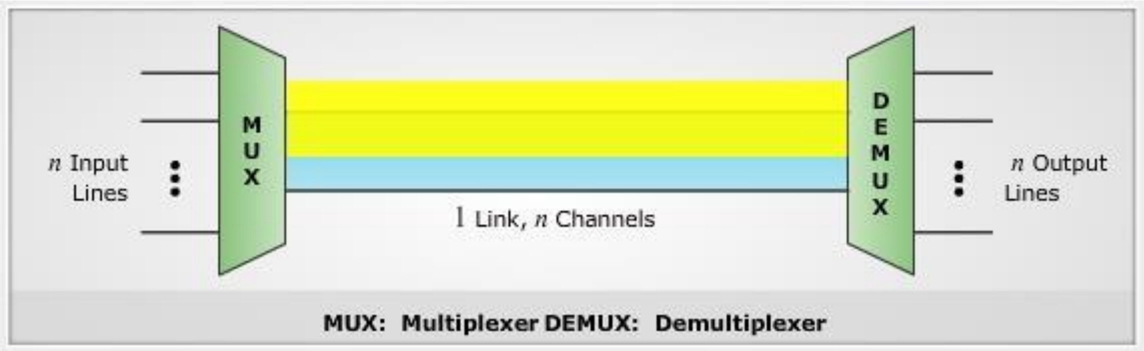
MULTIPLEXING:

- Multiplexing allows the simultaneous transmission of multiple signals across data link. A device that performs the multiplexing is called a multiplexer (MUX).
- Multiplexer combines *n* input lines to generate one output line.
- DE multiplexer (DEMUX) separates the stream back into its component transmissions and directs them to their corresponding lines.
- DE multiplexer has one input and *n* outputs.
- The word link refers to the physical path.
- The word channel refers to the portion of a link that carries a transmission between a given pair of lines. One link can have many (*n*) channels.



MULTIPLEXING TECHNIQUES:

1. Frequency-division multiplexing.
2. Time-division multiplexing.
3. Code Division multiplexing

The first two are techniques designed for analog signals and the third for digital signals.

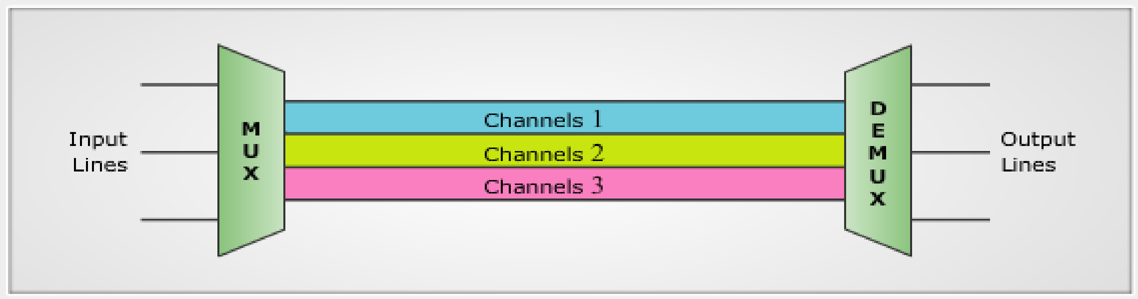
2.1 MULTIPLEXING

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

FREQUENCY-DIVISION MULTIPLEXING:

- Frequency-Division Multiplexing can be applied when the bandwidth of a link is greater than the combined bandwidths of the signals to be transmitted.
- FDM is an analog multiplexing technique that combines analog signals.

- In FDM, signals generated by each sending device modulate different carrier frequencies. These modulated signals are then combined into a single composite signal that can be transported by the link.



Advantages of FDM:

- A large of signals (channels) can be transmitted simultaneously
- FDM does not need synchronization between its transmitter and receiver for proper operation
- Demodulation of FDM is easy Due to slow narrow band fading only a single channel gets affected.

Disadvantages of FDM:

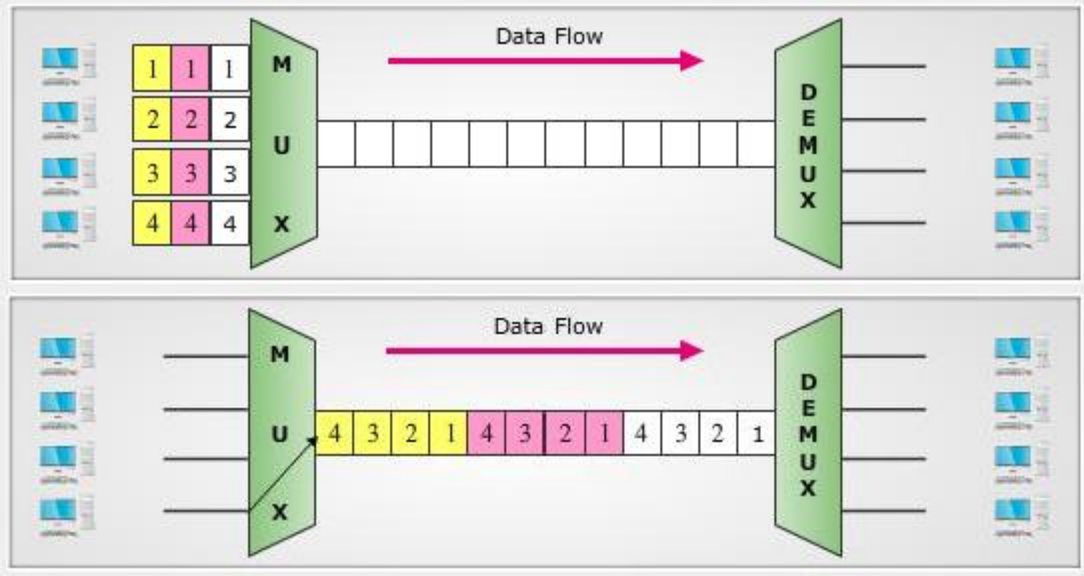
- The communication channel must have a very large bandwidth
- Intermodulation distortion takes place
- Large number of modulators and filters are required.
- FDM suffers from the problem of crosstalk.

