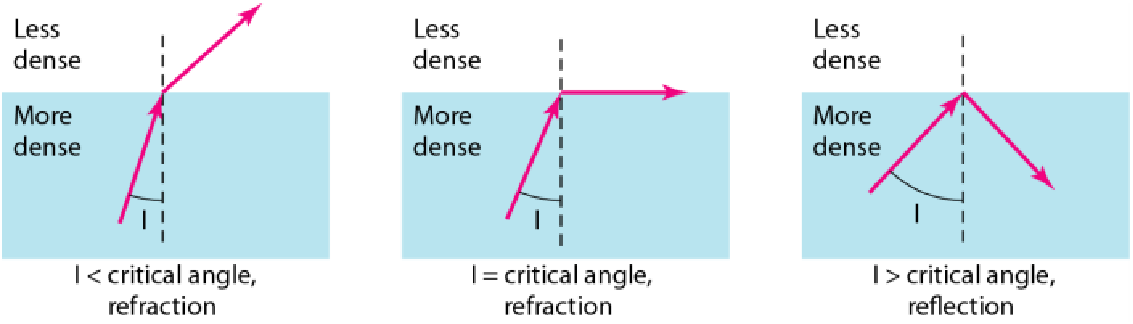
  64 kbps / 200 Hz = 320bits/s/Hz

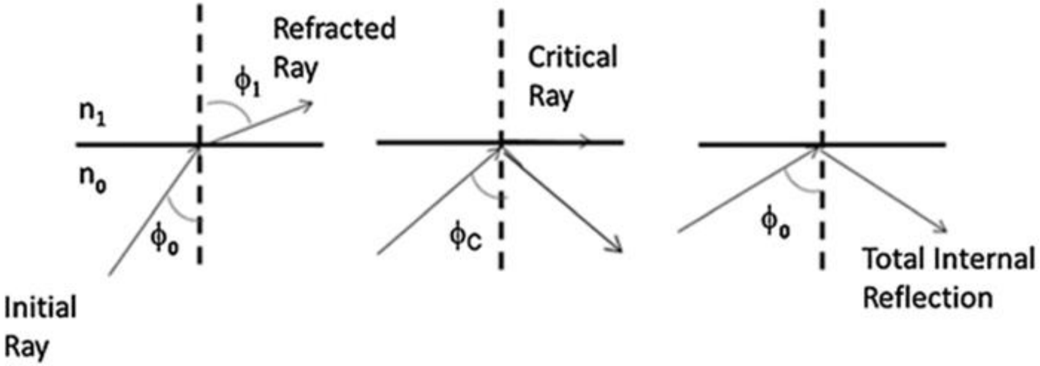
Q21. What is the significance of the twisting in twisted pair cable

- Twisting is done in twisted-pair cables because it tends to minimize the interference (noise) between the adjacent pair of wires in cable thereby reducing the crosstalk
- Twisting ensures that both wires are equally affected by external influences such as noise and crosstalk.
- In parallel cables, the effect of external influences is more in the cable closest to the source. By twisting we balance the interference and when the receiver calculates the difference between the two the unwanted signals are effectively cancelled out.
- By reducing crosstalk and EMI, twisting helps to prevent signal degradation and maintain high data transmission rates over longer distances.



Q22. What is the purpose of cladding in optical fiber cable?

