Chapter 2- Multiplexing and Multiple access techniques

2.1 Multiplexing and Concentration

2.2 Space Division Multiplexing (SDM)

2.3 Wavelength-Division Multiplexing (WDM)

2.4 Time-Division Multiple Access (TDMA)

2.5 Code-Division Multiple Access (CDMA)

2.6 Space-Division Multiple Access (SDMA)

2.7 ALOHA, Slotted-ALOHA, CSMA/CD

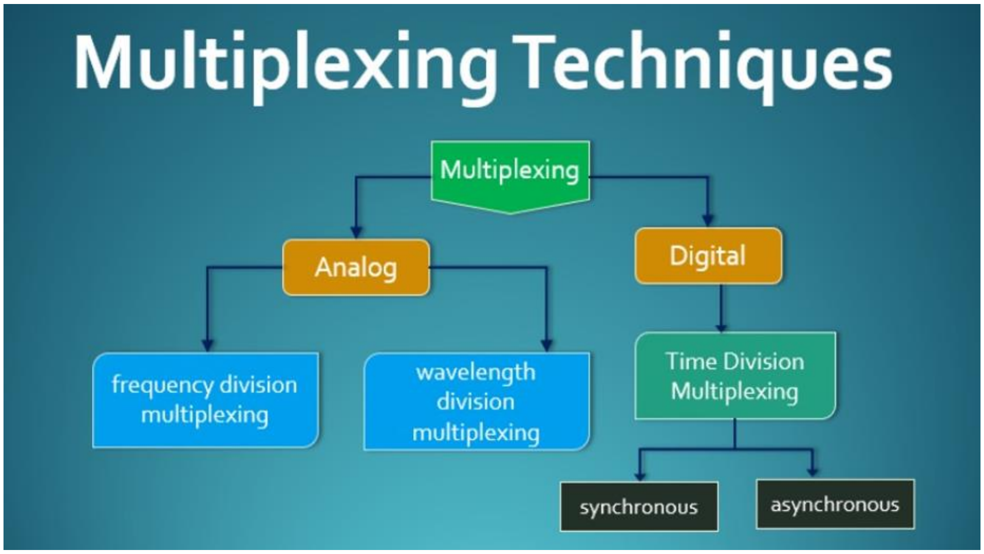
2.1 Multiplexing and Concentration

What is Multiplexing and De-multiplexing?

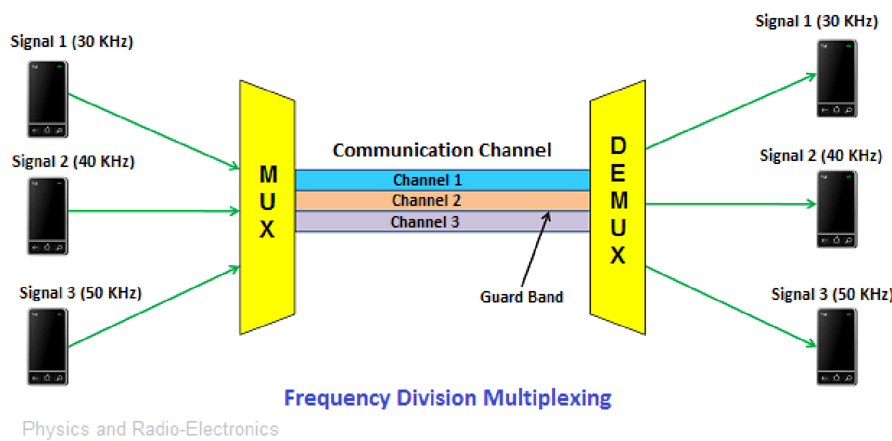
- Multiplexing is a technique that allows the simultaneous transmission of multiple signals across a single data link. De-multiplexing is the process of separating a composite signal, which contains multiple multiplexed signals, back into its individual components
- When many nodes are competing for the use of a network, the capacity or bandwidth of the network can be divided, or allocated, in a variety of ways to make the most effective use of the available channel capacity. (This is accomplished using multiplexing)
- maximizes the use of the available bandwidth by combining multiple signals
- Minimizes the need for multiple physical links or channels

Advantages:

a. Efficient Bandwidth Utilization
b. Cost-Effectiveness
c. Scalability
d. Simplified Network Design
e. Improved Data Transmission Rates
f. Flexibility in Communication

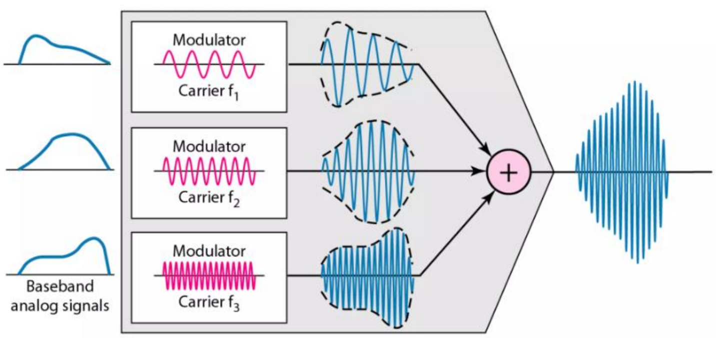


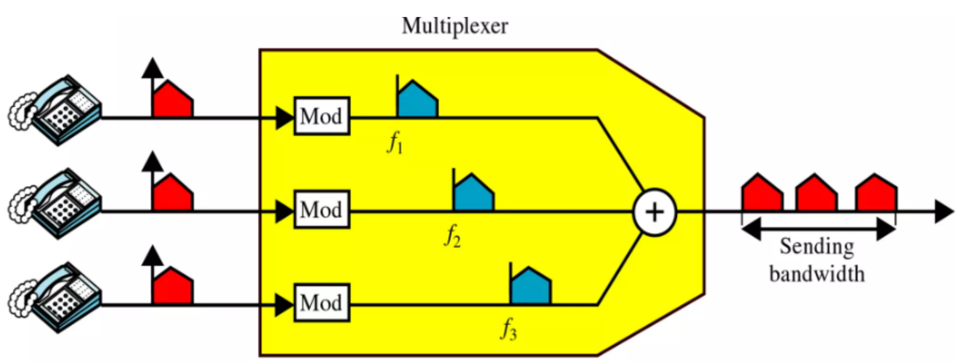
Frequency Division Multiplexing



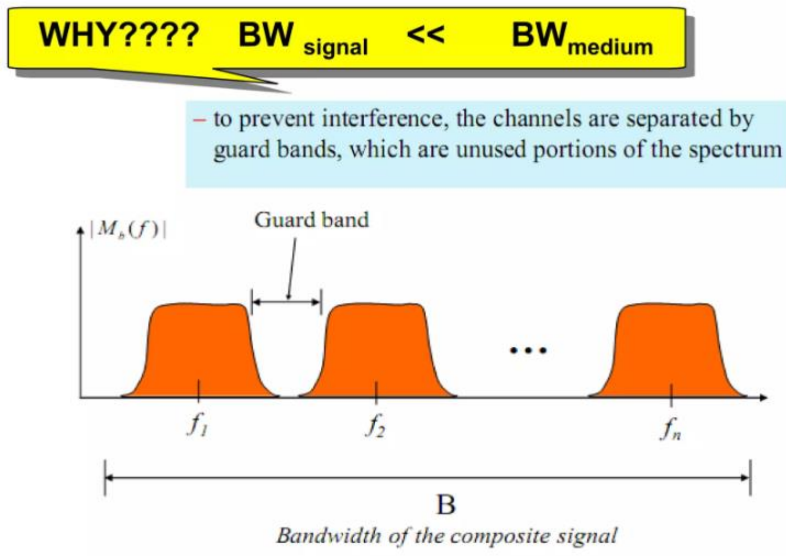
- FDM is an analog multiplexing method used when the bandwidth of a communication link exceeds the combined bandwidth of the signals being transmitted
- Each signal from a sender modulates a unique carrier frequency
- These modulated signals are combined into a single composite signal, allowing multiple signals to share the same medium

- Each signal is assigned a distinct carrier frequency, ensuring that their respective channels remain separate
- Sufficient bandwidth is allocated around each carrier frequency to avoid signal interference
- The medium is divided into channels, where each channel corresponds to a specific frequency range





- These channels act as pathways for the individual signals
- To prevent overlap and interference between adjacent signals, small unused frequency ranges called **guard bands** are placed between channels
- Can simultaneously transmit multiple signals over the same medium, optimizing the use of available bandwidth
- This principle is fundamental in analog broadcasting systems, cable TV, and early telephone networks



Frequency (MHz)	Channel
54-60	2
60-66	3
66-72	4
76-82	5
82-88	6
174-180	7
180-186	8
186-192	9
192-198	10
198-204	11
204-210	12
210-216	13

Example table of assignment of frequency to TV channel

Advantages of FDM:

- Efficient Use of Bandwidth
- No Time Synchronization Required
- Low Implementation Cost