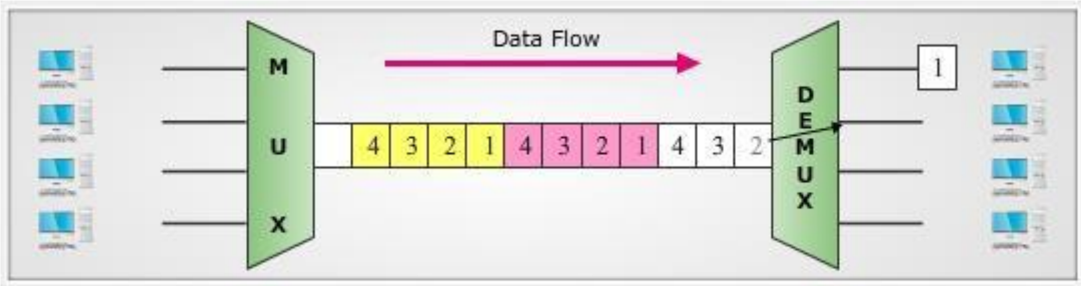
Application of FDM:

- FDM is used for FM & AM radio broadcasting
- FDM is used in television broadcasting
- First generation cellular telephone also uses FDM

TIME DIVISION MULTIPLEXING:

- Time-Division Multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a link.Each connection occupies a portion of time in the link.
- TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.





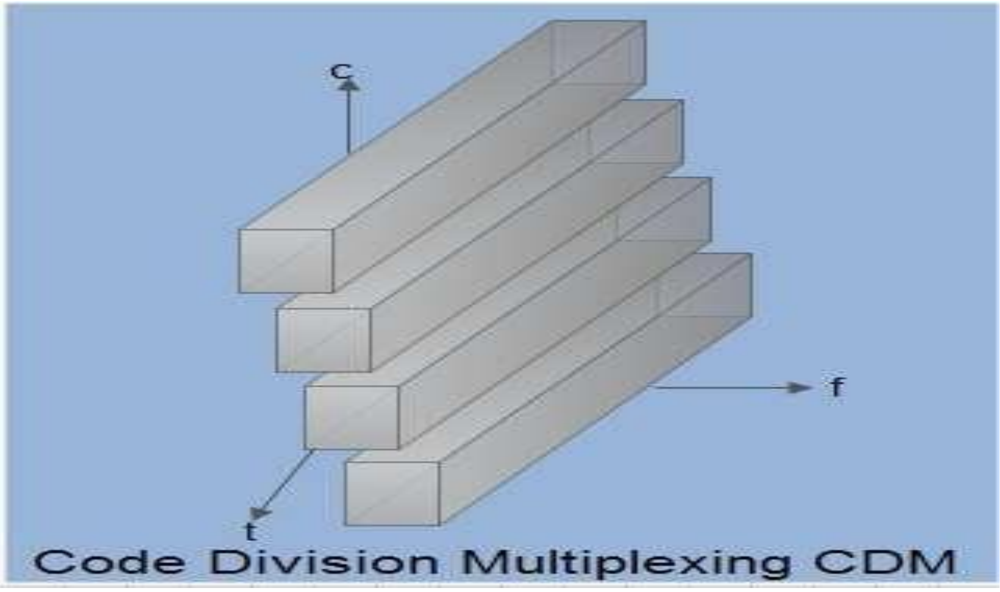
Application:

- Cellular telephone companies use synchronous TDM.
- Cellular telephony divides the available bandwidth into 30-kHz bands.

Code Division Multiplexing

Multiple data signals can be transmitted over a single frequency by using Code Division Multiplexing. FDM divides the frequency in smaller channels but CDM allows its users to full bandwidth and transmit signals all the time using a unique code. CDM uses orthogonal codes to spread signals.

Each station is assigned with a unique code, called chip. Signals travel with these codes independently, inside the whole bandwidth. The receiver knows in advance the chip code signal it has to receive.



Disadvantages:

1. Each user's transmitted bandwidth is enlarged than the digital data rate of the source. The result is an occupied bandwidth approximately equal to the coded rate. Therefore, CDM and spread spectrum are used interchangeably.
2. The transmitter and receiver require a complex electronic circuitry.

Advantages:

1. CDM is protection from interference and tapping because only the sender the receiver knows the spreading code.

Poll/Select

The Poll/Select method of line discipline works with those topologies where one device is designated as a primary station, and other devices are secondary stations.