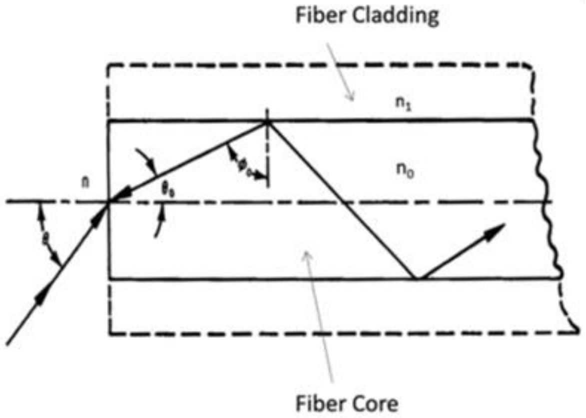


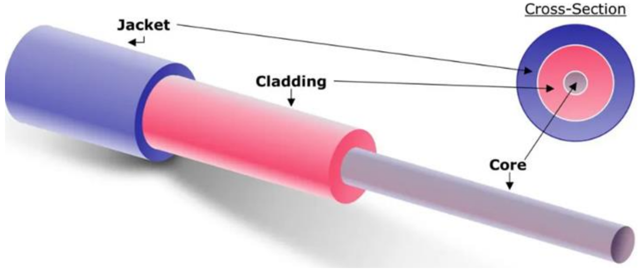


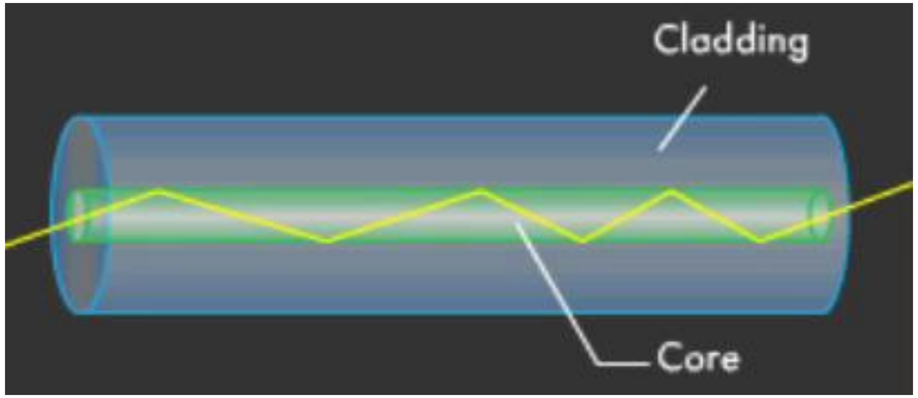
- ❑ To effectively propagate the signal down to the optical fiber's core. (The cladding has a lesser density compared to the optical fiber's core).

Trapping Light in a Core

The core has a higher refractive index than the cladding, causing light to undergo total internal reflection at the boundary, ensuring the light signals remain within the core and travel smoothly.







Q23. Name the advantages of optical fiber over twisted pair and coaxial cable.

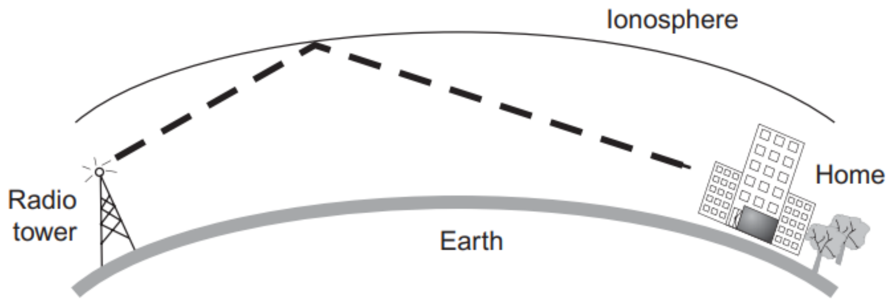
Fiber-optic cables are extensively used in various fields, including telephone and cable television networks. Their advantages include:

- **Immunity to Noise**: Since they use light for transmission instead of electricity, fiber-optic cables are resistant to electromagnetic interference.
- **Greater Transmission Distance**: They offer longer transmission distances compared to other guided media due to lower signal attenuation (less degradation over distance).
- **Enhanced Security**: Fiber-optic cables are difficult to tap into, making them a secure choice.
- Compact and Durable: They are smaller, lighter, and immune to corrosion, unlike copper wires.
- **High Bandwidth**: Fiber-optic cables provide the highest bandwidth among transmission systems.
- **Fewer Repeaters Needed**: They require fewer repeaters for covering longer distances, making them more efficient for extensive networks.
- Fiber-optic cables experience significantly less signal attenuation compared to coaxial or twisted-pair cables. This means fiber-optic cables can transmit signals over distances of up to 50 km without needing regeneration, whereas coaxial or twisted-pair cables typically require signal regeneration every 5 km.

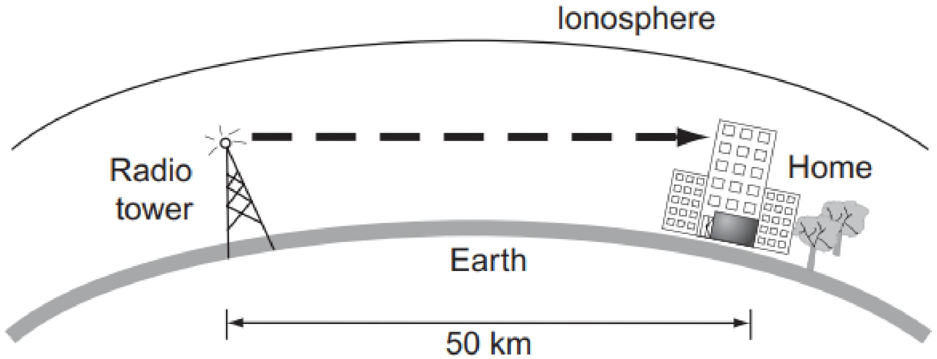
Q24. How does sky propagation differ from line-of-sight propagation?