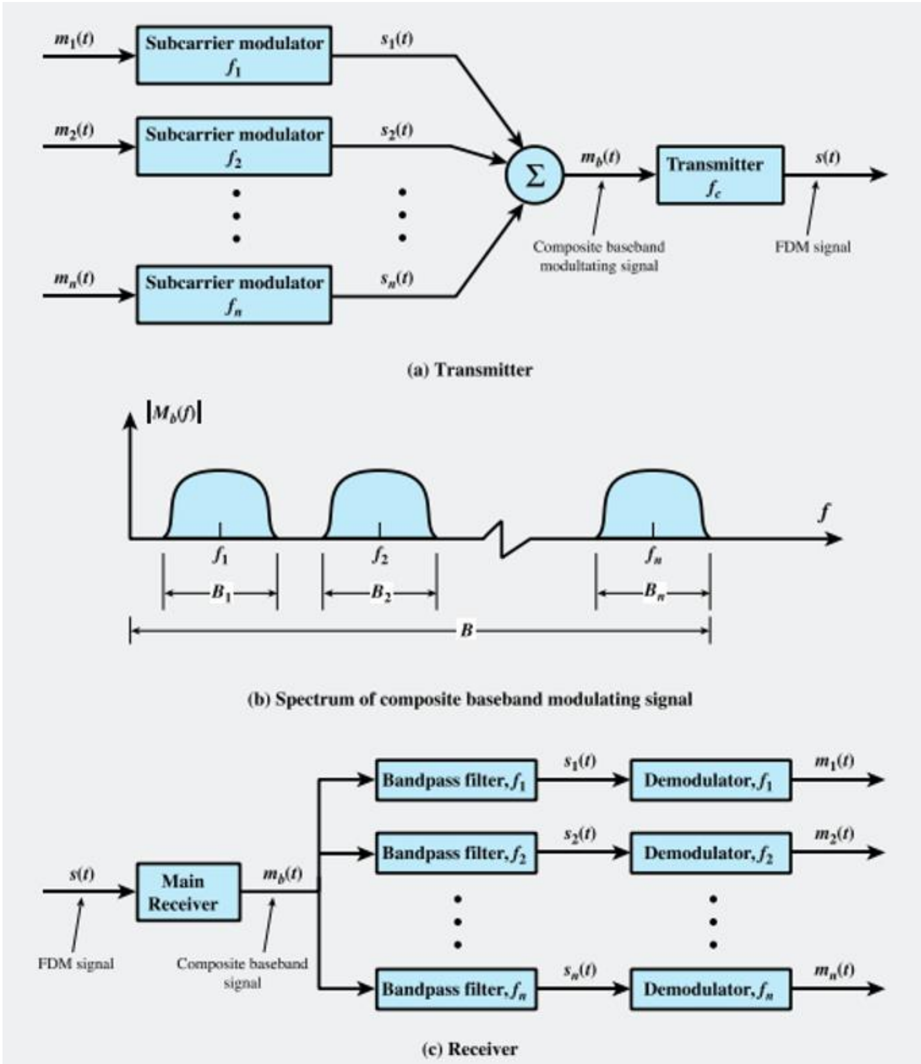


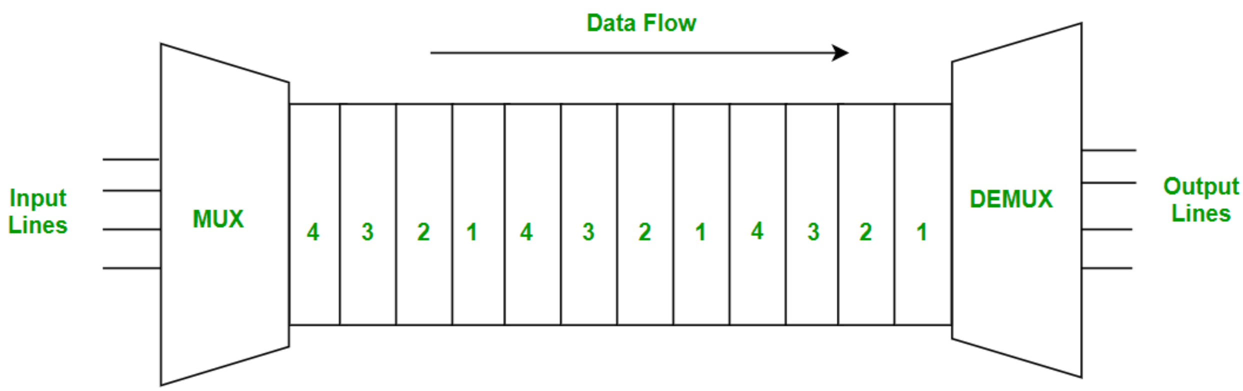
Figure that shows FDM between Transmitter and Receiver

Disadvantages of FDM:

- Interference
- Difficulty in Assigning Frequencies

Time Division Multiplexing (TDM)

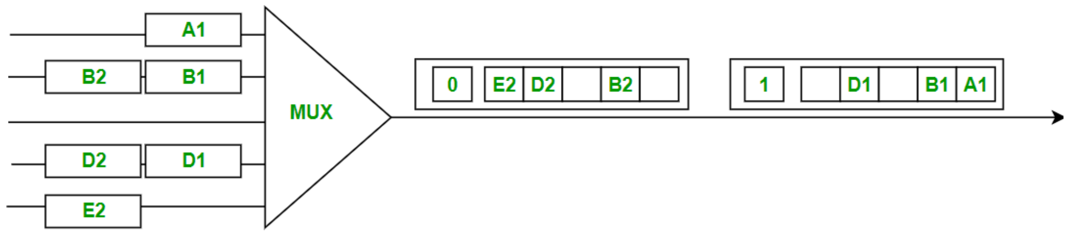
- It is a digital multiplexing technique that allows multiple signals to share the same communication channel by dividing the available time into fixed intervals, or time slots
- Each signal is assigned a unique time slot during which it can transmit its data, and this process is repeated in a cyclic manner

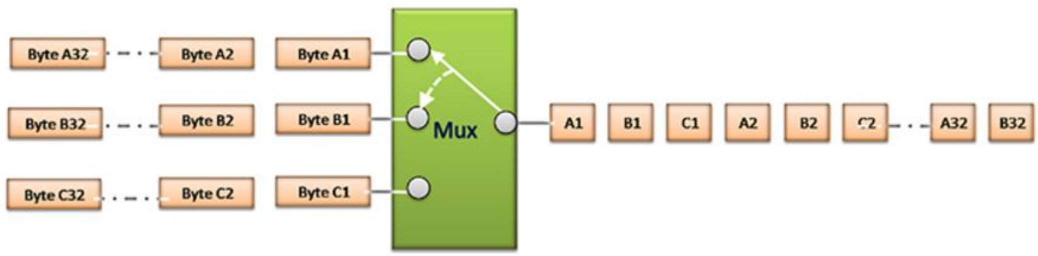


Types of TDM:

i. **Synchronous TDM**

- In synchronous TDM, every device which is present in this has given the same time slot to transmit data
- It does not consider whether the device contains data or not
- The devices place their data on the link when their time slots arrive, if somehow any device does not contain data its time-slot remains empty
- There are various kinds of time slots that are organized into frames and each frame consist of one or more time slots dedicated to each sending device





Advantages of Synchronous TDM

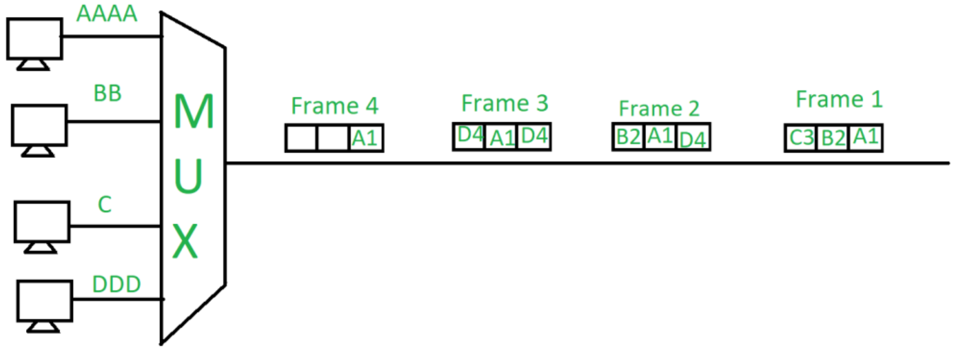
- bandwidth is guaranteed because each data stream has time slot assigned
- Predictable latency so that signal transfer is easier
- Simpler synchronization as time slots are pre-defined
- Efficient for continuous data

Disadvantages of Synchronous TDM

- Inefficient use of bandwidth
- Rigid Allocation: Time slots are pre-defined and can be difficult to adjust for data streams that either require more or less bandwidth
- Unsuitable for bursty data: because of no scope for dynamic allocation of slots due to demand
- Even when no data is being transmitted, it considers the channel as busy, which may further raise the operational cost

ii. Asynchronous TDM

- allocates the time slots dynamically to the data streams based on requirements
- time slot is assigned only when the data stream has some information to be sent, making it more flexible



Advantages

- Suitable for bursty or irregular data transmission
- Latency may vary based on demand and slot availability
- Efficient; slots are only used when data is present
- Transmits only when data is ready to be sent
- More cost-efficient, as resources are allocated on demand

Disadvantages

- More complex due to dynamic slot assignment
- Harder to synchronize with dynamic allocation

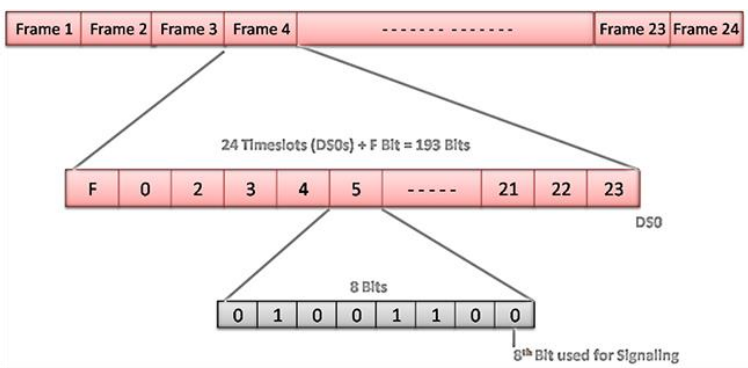
Comparison:

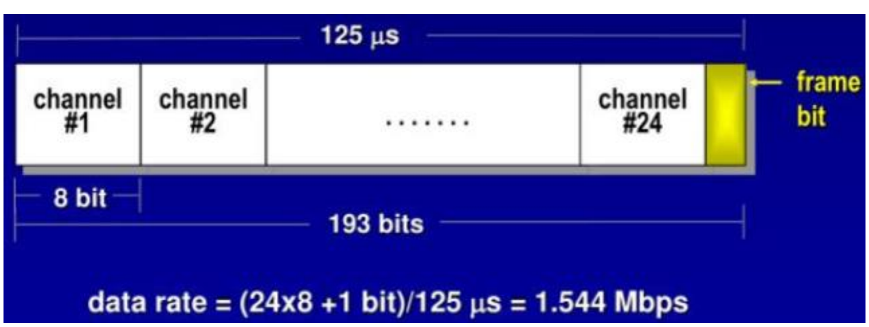
TDM	FDM
TDM stands for Time division multiplexing.	FDM stands for Frequency division multiplexing.
TDM works with digital signals as well as analog signals.	While FDM works with only analog signals.
TDM has low conflict.	While it has high conflict.
Wiring or chip of TDM is simple.	While it’s wiring or chip is complex rather than simple.
TDM is efficient.	While it is inefficient.
In TDM, time sharing takes place.	While in this, frequency sharing takes place.
In TDM, synchronization pulse is necessary.	While in it Guard band is necessary.