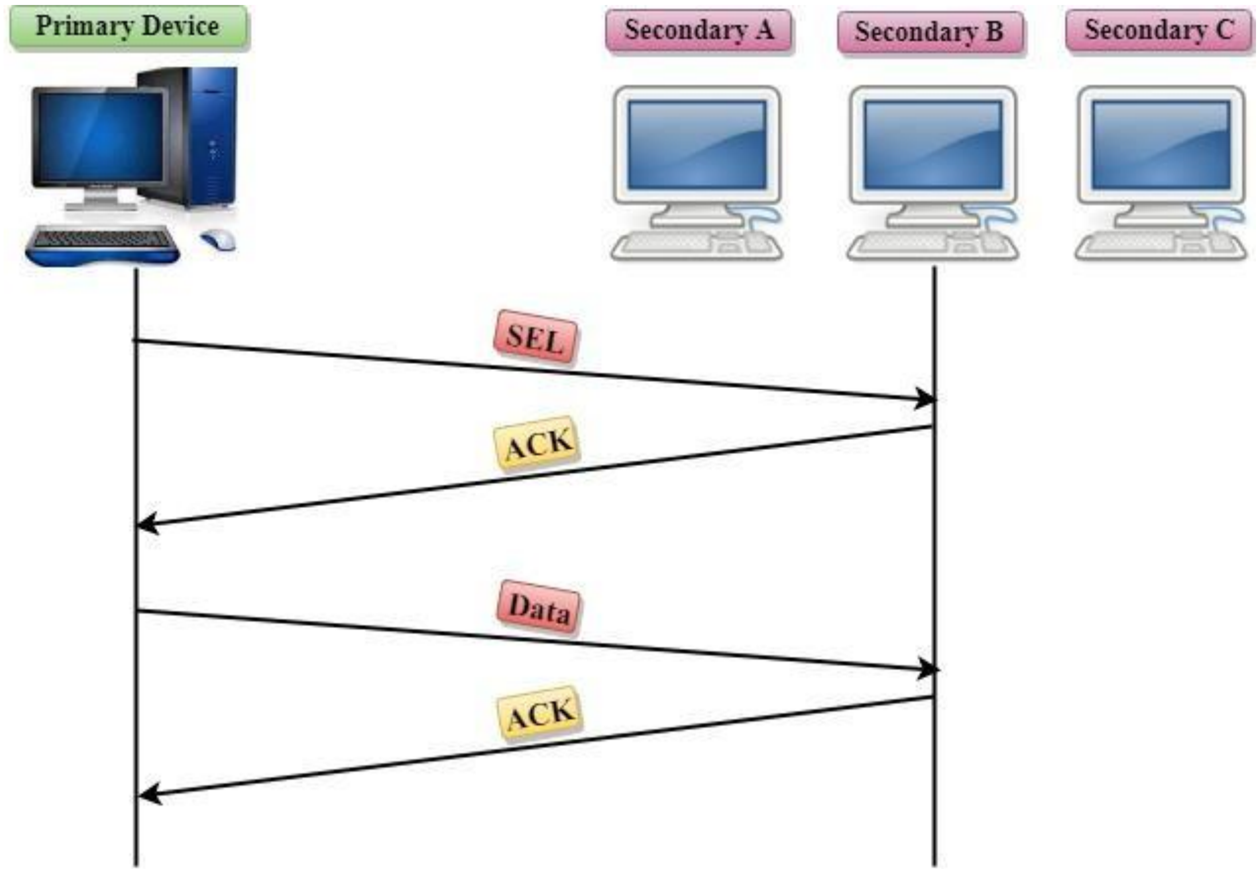
Working of Poll/Select

- In this, the primary device and multiple secondary devices consist of a single transmission line, and all the exchanges are made through the primary device even though the destination is a secondary device.
- The primary device has control over the communication link, and the secondary device follows the instructions of the primary device.

- The primary device determines which device is allowed to use the communication channel. Therefore, we can say that it is an initiator of the session.
- If the primary device wants to receive the data from the secondary device, it asks the secondary device that they anything to send, this process is known as polling.
- If the primary device wants to send some data to the secondary device, then it tells the target secondary to get ready to receive the data, this process is known as selecting.