- **Ionospheric (Sky) Propagation**: In this propagation method, the higher frequency radio waves transmitted by antenna travel upwards into ionosphere layer in the upper portion of atmosphere and bounced off by the layer towards earth.
- It operates in the frequency range of 2–30 MHz. As this type of propagation dependson the earth's ionosphere, it changes with the day timings and weather.
- This method of propagationis also known as sky wave propagation.

- **Line-of-Sight Propagation**: In this propagation method, very high frequency signals are transmitted which travel exactly in straight line.
- This method demands both transmitting and receiving antennas to be in line of sight of each other, that is, the receiving antenna must be in view of the transmitting antenna.
- It is sometimes called space waves or tropospheric propagation.
- It is limited by the curvature of the earth for ground-based stations (50 km)



Ionosphere Propagation



Line-of-Sight Propagation

Q25. List three traditional switching methods

- Switches are devices capable of creating temporary connections between two or more devices linked to the switch.

- Traditionally, three methods of switching have been important;

Circuit switching

Packet switching
- Virtual-circuit networks
- Datagram networks

Message switching

- Circuit switching and packet switching are commonly used today.

- Packet-switched networks can further be divided into two subcategories.

Q26. What are the two approaches for packet switching?

Packet switching

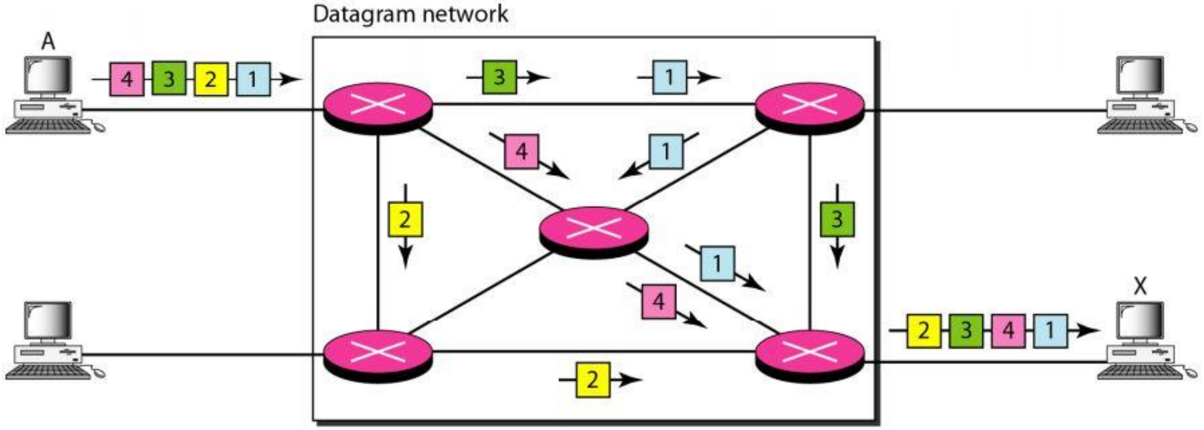
- Virtual-circuit networks
- Datagram networks

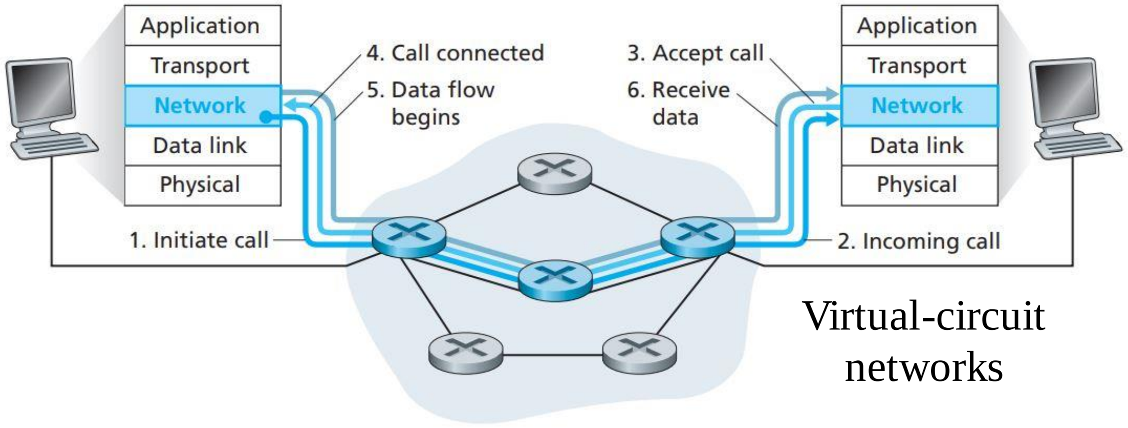
Datagram networks

- Datagram networks are the connectionless networks used for packet switching at the network layer.
- No virtual connection exists between the source and the destination.
- There is no need of any connection setup or teardown phase.