T1 and E1 system:

Calculation of T1:

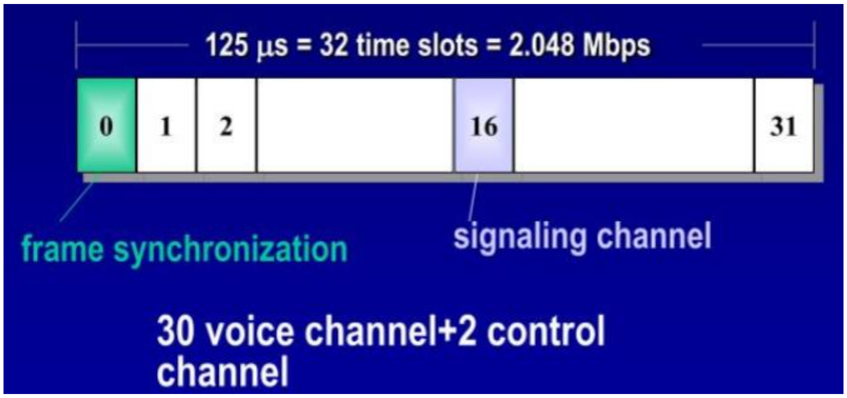
- In telephony system, Voice Signal is given by 4khz frequency (where 3100hz for voice and 900hz for guard band)
- Required digital sampling rate = 8000 hz (fs ≥ 2fm)
- 1 byte of voice data for each 24 channels i.e. system needs 8000 frames per second to maintain those 24 simultaneous voice channels
- Each frames of T1 is (24 Channels * 8bits per second + 1 framing bit = 193)
- The frame is 192 bits long (8 * 24), and is terminated with a 193rd bit, the framing bit, which is used to find the end of the frame
- Since 8000 frames per second (193 *8000 = 1.544 Mbps)





Calculation of E1:

- In telephony system, Voice Signal is given by 4khz frequency (where 3100hz for voice and 900hz for guard band)
- Required digital sampling rate = 8000 hz (fs ≥ 2fm)
- 32 time slot each being allocated
- 1 byte of voice data for each 32 channels i.e. system needs 8000 frames per second to maintain those 32 simultaneous voice channels
- (8*8000*32 = 2048000 = 2.048 Mbps) where 8000 is frames per second for sampling



Advantages of T1 Hierarchy

- Flexibility in Smaller Installations
- Efficient for Voice and Data
- Ease of Aggregation

Advantages of E1 Hierarchy

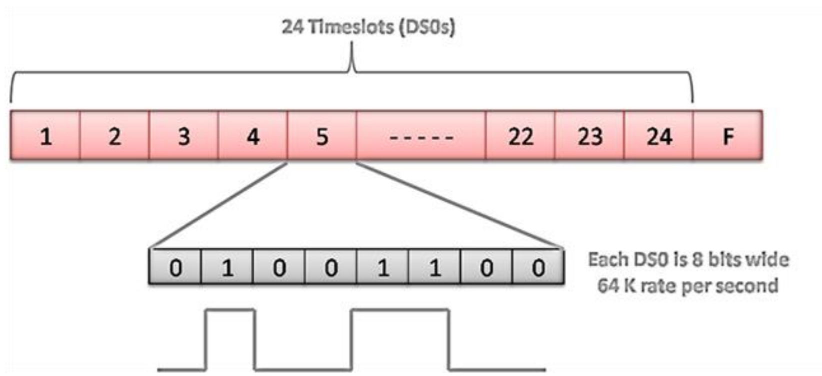
- Higher Channel Capacity
- Higher Data Rate
- Cost Efficiency for Larger Networks
- Scalability

Feature	**North American TDM (T1)**	**European TDM (E1)**
Channels	24 (23 for voice/data)	32 (30 for voice/data)
Frame Structure	193 bits/frame	256 bits/frame
Bit Rate	1.544 Mbps	2.048 Mbps
Signaling Method	In-band (robbed bit)	Out-of-band (dedicated slot)
Frame Synchronization	Framing bit (1 bit)	Time slot 0
Data Integrity	Slightly lower (due to robbed bit)	Higher (due to out-of-band signaling)
Usage Regions	North America, Japan	Europe, Asia, (Nepal) and others

T1 Frame Types: Frame, Super Frame, Extended Super Frame, Unframe

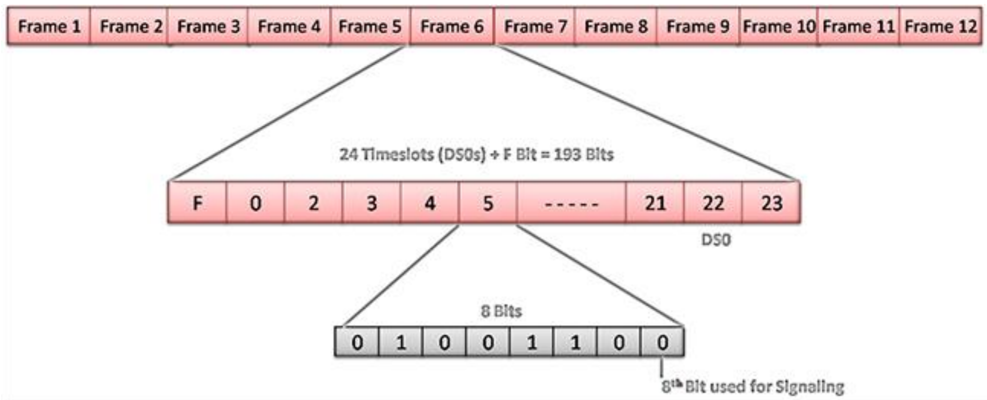
Frame

- A basic T1 frame DS1 (digital signal-level one) contains 24 DS0 (64kbps) time slots, numbered from 1 to 24, each time slot has 8 bits, a total of 192 bits. The T1 basic frame also includes an F bit (framing bit), which is used as a frame synchronization bit to indicate the end of the current frame and the beginning of the next frame. The transmission rate of DS1=193*8k= 1.544 Mbps.



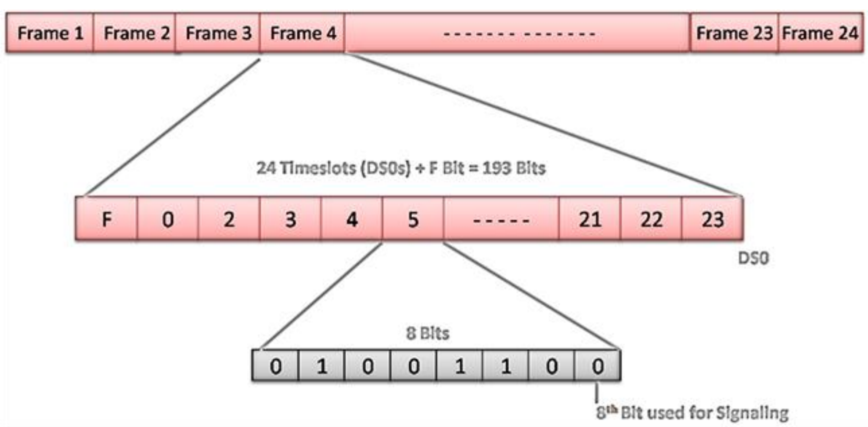
Super Frame (SF)

- The SF frame format (also known as the D4 frame format) is the most commonly used format in the current public switched telephone network
- Each SF consists of 12 basic DS1 frames. The 193th bit of each frame is used as the control bit, and the 12th 193bit of the SF Combine them to form a 12-bit control word (eg 100011011100) to provide frame synchronization and signaling management information
- The odd bits of the 12-bit control word of the SF frame (called the Ft bit, and the corresponding frame is called the terminal frame) are used to mark the frame and super frame boundary so that the receiving device can correctly process user data; the even bits of the control word (called Fs) Bit, the corresponding frame is called signaling frame) used to carry signaling flags



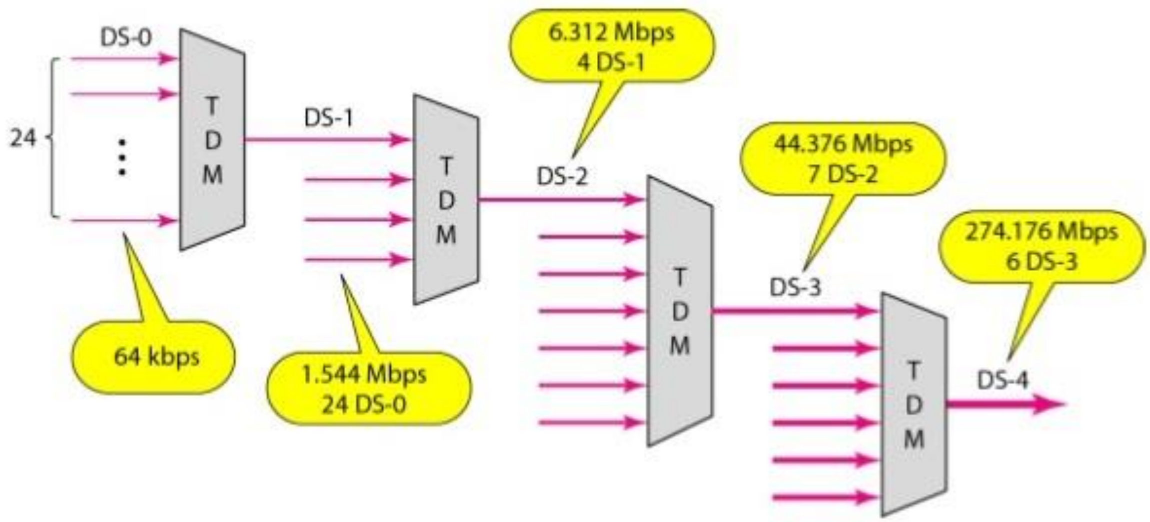
Extended Super Frame (ESF)