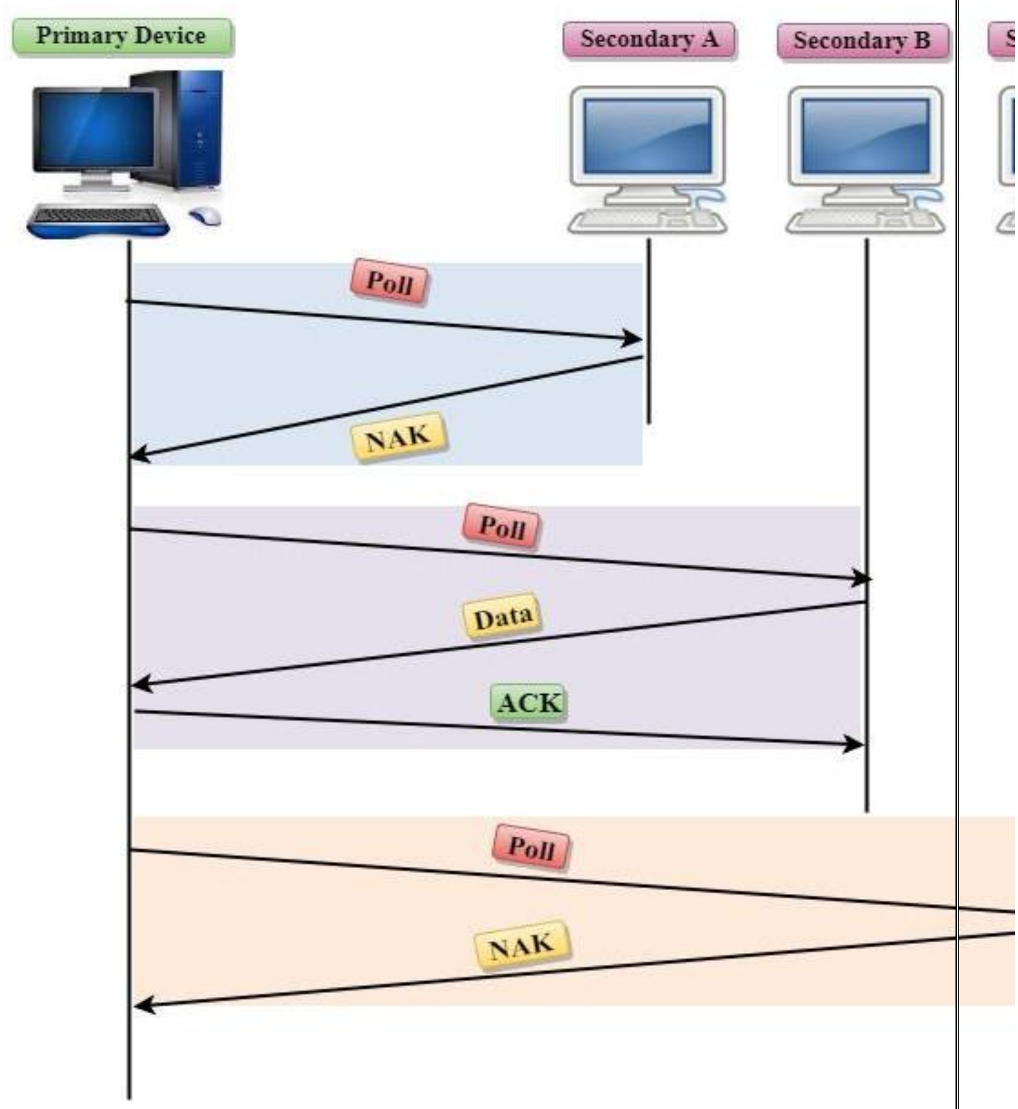
Select

- The select mode is used when the primary device has something to send.
- When the primary device wants to send some data, then it alerts the secondary device for the upcoming transmission by transmitting a Select (SEL) frame, one field of the frame includes the address of the intended secondary device.
- When the secondary device receives the SEL frame, it sends an acknowledgement that indicates the secondary ready status.
- If the secondary device is ready to accept the data, then the primary device sends two or more data frames to the intended secondary device. Once the data has been transmitted, the secondary sends an acknowledgement specifies that the data has been received.



Poll

- The Poll mode is used when the primary device wants to receive some data from the secondary device.
- When a primary device wants to receive the data, then it asks each device whether it has anything to send.
- Firstly, the primary asks (poll) the first secondary device, if it responds with the NACK (Negative Acknowledgement) means that it has nothing to send. Now, it approaches the second secondary device, it responds with the ACK means that it has the data to send. The secondary device can send more than one frame one after another or sometimes it may be required to send ACK before sending each one, depending on the type of the protocol being used.



Multiple access protocol- ALOHA, CSMA, CSMA/CA and CSMA/CD

Data Link Layer

The data link layer

is used in a computer network to transmit the data between two devices or nodes. It divides the layer into parts such as **data link control** and the **multiple access resolution/protocol**. The upper layer has the responsibility to flow control and the error control in the data link layer, and hence it is termed as **logical of data link control**. Whereas the lower sub-layer is used to handle and reduce the collision or multiple access on a channel. Hence it is termed as **media access control**

or the multiple access resolutions.

Data Link Control

A data link control

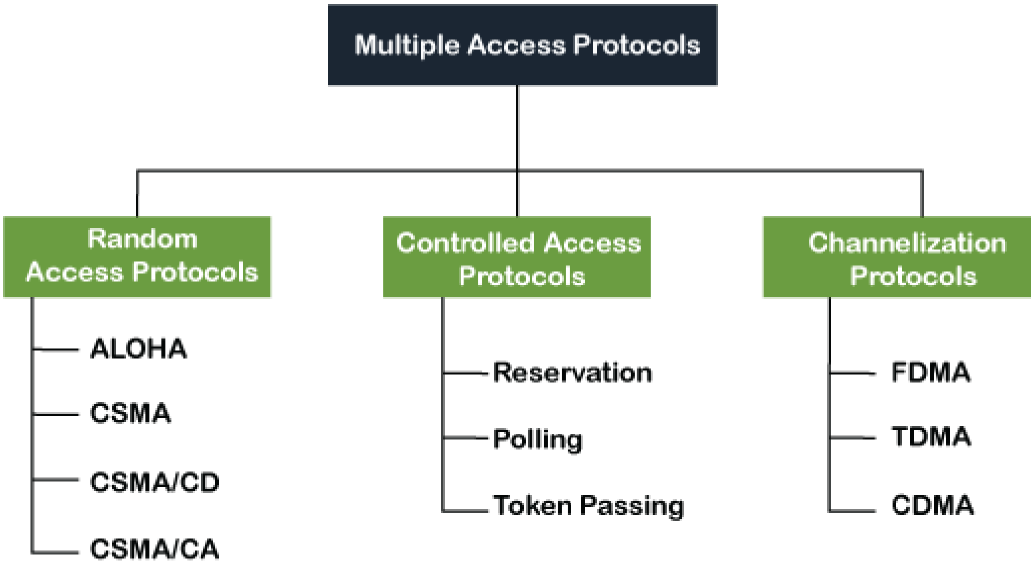
is a reliable channel for transmitting data over a dedicated link using various techniques such as framing, error control and flow control of data packets in the computer network.

What is a multiple access protocol?

When a sender and receiver have a dedicated link to transmit data packets, the data link control is enough to handle the channel. Suppose there is no dedicated path to communicate or transfer the data between two devices. In that case, multiple stations access the channel and simultaneously transmits the data over the channel. It may create collision and cross talk. Hence, the multiple access protocol is required to reduce the collision and avoid crosstalk between the channels.

For example, suppose that there is a classroom full of students. When a teacher asks a question, all the students (small channels) in the class start answering the question at the same time (transferring the data simultaneously). All the students respond at the same time due to which data is overlap or data lost. Therefore it is the responsibility of a teacher (multiple access protocol) to manage the students and make them one answer.