Virtual-circuit networks

- A virtual circuit network includes the characteristics of both circuit-switched and a datagram network and performs switching at the data link layer.
- It requires a virtual connection to be established between the communicating nodes before any data can be transmitted.

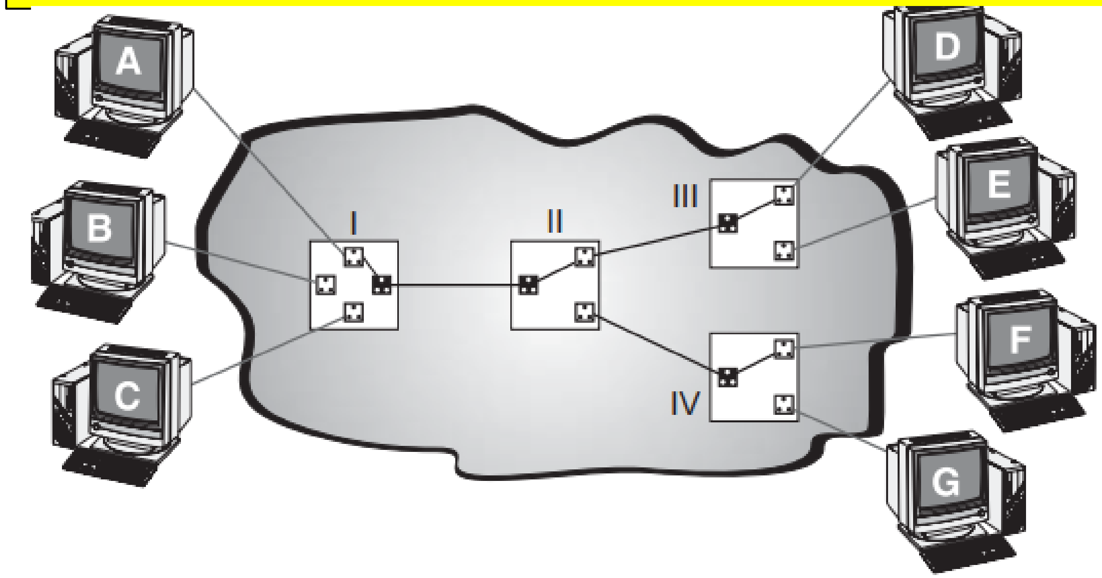


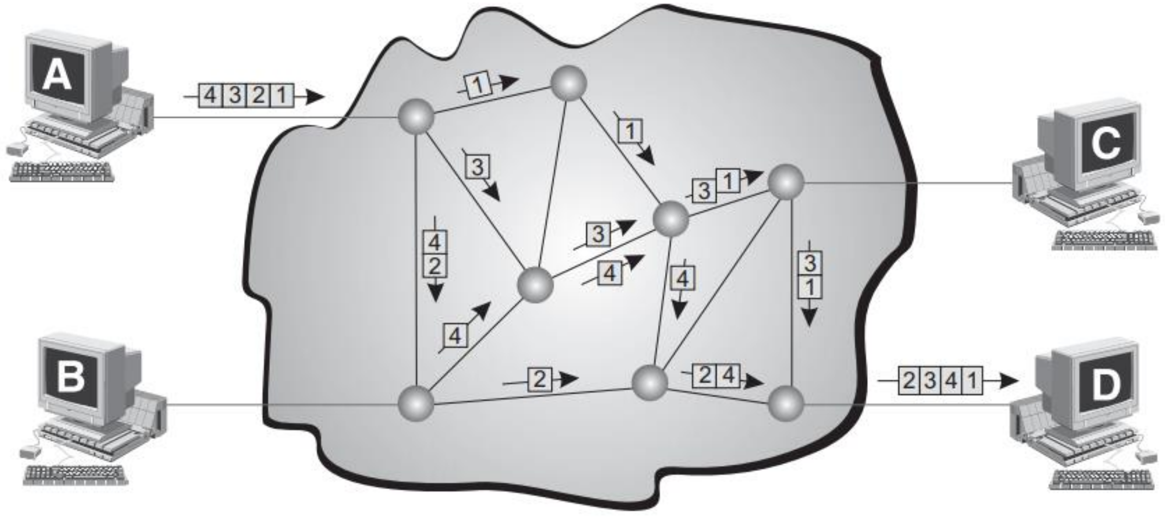


Virtual-circuit networks

Q27. Compare and contrast a circuit switched network and a packet switched network.