The ESF frame format extends the SF frame mode from 12 frames to 24 frames, a total of 193* 24 = 4632 bits



T1 and E1 Hierarchy:

- **T1 Hierarchy**



Key Components in the Diagram

1) DS-0 (Digital Signal Level 0)

- The basic unit of digital communication
- Each DS-0 channel carries 64 kbps (8 bits * 8000 (sampling rate)), which is typically one voice channel

2) DS-1 (Digital Signal Level 1)

- Combines 24 DS-0 channels using TDM
- Total bandwidth: 1.544 Mbps (24 × 64 kbps + framing bits).
- This is the T1 system

3) DS-2 (Digital Signal Level 2):

- Combines 4 DS-1 signals into a single stream
- Total bandwidth: 6.312 Mbps (4 × 1.544 Mbps + overhead)
- DS-1 (T1) is commonly used for voice and data in small-to-medium enterprises
- This is the T2 system

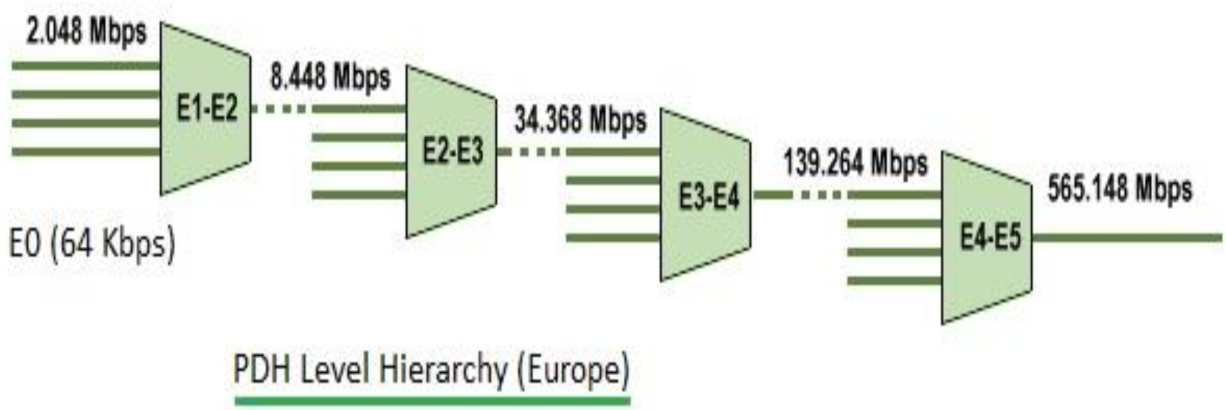
4) DS-3 (Digital Signal Level 3):

- Combines 7 DS-2 signals into one
- Total bandwidth: 44.376 Mbps (7 × 6.312 Mbps + overhead)
- DS-3 (T3) is backbone connections for internet service providers and large businesses
- This is the T3 system

5) DS-4 (Digital Signal Level 4)

- Combines 6 DS-3 signals into the highest level in the T-carrier hierarchy
- Total bandwidth: 274.176 Mbps (6 × 44.376 Mbps + overhead)
- DS-4 is rarely used but provides extremely high data capacity
- This is the T4 system

➢ **E1 Hierarchy**



- This figure illustrates the Plesiochronous Digital Hierarchy (PDH) used in Europe
- It highlights the multiplexing levels and data rates in the European PDH hierarchy, starting from basic E0 channels and progressing to higher levels
  - Fame types: Unframed (UNF), Framed (FR) and Multi-Framed (MF)

1. E0 (64 kbps):
   - The basic unit of digital communication in PDH
   - Each E0 channel typically carries one voice call or a 64 kbps data stream
2. E1 (2.048 Mbps)
   - Combines 32 E0 channels using Time Division Multiplexing
   - Total bandwidth: 2.048 Mbps (32 × 64 kbps)

- Used as the foundation for higher PDH levels

3. E2 (8.448 Mbps)
    - Combines 4 E1 channels into a single stream
    - Total bandwidth: 8.448 Mbps (4 × 2.048 Mbps + overhead)

4. E3 (34.368 Mbps)
    - Combines 4 E2 channels
    - Total bandwidth: 34.368 Mbps (4 × 8.448 Mbps + overhead)
    - Widely used in backbone communication links

5. E4 (139.264 Mbps):
    - Combines 4 E3 channels
    - Total bandwidth: 139.264 Mbps (4 × 34.368 Mbps + overhead)

6. E5 (565.148 Mbps)
    - Combines 4 E4 channels into the highest PDH level
    - Total bandwidth: 565.148 Mbps (4 × 139.264 Mbps + overhead)
    - Rarely used, but provides extremely high data capacity

Q.1: Among TDM and FDM, which is more susceptible (liable to be influenced) to interference?

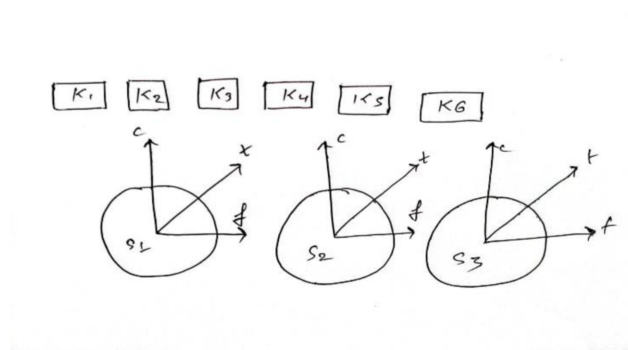
Answer: FDM is more susceptible to interference because signals mostly share the similar frequency range.

Q.2: Among TDM and FDM, which one is mostly used for voice and data integration?

Answer: TDM is generally used for voice and data integration because of its ability to allocate time slots dynamically.

2.2 Space Division Multiplexing (SDM)

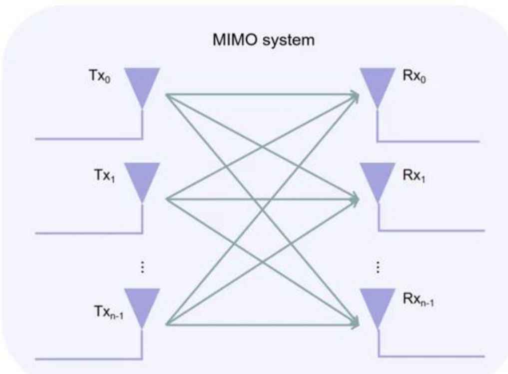
- SDM is a method of transmitting multiple communication channels or data streams simultaneously by using physically distinct transmission paths
- Unlike other multiplexing techniques that rely on frequency, time, or wavelength, SDM utilizes spatial separation to achieve multiplexing
- Utilizes multiple antennas for spatial paths in systems like Multiple-Input Multiple-Output (MIMO)
- Example: 5G cellular networks use MIMO technology to transmit multiple data streams



Working Of SDM:

- *Separate Transmission Paths*: In SDM, multiple signals are transmitted simultaneously through distinct physical paths, such as separate optical fibers, waveguides, or physical antennas.
- *Independent Channels:* Each spatial path serves as an independent communication channel, ensuring no interference between them.

- *Combination with Other Multiplexing Techniques:* SDM is often combined with techniques like Time Division Multiplexing (TDM), Wavelength Division Multiplexing (WDM), or Frequency Division Multiplexing (FDM) to further increase data transmission capacity.



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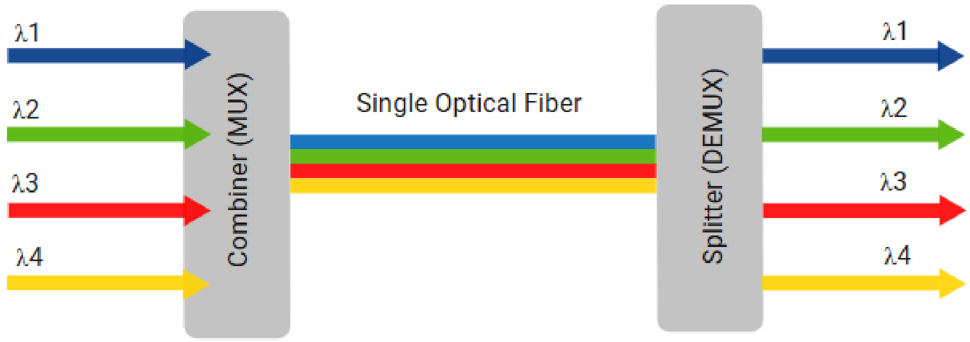
2.3 Wavelength Division Multiplexing (WDM)

- It is a technology used in fiber-optic communication to transmit multiple optical carrier signals simultaneously through a single optical fiber
- This is achieved by assigning unique wavelengths (or colors) of light to each data stream, which are then multiplexed and sent down the fiber. At the receiving end, a demultiplexer separates the combined signal back into its individual wavelengths



Key Principles of WDM

a) *Multiplexing Multiple Wavelengths:* Different data streams are modulated onto different wavelengths of light. These wavelengths act as separate channels. For example, one wavelength could carry internet traffic while another could carry video conferencing data

b) *Communication in Both Directions:* WDM supports bi-directional communication using the same fiber by assigning specific wavelengths for upstream and downstream traffic

c) *Optical Spectrum Utilization:* Signals operate within specific wavelength ranges in the optical spectrum (commonly between 1260 nm and 1625 nm, covering the O-band (Original Band) to L-band (Long Wavelength Band) in fiber-optic communication)

d) *Parallel Transmission:* Each wavelength functions as an independent communication channel, allowing multiple signals to traverse the fiber simultaneously without interference

Components of a WDM System

- ✓ *Multiplexer (MUX):* Combines multiple optical signals (at different wavelengths) into one fiber
- ✓ *Demultiplexer (DEMUX):* Separates the combined optical signal back into individual wavelengths at the receiving end
- ✓ *Optical Filters:* Used to isolate and route specific wavelengths
- ✓ *Transceivers:* Convert electrical signals into optical signals and vice versa
- ✓ *Optical Amplifiers:* Boost the signal strength across long distances to compensate for attenuation