Following are the types of multiple access protocol that is subdivided into the different process as:



A. Random Access Protocol

In this protocol, all the station has the equal priority to send the data over a channel. In random access protocol, one or more stations cannot depend on another station nor any station control another station. Depending on the channel's state (idle or busy), each station transmits the data frame. However, if more than one station sends the data over a channel, there may be a collision or data conflict. Due to the collision, the data frame packets may be lost or changed. And hence, it does not receive by the receiver end.

Following are the different methods of random-access protocols for broadcasting frames on the channel.

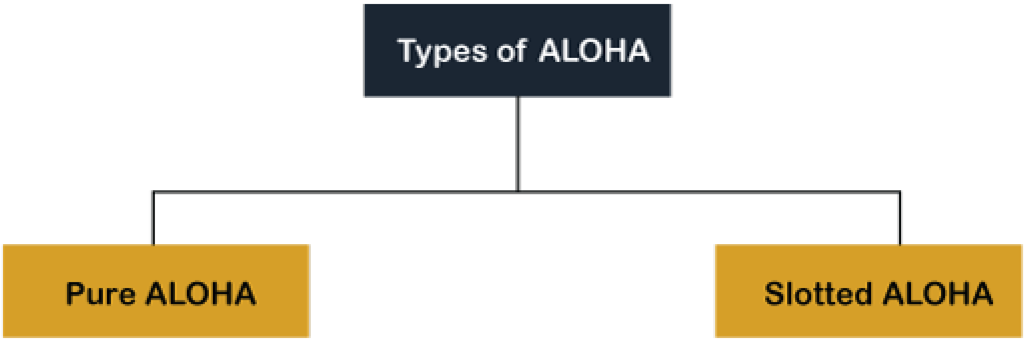
- Aloha
- CSMA
- CSMA/CD
- CSMA/CA

ALOHA Random Access Protocol

It is designed for wireless LAN (Local Area Network) but can also be used in a shared medium to transmit data. Using this method, any station can transmit data across a network simultaneously when a data frameset is available for transmission.

Aloha Rules

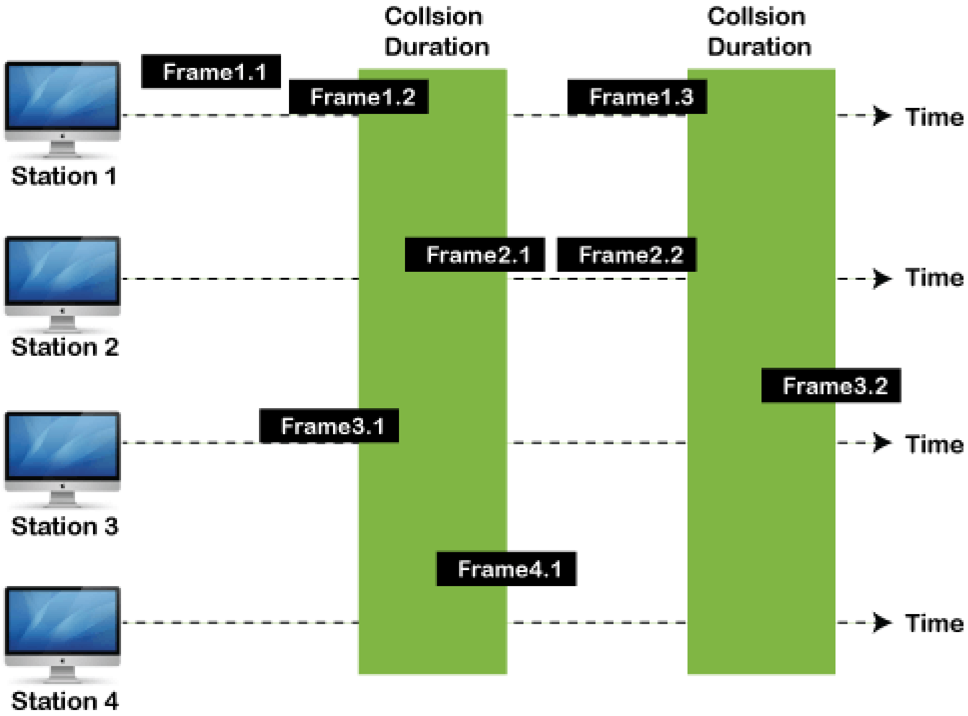
1. Any station can transmit data to a channel at any time.
2. It does not require any carrier sensing.
3. Collision and data frames may be lost during the transmission of data through multiple stations.
4. Acknowledgment of the frames exists in Aloha. Hence, there is no collision detection.
5. It requires retransmission of data after some random amount of time.



Pure Aloha

Whenever data is available for sending over a channel at stations, we use Pure Aloha. In pure Aloha, when each station transmits data to a channel without checking whether the channel is idle or not, the chances of collision may occur, and the data frame can be lost. When any station transmits the data frame to a channel, the pure Aloha waits for the receiver's acknowledgment. If it does not acknowledge the receiver end within the specified time, the station waits for a random amount of time, called the backoff time (Tb). And the station may assume the frame has been lost or destroyed. Therefore, it retransmits the frame until all the data are successfully transmitted to the receiver.

1. The total vulnerable time of pure Aloha is 2 * Tfr.
2. Maximum throughput occurs when G = 1/ 2 that is 18.4%.
3. Successful transmission of data frame is S = G * e ^ - 2 G.