Circuit switching	Packet switching
❑ A physical circuit is established before transmission begins. ❑ Message to be transmitted is in continuous bits. ❑ Three phases: Setup, Data transfer and Teardown ❑ Less efficient in resource utilization. ❑ Occurs at the physical layer. ❑ It is used in telephone network for bi-directional, fast and real-time data transfer.	❑ No physical circuit is established before transmission. ❑ Message to be transmitted is in the form of packets. ❑ No setup or teardown phase for establishing a communication link. ❑ More efficient in resource utilization. ❑ Occurs either at the data link layer (virtual-circuit approach) or at the network layer (datagram approach). ❑ It is used for the Internet.

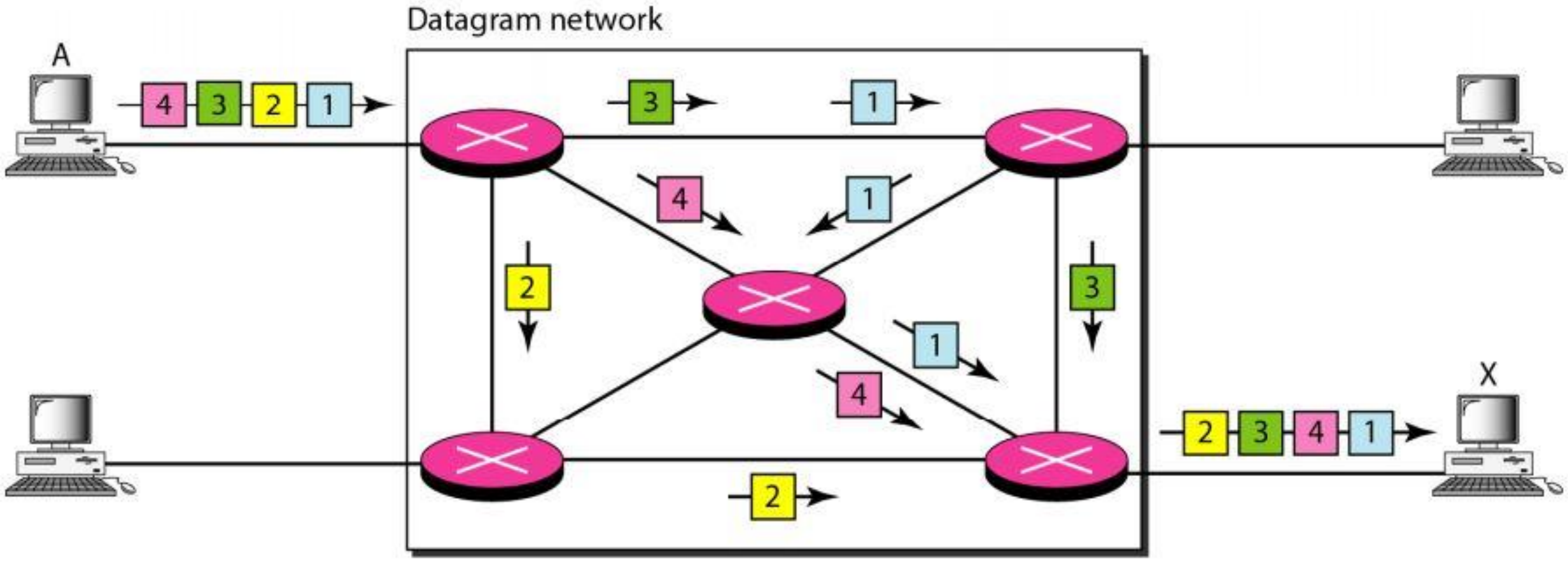




Q28. What is the role of the address field in a packet travelling through a datagram network?

Datagram networks

- Datagram networks are the connectionless networks used for packet switching at the network layer.
- No virtual connection exists between the source and the destination.
- There is no need of any connection setup or teardown phase.