Wavelength according to color

Violet: shortest wavelength, ranging from 380–450 nm

Violet light has the highest frequency and energy

Indigo: Has a wavelength of 420–440 nm

Blue: Has a wavelength of 450–495 nm

Green: Has a wavelength of 495–570 nm

Yellow: Has a wavelength of 570–590 nm

Orange: Has a wavelength of 590–620 nm

Red: Has the longest wavelength, ranging from 620–750 nm

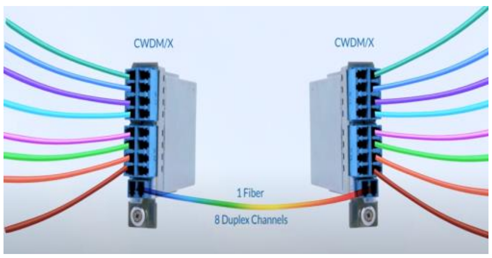
- Advantages of WDM
  - *Efficient Utilization of Fiber*
  - Scalability
  - High Capacity: Enables terabits of data per second
  - Cost Savings
  - Flexibility

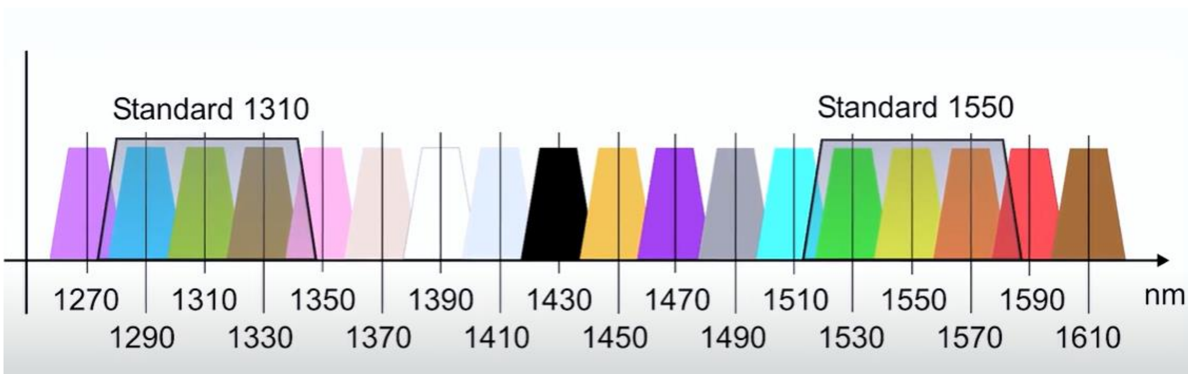
- Applications of WDM
  - Long-distance communication
  - High-speed data transmission
  - Multiplexing onto a single fiber for distribution

Types of WDM:

1) CWDM (Coarse Wavelength Division Multiplexing):

- Wavelength spacing: 20 nm (ranging 1270 nm to 1610 nm)
- Number of channels: Typically up to 18
- Application: Cost-effective, used for short-range networks
- Advantages: Lower cost, simpler equipment





2) DWDM (Dense Wavelength Division Multiplexing):

- Wavelength spacing: 0.8 nm or less (ranging 1525 nm to 1565 nm in the C-band, and 1570 nm to 1610 nm in the L-band)
- Number of channels: Up to 80 or more

- Application: High-capacity, long-distance communication
- Advantages: Higher channel density and capacity

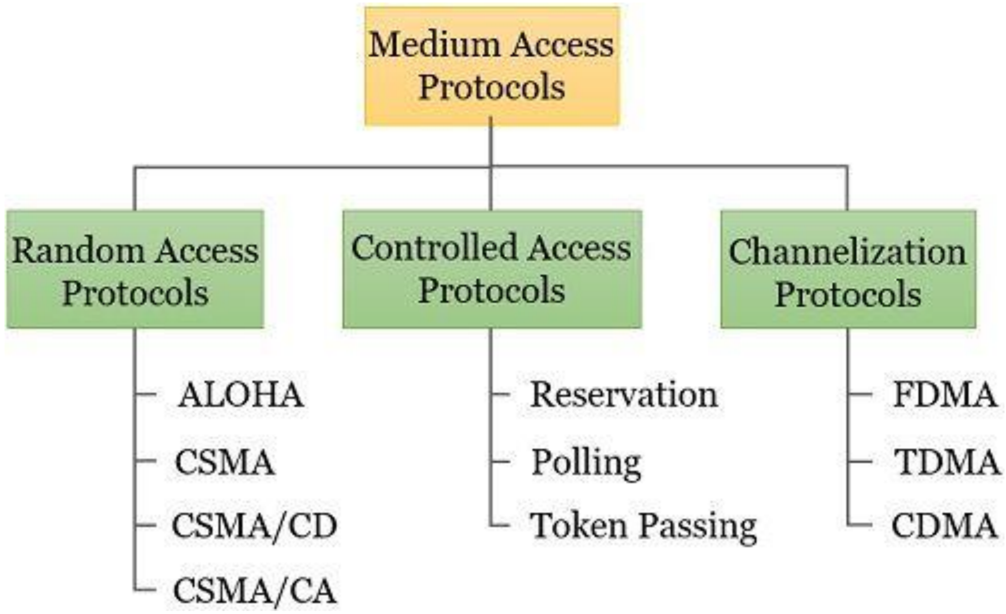
Q) How interference are minimized in WDM?

- In optical fibers, total internal reflection ensures that light signals remain confined within their respective modes without leaking into other channels
- wavelengths are orthogonal, they do not interfere with each other
- Lasers emit light at specific, stable wavelengths with minimal spectral drift
- Optical Amplifiers like EDFAs (Erbium-Doped Fiber Amplifiers) amplify all channels uniformly without distorting the spectral characteristics

Comparison on CWDM and DWDM:

https://www.youtube.com/watch?v=Y7_mX98gTqE

FDM	TDM	WDM
FDM is a multiplexing method used in analog systems that requires a guard band and has low spectral efficacy.	TDM (Time Division Multiplexing) is a multiplexing technology and has low conflict, working with both digital and analog signals.	Wavelength division multiplexing (WDM) is often used for multiplexing numerous optical carrier signals into a single optical fiber channel.
FDM divides the bandwidth into smaller frequency ranges, and transmitters broadcast data concurrently across a shared channel inside each frequency range.	TDM provides each user a defined time slot to deliver signals across a shared channel. The user receives the complete bandwidth during that time frame.	WDM combines numerous light beams from different channels into a single light beam and delivers it over a fiber optic thread similar to FDM.
FDM refers to Frequency Division Multiplexing.	TDM refers to Time Division Multiplexing.	WDM refers to Wave Length Multiplexing.
FDM is used in a communications network to send and receive input signals at maximum speed at all times.	This technology is used in GSM and also in SDH Transmission.	It is used in ultra-long-distance and high-capacity fiber systems.



1. TDMA (Time Division Multiple Access)

TDMA divides the available bandwidth into discrete time slots, and each user is assigned a specific time slot for communication. Users transmit sequentially in their allocated time slots

Key Features:

- Time slots are pre-allocated or dynamically assigned.
- Only one user transmits in a time slot, avoiding interference.
- Synchronization is critical to prevent overlapping of time slots.

Applications:

- 2G mobile systems like GSM.
- Satellite communication.

Advantages:

- Simple implementation.
- Efficient use of the spectrum when users' traffic is bursty.

Disadvantages:

- Requires precise synchronization.
- Idle slots if a user has no data to send.

2. CDMA (Code Division Multiple Access)

CDMA allows multiple users to transmit simultaneously over the same frequency band by encoding their signals with unique pseudo-random codes. The receiver uses the corresponding code to extract the desired signal while treating other users' signals as noise.

Key Features:

- All users share the same frequency band and time but use unique codes.
- Based on spread-spectrum technology: signals are spread over a wide bandwidth using spreading codes.
- High resistance to interference and eavesdropping.

Applications:

- 3G mobile systems like WCDMA and CDMA2000.

- GPS systems.

Advantages:

- High spectral efficiency.
- Robust to interference and noise.
- Can support asynchronous transmission.

Disadvantages:

- Complex implementation due to code synchronization.
- Performance degrades with more users (capacity limit).

3. SDMA (Space Division Multiple Access)

SDMA uses the spatial separation of users to allocate resources. It relies on smart antenna technology to create distinct spatial beams for each user, allowing multiple users to share the same frequency and time without interfering with each other.

Key Features:

- Leverages beamforming and directional antennas.
- Maximizes capacity by reusing frequencies in different spatial regions.
- Utilized in systems where users are distributed over a geographical area.

Applications:

- Cellular networks (e.g., LTE, 5G with massive MIMO).
- Satellite communication.
- Wi-Fi systems with beamforming.

Advantages:

- Very efficient in frequency reuse.
- Enhances system capacity and reduces interference.

Disadvantages:

- High implementation complexity (smart antennas and beamforming algorithms).
- Performance depends on the accuracy of spatial separation.

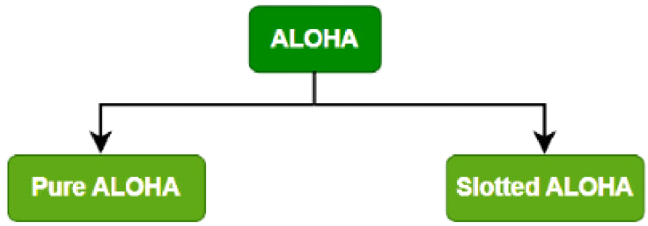
FDMA	TDMA	CDMA
FDMA stands for Frequency Division Multiple Access.	TDMA stands for Time Division Multiple Access.	CDMA stands for Code Division Multiple Access.
In this, sharing of bandwidth among different stations takes place.	In this, only the sharing of time of satellite transponder takes place.	In this, there is sharing of both i.e. bandwidth and time among different stations takes place.
There is no need of any codeword.	There is no need of any codeword.	Codeword is necessary.
In this, there is only need of guard bands between the adjacent channels are necessary.	In this, guard time of the adjacent slots are necessary.	In this, both guard bands and guard time are necessary.
Synchronization is not required.	Synchronization is required.	Synchronization is not required.
The rate of data is low.	The rate of data is medium.	The rate of data is high.
Mode of data transfer is continuous signal.	Mode of data transfer is signal in bursts.	Mode of data transfer is digital signal.
It is little flexible.	It is moderate flexible.	It is highly flexible.