Frames in Pure ALOHA

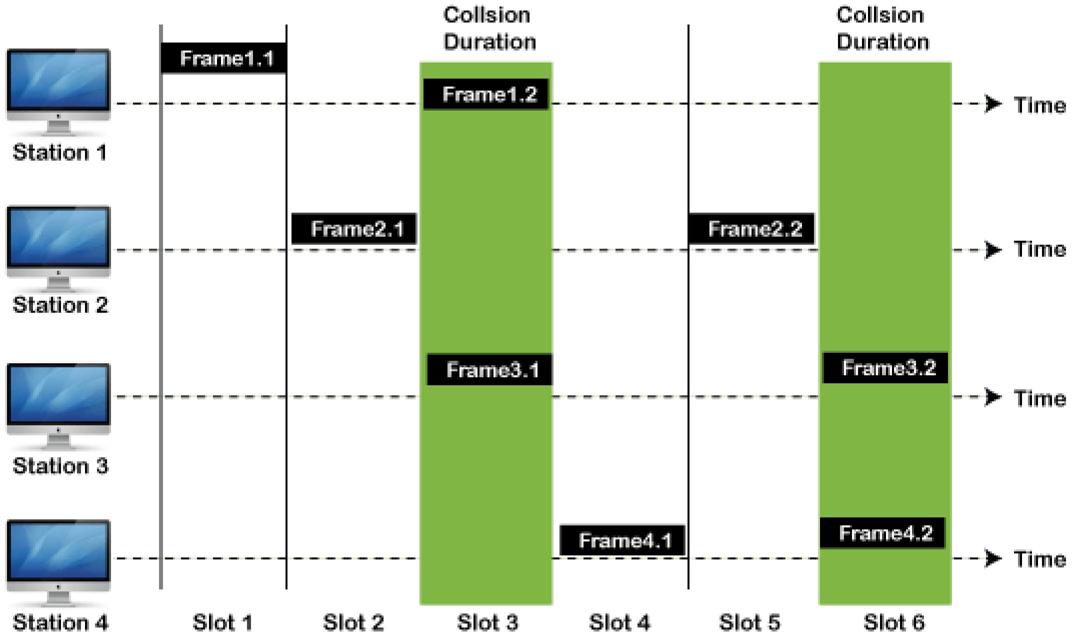
As we can see in the figure above, there are four stations for accessing a shared channel and transmitting data frames. Some frames collide because most stations send their frames at the same time. Only two frames, frame 1.1 and frame 2.2, are successfully transmitted to the receiver end. At the same time, other frames are lost or destroyed. Whenever two frames fall on a shared channel simultaneously, collisions can occur, and both will suffer damage. If the new frame's first bit enters the channel before finishing the last bit of the second frame. Both frames are completely finished, and both stations must retransmit the data frame.

Slotted Aloha

The slotted Aloha is designed to overcome the pure Aloha's efficiency because pure Aloha has a very high possibility of frame hitting. In slotted Aloha, the shared channel is divided into a fixed time interval called **slots**. So that, if a station wants to send a frame to a shared channel, the frame can only be sent at the beginning of the slot, and only one frame is allowed to be sent to each slot. And if the stations are unable to send data to the beginning of the slot, the station will have to wait until the beginning of the slot for the next time. However, the possibility of a collision remains when trying to send a frame at the beginning of two or more station time slot.

1. Maximum throughput occurs in the slotted Aloha when G = 1 that is 37%.

2. The probability of successfully transmitting the data frame in the slotted Aloha is S = G * e ^ - 2 G.
3. The total vulnerable time required in slotted Aloha is Tfr.



Frames in Slotted ALOHA

CSMA (Carrier Sense Multiple Access)

It is a **carrier sense multiple access** based on media access protocol to sense the traffic on a channel (idle or busy) before transmitting the data. It means that if the channel is idle, the station can send data to the channel. Otherwise, it must wait until the channel becomes idle. Hence, it reduces the chances of a collision on a transmission medium.

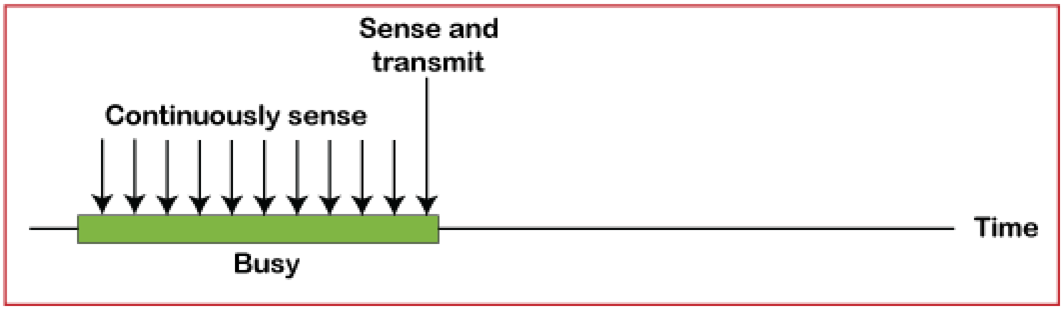
CSMA Access Modes

1-Persistent: In the 1-Persistent mode of CSMA that defines each node, first sense the shared channel and if the channel is idle, it immediately sends the data. Else it must wait and keep track of the status of the channel to be idle and broadcast the frame unconditionally as soon as the channel is idle.

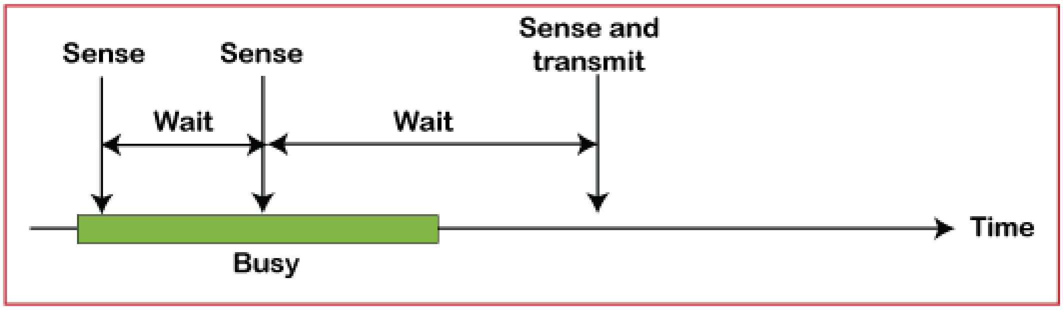
Non-Persistent: It is the access mode of CSMA that defines before transmitting the data, each node must sense the channel, and if the channel is inactive, it immediately sends the data. Otherwise, the station must wait for a random time (not continuously), and when the channel is found to be idle, it transmits the frames.