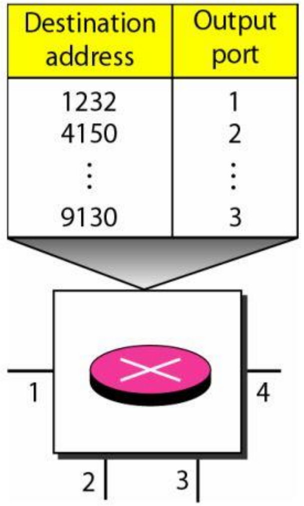


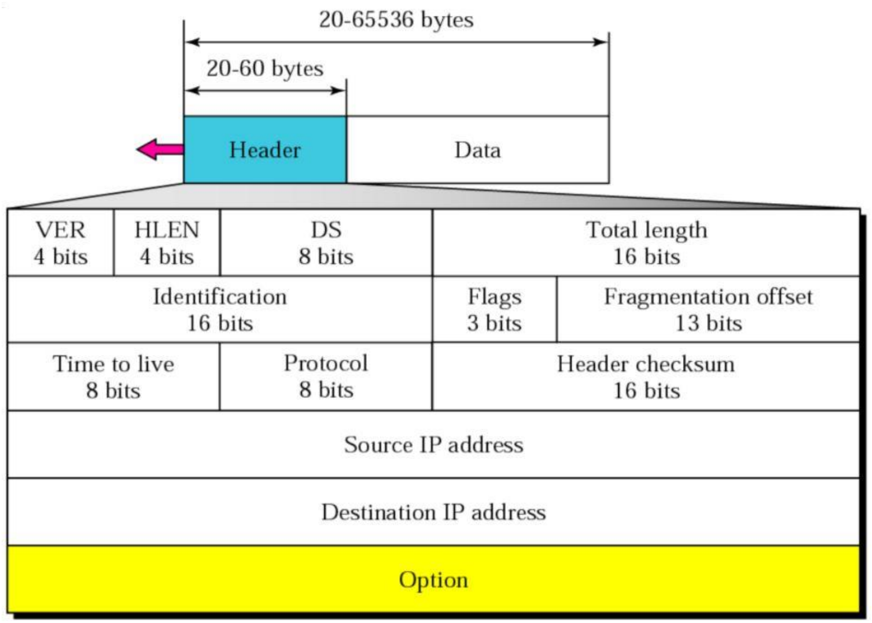
THE UNIVERSITY OF SYDNEY

Q28. What is the role of the address field in a packet travelling through a datagram network?

Role of the address field

- When a source creates a datagram, it inserts its IP address into the source IP address field and inserts the address of the ultimate destination into the destination IP address field.
- The destination addresses and the corresponding forwarding output ports are recorded in the routing tables.
- When the switch receives the packet, this destination address is examined.
- The routing table is consulted to find the corresponding port through which the packet should be forwarded.
- This address remains the same during the entire journey of the packet.

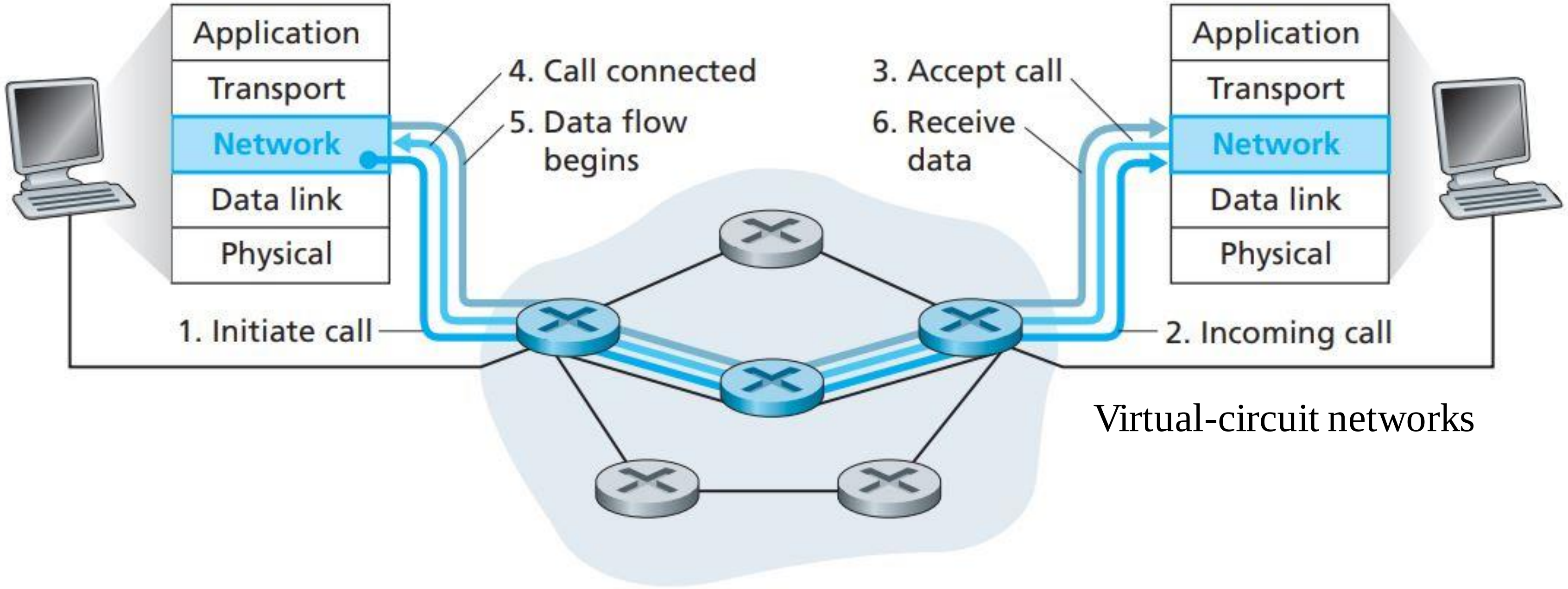




Q29. What is the role of the address field in a packet travelling through a virtual circuit network?