Assignment3:
Explain about Aloha, Slotted Aloha, CSMA/CD

2.7 ALOHA

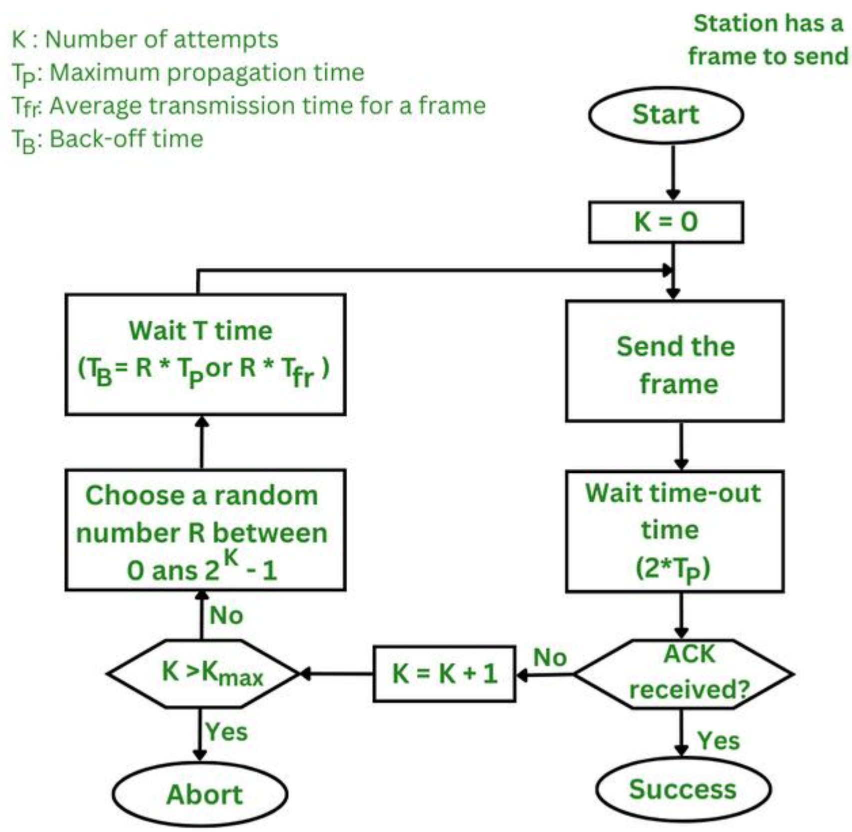
ALOHA handles collision, which happen when two devices try to send data at a public network channel, causing interference. It is a random access protocol.

Types:



1. Pure ALOHA

- Each station sends a frame whenever one's frame is available. Because there is only one channel to share, there is a chance that frames from different stations will collide.
- When a user sends a frame, it expects confirmation from the receiver for successful transmission. If no acknowledgment is received within a designated time period, the sender assumes that the frame was not received and retransmits the frame.
- If the first bit of a new frame overlaps with the last bit of a frame that is almost finished, **both frames will be completely destroyed** and will need to be retransmitted
- To prevent this, the pure ALOHA protocol dictates that each user waits a random amount of time, known as the **back-off time** (independent and randomly chosen), before retransmitting the frame. This randomness helps to avoid further collisions.



Throughput of Pure ALOHA

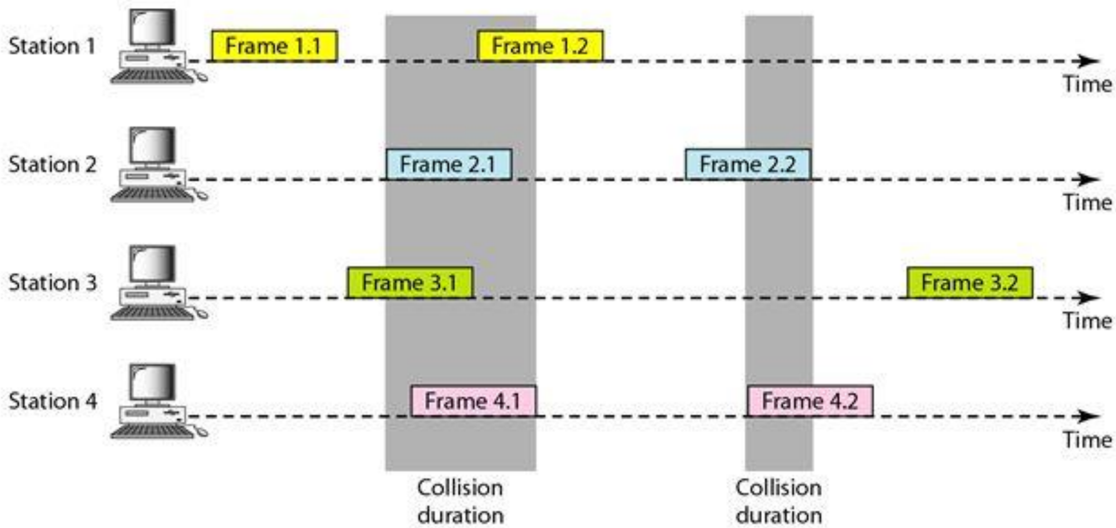
$$S = G \times e^{-2G} \qquad \text{where,}$$

- S is the throughput (the average number of successful packet transmissions per packet time)
- G is the average number of packets generated by the system in one packet time

The maximum throughput occurs when G=0.5

$$S_{max} = 0.5 \times e^{-1} \approx 0.184$$

This means only about 18.4% of the time is used for successful transmissions, and the rest is lost due to collisions.



Station 1
Frame 1.1
Frame 1.2
Time
Station 2
Frame 2.1
Frame 2.2
Time
Station 3
Frame 3.1
Frame 3.2
Time
Station 4
Frame 4.1
Frame 4.2
Time
Collision duration
Collision duration

Slotted ALOHA

Here, the channel is divided into small, fixed-length time slots and users are only allowed to transmit data at the beginning of each time slot. This synchronization of transmissions reduces the chances of collisions between devices, increasing the overall efficiency of the network.

Working of Slotted ALOHA

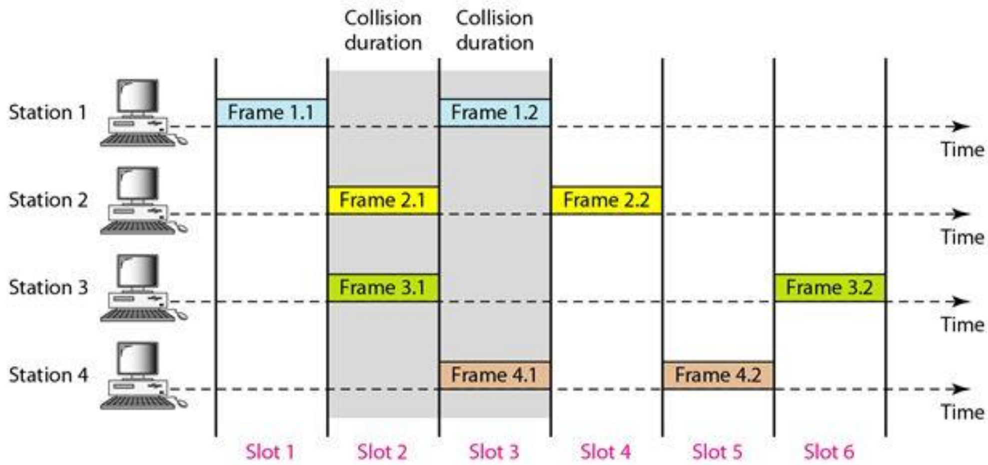
- All users are synchronized to these time slots so that whenever a user sends a packet, it must precisely match the next available channel slot.
- When a user wants to transmit a frame, it waits until the next time slot and then sends the frame
- If the frame is received successfully, the receiver sends an acknowledgment. If the acknowledgment is not received within a time-out period, the sender assumes that the frame was not received and retransmits the frame in the next time slot
  - In a variant of slotted ALOHA called “non-persistent slotted ALOHA”, the station that wants to send data, first listens to the channel before sending the data. If the channel is busy it waits for a certain time before trying again.

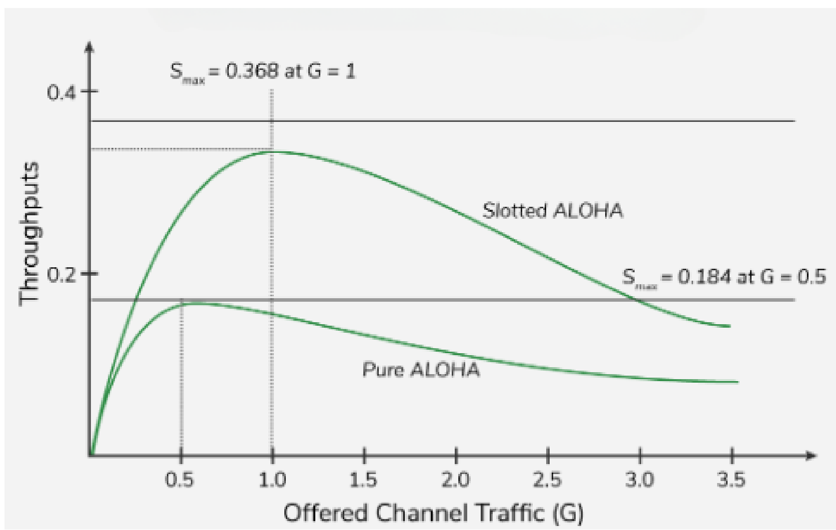
Throughput (S) = G x e^{-G}

The maximum Throughput occurs at G = 1,

I.e. S = 1/e = 0.368

It is important to note that the above equation assumes that all the packets are of the same length and that the channel is error-free





How does Slotted ALOHA differ from Pure ALOHA?