P-Persistent: It is the combination of 1-Persistent and Non-persistent modes. The P-Persistent mode defines that each node senses the channel, and if the channel is inactive, it sends a frame with a **P** probability. If the data is not transmitted, it waits for a (**q = 1-p probability**) random time and resumes the frame with the next time slot.

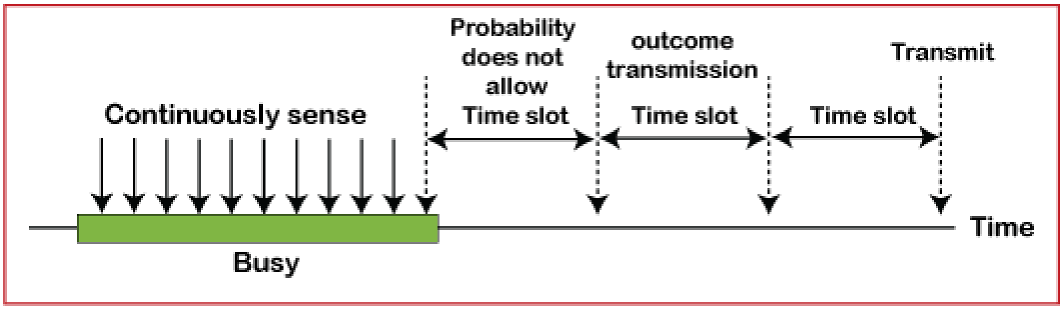
O- Persistent: It is an O-persistent method that defines the superiority of the station before the transmission of the frame on the shared channel. If it is found that the channel is inactive, each station waits for its turn to retransmit the data.



a. 1-persistent



b. Nonpersistent



c. p-persistent

CSMA/ CD

It is a **carrier sense multiple access/ collision detection** network protocol to transmit data frames. The CSMA/CD protocol works with a medium access control layer. Therefore, it first senses the shared channel before broadcasting the frames, and if the channel is idle, it transmits a frame to check whether the transmission was successful. If the frame is successfully received, the station sends another frame. If any collision is detected in the CSMA/CD, the station sends a jam/ stop signal to the shared channel to terminate data transmission. After that, it waits for a random time before sending a frame to a channel.

CSMA/ CA

It is a **carrier sense multiple access/collision avoidance** network protocol for carrier transmission of data frames. It is a protocol that works with a medium access control layer. When a data frame is sent to a channel, it receives an acknowledgment to check whether the channel is clear. If the station receives only a single (own) acknowledgments, that means the data frame has been successfully transmitted to the receiver. But if it gets two signals (its own and one more in which the collision of frames), a collision of the frame occurs in the shared channel. Detects the collision of the frame when a sender receives an acknowledgment signal.

Following are the methods used in the CSMA/ CA

to avoid the collision:

Interframe space: In this method, the station waits for the channel to become idle, and if it gets the channel is idle, it does not immediately send the data. Instead of this, it waits for some time, and this time period is called the **Interframe** space or IFS. However, the IFS time is often used to define the priority of the station.

Contention window: In the Contention window, the total time is divided into different slots. When the station/ sender is ready to transmit the data frame, it chooses a random slot number of slots as **wait time**. If the channel is still busy, it does not restart the entire process, except that it restarts the timer only to send data packets when the channel is inactive.

Acknowledgment: In the acknowledgment method, the sender station sends the data frame to the shared channel if the acknowledgment is not received ahead of time.

B. Controlled Access Protocol

It is a method of reducing data frame collision on a shared channel. In the controlled access method, each station interacts and decides to send a data frame by a particular station approved by all other stations. It means that a single station cannot send the data frames unless all other stations are not approved. It has three types of controlled access: **Reservation, Polling**, and **Token Passing**.

In the Controlled access technique, all stations need to consult with one another in order to find out which station has the right to send the data.

- The controlled access protocols mainly grant permission to send only one node at a time; thus in order to avoid the collisions among the shared mediums.
- No station can send the data unless it has been authorized by the other stations.

The protocols lies under the category of Controlled access are as follows

:

1. Reservation
2. Polling
3. Token Passing

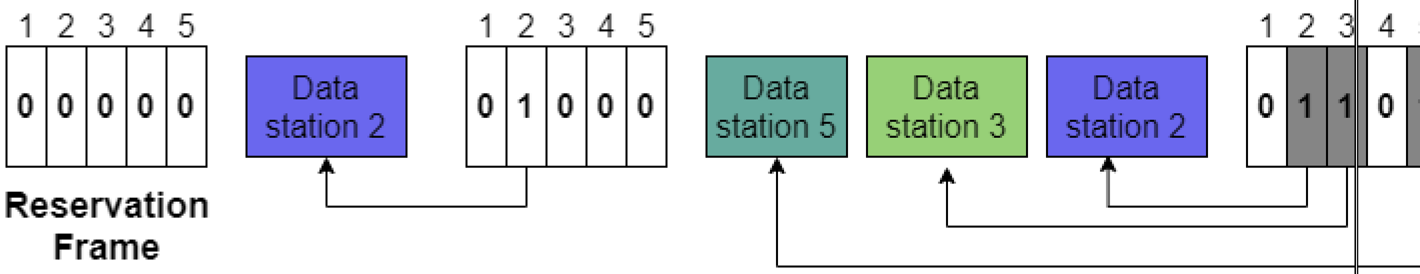
Let us discuss each protocol one by one:

1. Reservation

In this method, a station needs to make a reservation before sending the data.