Virtual-circuit networks

- A virtual circuit network includes the characteristics of both circuit-switched and a datagram network and performs switching at the data link layer.
- It requires a virtual connection to be established between the communicating nodes before any data can be transmitted.



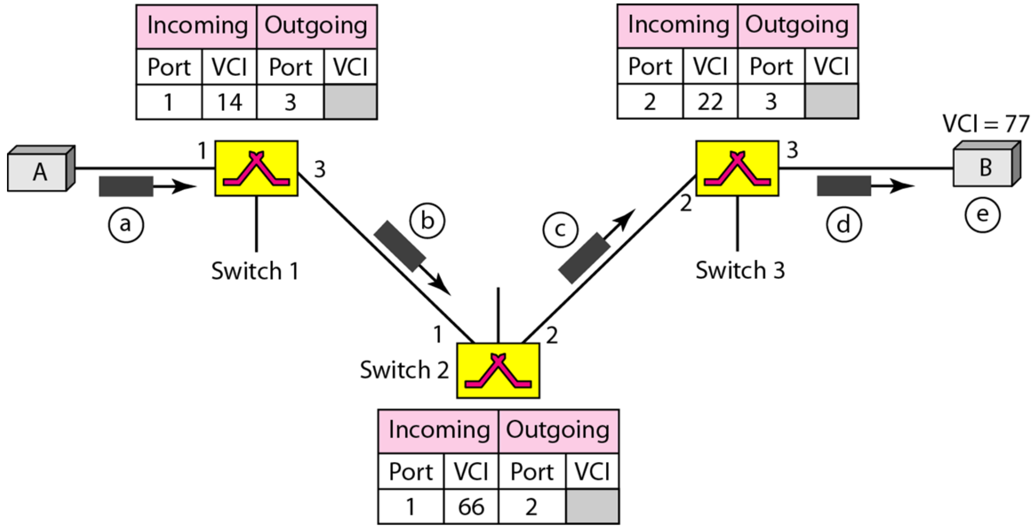
Virtual-circuit networks

Q29. What is the role of the address field in a packet travelling through a virtual circuit network?

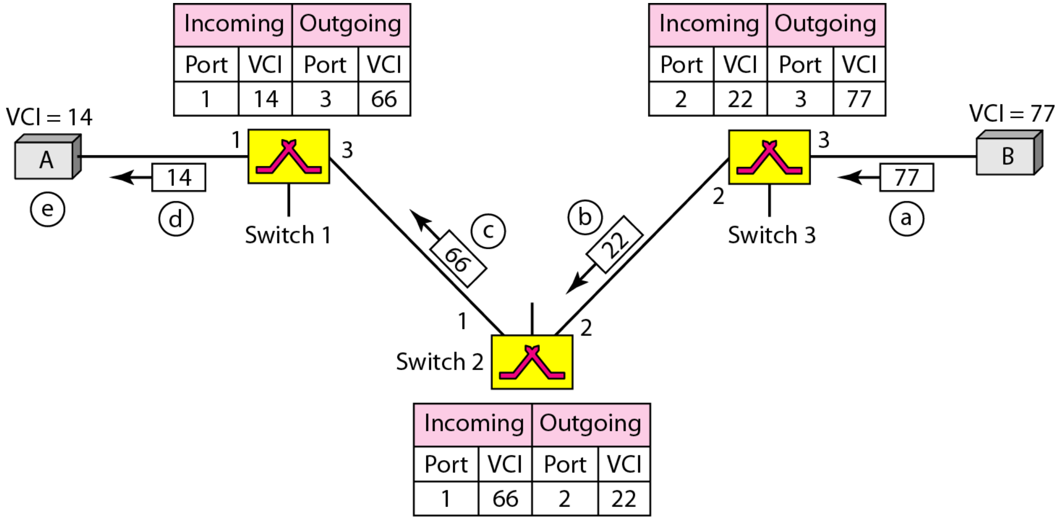
- In a virtual-circuit network, two types of addressing are involved: **global** and **local.**
- **Global Addressing**: Source and destination needs unique addresses (IP).
- **Local Addressing**: A small address used by a frame between two switches called virtual-circuit identifier (VCI).