Answer: In Pure ALOHA, devices can send data at any time, which increases the chance of collisions. In Slotted ALOHA, devices can only send data at the start of time slots, reducing the chance of collisions.

How are collisions handled in Slotted ALOHA?

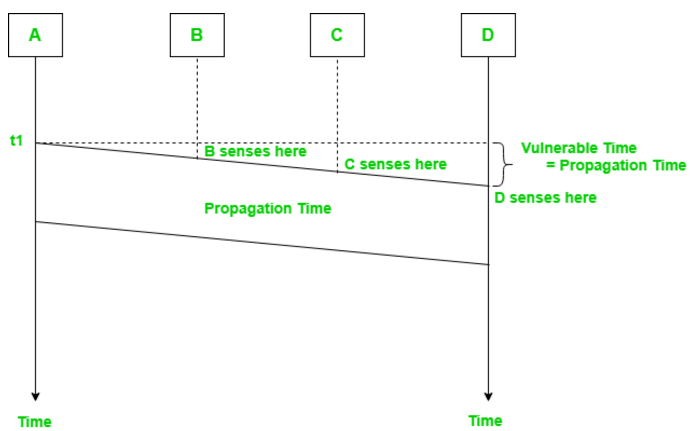
Answer: When a collision occurs, each device involved waits for a random time before attempting to resend its data in a new time slot.

Pure Aloha	Slotted Aloha
Any station can transmit the data at any time.	Any station can transmit the data at the beginning of any time slot.
The time is continuous and not globally synchronized.	The time is discrete and globally synchronized.
Vulnerable time in which collision may occur $= 2 \times T_{Fr}$	Vulnerable time in which collision may occur $= T_{Fr}$
Probability of successful transmission of data packet= $G \times e^{-2G}$	Probability of successful transmission of data packet= $G \times e^{-G}$
Maximum efficiency = 18.4% (Occurs at G = 1/2)	Maximum efficiency = 36.8% (Occurs at G = 1)
Main advantage: Simplicity in implementation.	Main advantage: It reduces the number of collisions to half and doubles the efficiency of pure aloha.

Carrier Sense Multiple Access (CSMA)

- A network protocol that ensures devices share communication channels efficiently.
- Each device checks the channel before sending data and if the channel is busy, the device waits until it is free

Vulnerable time = Propagation time (Tp)



{Imagine you're in a room with several people trying to talk at once.

In 1-persistent CSMA everyone keeps checking to see if the room is free and speaks up immediately when it is which often leads to people talking over each other.

In p-persistent CSMA the room is divided into time slots and people decide to speak based on a set chance reducing the chances of talking over each other.

Non-persistent CSMA is like waiting and then checking again randomly so people aren't constantly trying to talk at once which cuts down on collisions but might delay the conversation.

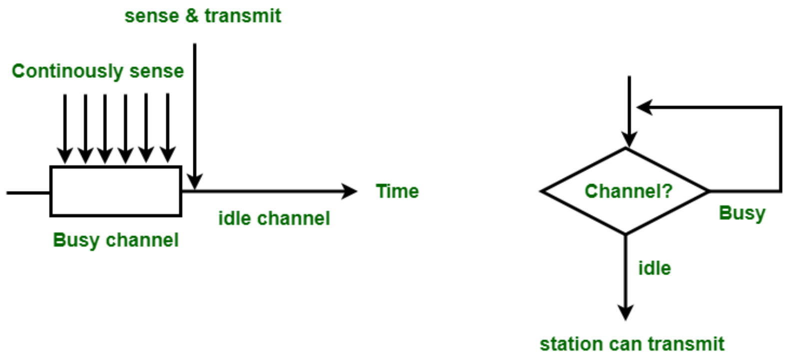
Each method has its trade-offs with 1-persistent being quick but collision-prone p-persistent balancing speed and collisions and non-persistent minimizing collisions at the cost of potential delays. }

1-Persistent CSMA

- A method where a station senses the channel continuously
- If the channel is busy, the station waits until it becomes idle
- Once idle, the station transmits immediately with a 100% (probability = 1) chance
- The station always transmits as soon as the channel is idle, without any delay, ensuring a 1-persistent behavior

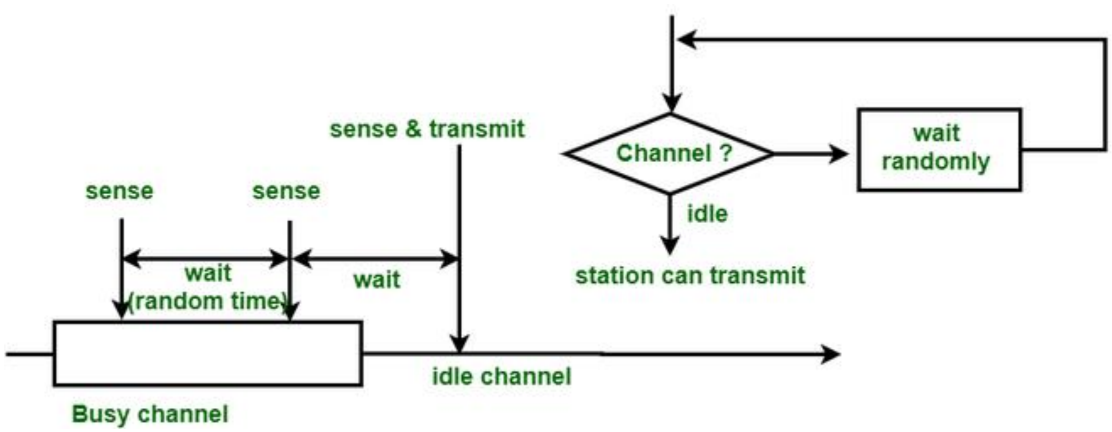
Problem with 1-Persistent CSMA:

- High Collision Chances
- Worse in Burst Situations



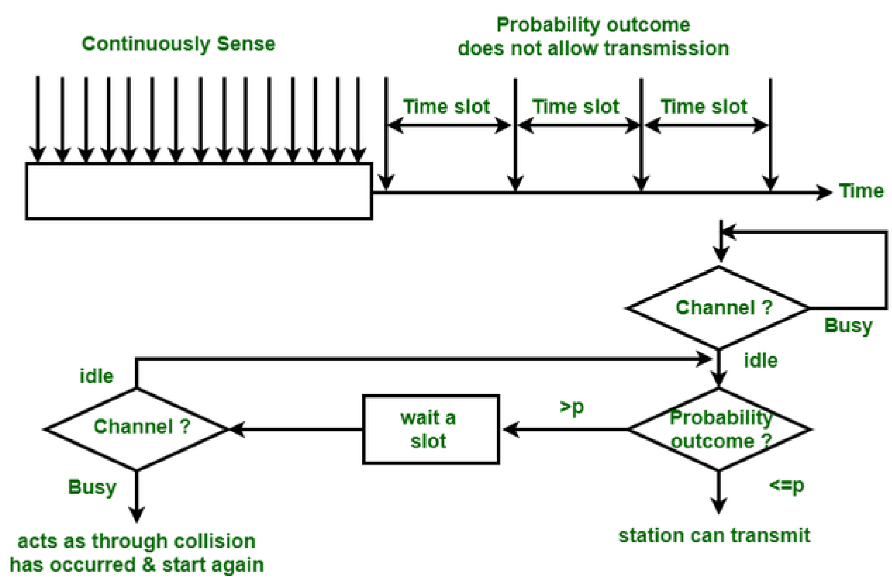
Non-Persistent CSMA

- A method where a station senses the channel only when it has data to send
- Unlike persistent methods, it does not continuously monitor the channel if it's busy
- If the channel is idle: The station immediately sends the frame without delay.
- If the channel is busy: The station waits for a random period before checking the channel again



P-Persistent CSMA

- A method used in networks with time-slots, where each time-slot is at least as long as the maximum propagation delay
- A station senses the channel before sending data
- If the channel is busy: Wait for the next time-slot
- If the channel is idle: Transmit the frame with probability p
- Wait for the next time-slot with probability $q = (1-p)$
- If the channel remains idle in the next slot, the station again decides to transmit or wait based on probabilities p and q
- The process repeats until either: The frame is transmitted successfully, or another station starts transmitting, causing a collision



O-Persistent CSMA:

- Each node is assigned a transmission order by a supervisory node
- When the transmission medium goes idle, nodes wait for their time slot on accordance with their assigned transmission order
- The node assigned to transmit first transmits immediately
- The node assigned to transmit second waits one time slot (but by that time the first node has already started transmitting)
- Nodes monitor the medium for transmission from other nodes and update their assigned with each detected transmission (i.e. they move one position closer to the front the queue)
- O-persistent CSMA is used by CobraNet, LonWorks and the controller area network

Parameter	1-persistent CSMA	p-persistent CSMA	Non-persistent CSMA
Carrier Sense	It sends with the probability of 1 when channel is idle.	It sends with the probability of p when channel is idle.	It send when channel is idle.
Waiting	It continuously senses the channel or carrier.	It waits for the next time slot.	It will wait for the random amount of time to check the carrier.
Chances of Collision	There is highest chances of collision in this.	Less chances as compared to 1-persistence and non-persistence.	Less chances as compared to 1-persistence but more than the p-persistence.
Utilization	It's utilization is above ALOHA as frames are only sent when the channel is idle.	It's utilization is depend upon the probability p.	It's utilization is above 1-persistent as not all the stations constantly check the channel at the same time.
Delay Low Load	It is low as frames are sent when the channel become idle.	It is large when p is small as station will not always send when channel is idle.	It is small as station will send whenever channel is found idle but longer than 1-persistent since it checks for the random time when busy.
Delay High Load	It is high due to collision.	It is large when the probability p of sending is small when channel is idle and channel is rarely idle.	It is longer than 1-persistent as channel is checked randomly when busy.

How Does CSMA/CD Work?

Step 1: Check if the sender is ready to transmit data packets

Step 2: Check if the transmission link is idle.

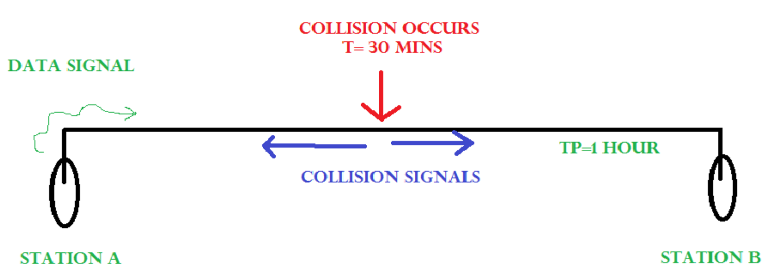
The sender has to keep on checking if the transmission link/medium is idle. For this, it continuously senses transmissions from other nodes. The sender sends dummy data on the link. If it does not receive any collision signal, this means the link is idle at the moment. If it senses that the carrier is free and there are no collisions, it sends the data. Otherwise, it doesn't send data

Step 3: Transmit the data & check for collisions.

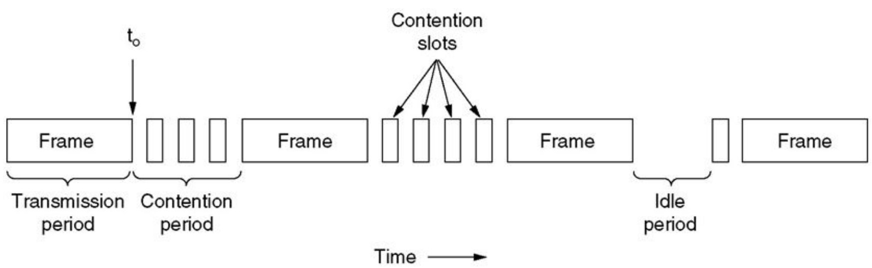
The sender transmits its data on the link. CSMA/CD does not use an 'acknowledgment' system. *It checks for successful and unsuccessful transmissions through collision signals*. During transmission, as soon as collision signal is received by the node, transmission is stopped. The station then transmits a jam signal onto the link and waits for random time intervals before it resends the frame. After some random time, it again attempts to transfer the data and repeats the above process.

Step 4: If no collision was detected in propagation,

the sender completes its frame transmission and resets the counters.



CSMA with Collision Detection



CSMA/CD can be in one of three states: contention, transmission, or idle.

- Just after the completion of frame, if 2 or more stations try to transmit signal at same time then again collision is occurred and have to wait for random period

- Before next frame is sent there is contention period (period where stations / hosts will check where there is occurrence of collision or not). In between there are some idle periods too

- Therefore, model for CSMA\CD will consist of alternating contention and transmission periods, with idle periods occurring when all stations are quiet.

Q) How CSMA/CD differed from CSMA?

Answer:

Aspect	CSMA	CSMA/CD
Collision Handling	Avoids collisions by sensing the channel before transmitting.	Detects and resolves collisions during transmission.
Efficiency	Less efficient, cannot detect collisions during transmission.	More efficient, stops transmission and retries upon detecting a collision.
Usage	Commonly used in wireless networks (e.g., Wi-Fi).	Primarily used in wired Ethernet networks.

Features:

- Carrier Sense (Listen Before Transmitting)
  - Before a device sends data, it listens to check whether the channel is idle or in use
- Collision Detection
  - While transmitting, the device also listens to the channel to check collision. If a collision occurs, the device immediately detects it because the data it receives back is garbled or corrupted. Quick terminating damaged frames saves time and bandwidth.
- Collision Handling (Back off)
  - Once a collision is detected, both devices stop transmitting immediately. After stopping, they wait for a random amount of time (back off time) before attempting to retransmit.
- Retry the Transmission
  - After the random waiting time, both devices check if the channel is idle again and retransmit their data

CSMA/CA:

- ✓ Carrier-sense multiple access with collision avoidance is network multiple access method in which carrier sensing is used, but nodes attempt to avoid collisions by beginning transmission only after the channel is sensed to be “idle”
- ✓ It is particularly important for wireless networks, where collision detection, as used in CSMA/CD, is not possible because wireless transmitters desensitize their receivers during packet transmission
- ✓ In CSMA/CD, First transmission then only detection is found, but in CSMA/CA, First detection of collision to avoid collision

Step-by-Step Working of CSMA/CA

1) Sense the Channel (Carrier Sense):

- ✓ Before transmitting data, the device listens to the communication channel to check if it is idle or busy.
- ✓ If the channel is idle, the device moves to the next step.
- ✓ If the channel is busy, the device waits and checks again after a random back off period

2) Start the Back off Timer:

- ✓ If the channel is idle, the device does not transmit immediately.

- ✓ It waits for a random back off time to avoid simultaneous transmissions from other devices that might have also sensed the idle channel.

3) Send a Request-to-Send (RTS) Packet:

- ✓ Before sending the actual data, the device sends a small RTS (Request-to-Send) packet to the receiver
- ✓ This informs the receiver and nearby devices that it intends to send data, reserving the channel for its use

4) Receive a Clear-to-Send (CTS) Packet:

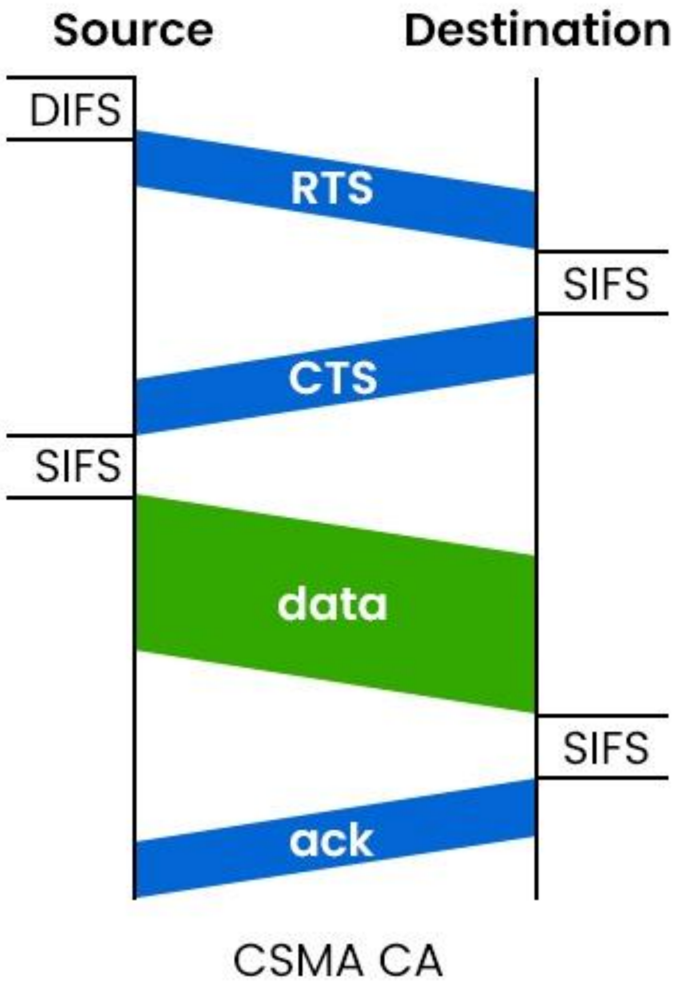
- ✓ If the receiver agrees to communicate, it responds with a CTS (Clear-to-Send) packet
- ✓ This confirms that the receiver is ready and the channel is reserved for the sender’s data transmission
- ✓ If no CTS is received (due to interference or another device transmitting), the sender starts over from step 1

5) Transmit Data:

- ✓ Once the CTS packet is received, the sender transmits its data over the channel
- ✓ During this time, other devices avoid using the channel as they know it is reserved

6) Wait for an Acknowledgment (ACK):

- ✓ After sending the data, the sender waits for an ACK (Acknowledgment) packet from the receiver
- ✓ The ACK confirms that the data was received successfully
- ✓ If no ACK is received, the sender assumes the data was lost or corrupted and retries the transmission from step 1



DIFS (Distributed Inter-Frame Space) and SIFS (Short Inter-Frame Space)

PSTN vs. VoIP: Feature-by-feature comparison

FEATURE	VOIP	PSTN
Connectivity type	IP connectivity over the internet or private WAN service.	Dedicated telephone lines or access via SIP trunking or PRI.
Required bandwidth	One VoIP line requires 100 Kbps, but the total amount of bandwidth required depends on the number of concurrent VoIP calls and the codec.	One link typically supports 64 Kbps in each direction.
Pricing	Business VoIP providers offer monthly or annual subscription fees, ranging from $20 to $50 per month. Most basic VoIP plans offer unlimited local and long-distance calling, while more advanced plans include unlimited international calling.	Most providers offer unlimited local and long-distance calling. Monthly phone plans range from $10 to $30 per month, depending on the service provider.
Scalability	Adding additional lines usually requires more bandwidth and software updates.	Additional lines require purchasing more hardware and dedicated lines, which can be complex and costly.
Remote extensions	This feature is typically standard.	This feature typically requires dedicated lines for each extension and can be pricey.
Business continuity and disaster recovery	Service terminates when data network connectivity is lost. Organizations must have a VoIP disaster recovery plan. VoIP may not be feasible for alarms, elevators and other areas due to building code requirements.	Service usually remains active during power outages, because phone jacks are powered by the PSTN provider. But cordless phones would be unusable.
Call waiting	Most VoIP providers include call waiting as a standard feature.	PSTN providers usually include call waiting as a standard feature, but sometimes it's an extra cost.
Call forwarding	Some VoIP providers include call forwarding with their services, while others offer it as an optional capability.	PSTN providers usually include call forwarding as a standard feature, but sometimes it's an extra cost.
Call transferring	Most VoIP providers offer call transferring as a standard feature.	PSTN providers usually include call transferring as a standard feature, but sometimes it's an extra cost.
Emergency calling	The FCC requires interconnected VoIP services that use the PSTN to meet E911 standards. VoIP service providers will usually support E911, but will require organizations to confirm a location. However, some providers don't support E911.	Emergency calling is enabled, and services are traceable to location.
Fax	Most VoIP providers offer fax over IP, which connects fax lines to the internet using an analog terminal adapter, as a separate product.	Supports fax over a dedicated line.