- **Three Phases**: Setup request, Setup acknowledgement and Data Transfer

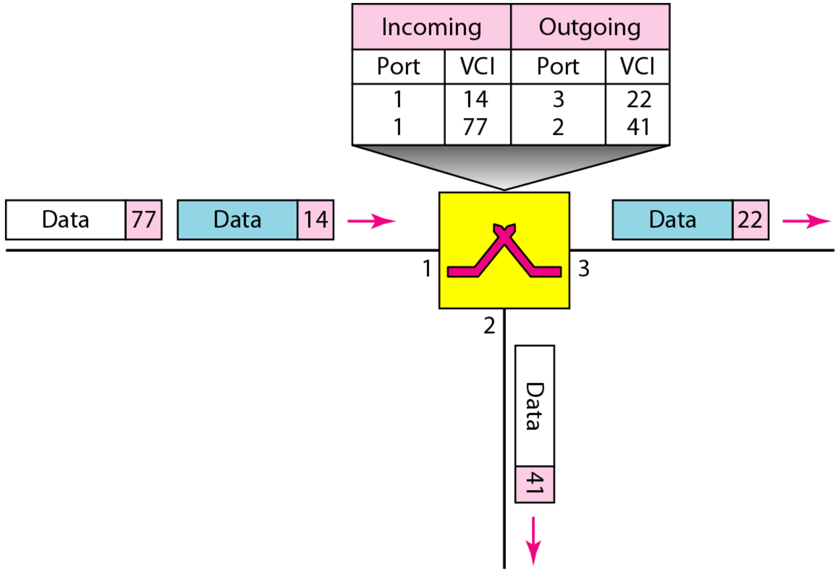
Setup request in a virtual-circuit network



Setup acknowledgment in a virtual-circuit network



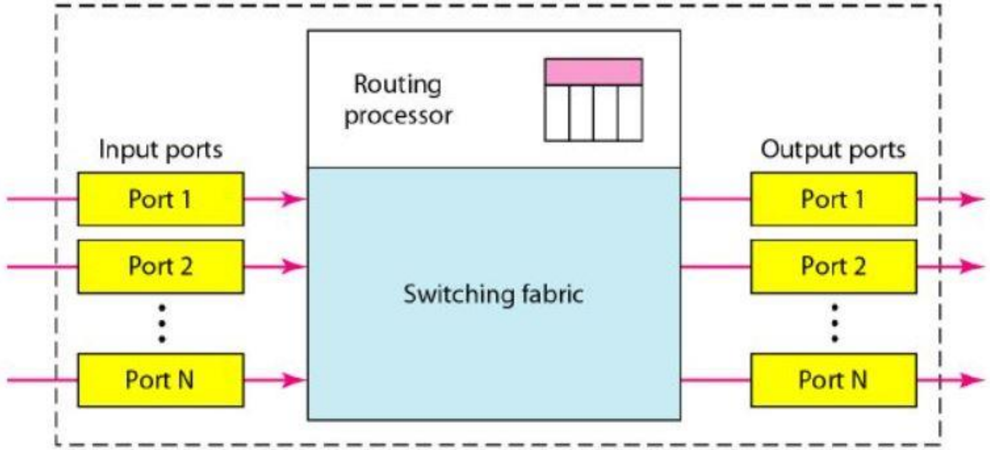
Switch and tables in a virtual-circuit network



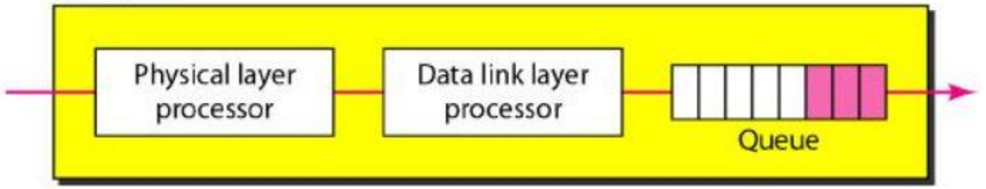
Q30. List four major components of a packet switch and their functions.

- A switch used in a packet-switched network has a different structure from a switch used in a circuit-switched network.

1. **Input Port**: Performs the physical and data link functions of the packet switch. The input port has buffers (queues) to hold the packet before it is directed to the switching fabric.
2. **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, and finally transmitted.
3. **Routing Processor**: The routing processor performs the functions of the network layer and searches the routing table to find the next hop address.
4. **Switching Fabrics**: Responsible for moving the packet from the input queue to the output queue. Different switching techniques are used to move the packets, i.e., Crossbar Switch and Banyan Switch.



Input port



Output port