- Time is mainly divided into intervals.
- Also, in each interval, a reservation frame precedes the data frame that is sent in that interval.

- Suppose if there are **'N'** stations in the system in that case there are exactly **'N'** reservation minislots in the reservation frame; where each minislot belongs to a station.
- Whenever a station needs to send the data frame, then the station makes a reservation in its own minislot.
- Then the stations that have made reservations can send their data after the reservation frame.
- **Example**
- Let us take an example of 5 stations and a 5-minislot reservation frame. In the first interval, the station 2,3 and 5 have made the reservations. While in the second interval only station 2 has made the reservations.



2. Polling

The polling method mainly works with those topologies where one device is designated as the primary station and the other device is designated as the secondary station.

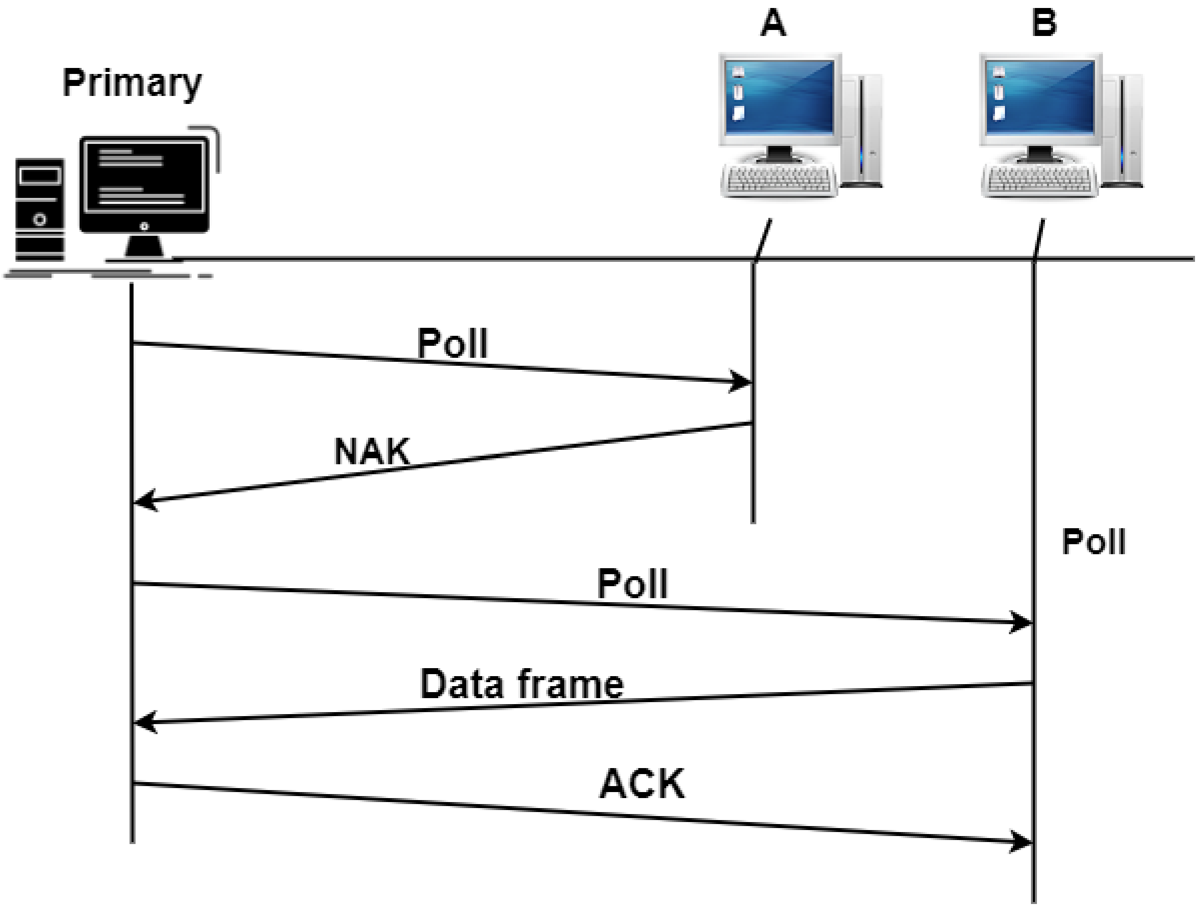
- All the exchange of data must be made through the primary device even though the final destination is the secondary device.
- Thus to impose order on a network that is of independent users, and in order to establish one station in the network that will act as a controller and periodically polls all other stations is simply referred to as **polling**.

- The Primary device mainly controls the link while the secondary device follows the instructions of the primary device.
- The responsibility is on the primary device in order to determine which device is allowed to use the channel at a given time.
- Therefore the primary device is always an initiator of the session.

Poll Function

In case if primary devices want to receive the data, then it usually asks the secondary devices if they have anything to send. This is commonly known as **Poll Function**.

- There is a **poll function** that is mainly used by the primary devices in order to solicit transmissions from the secondary devices.
- When the primary device is ready to receive the data then it must **ask(poll)** each secondary device in turn if it has anything to send.
- If the secondary device has data to transmit then it sends the data frame, otherwise, it sends a **negative acknowledgment (NAK)**.
- After that in case of the negative response, the primary then polls the next secondary, in the same manner until it finds the one with the data to send. When the primary device received a positive response that means (a data frame), then the primary devices reads the frame and then returns an acknowledgment **(ACK)**frame,

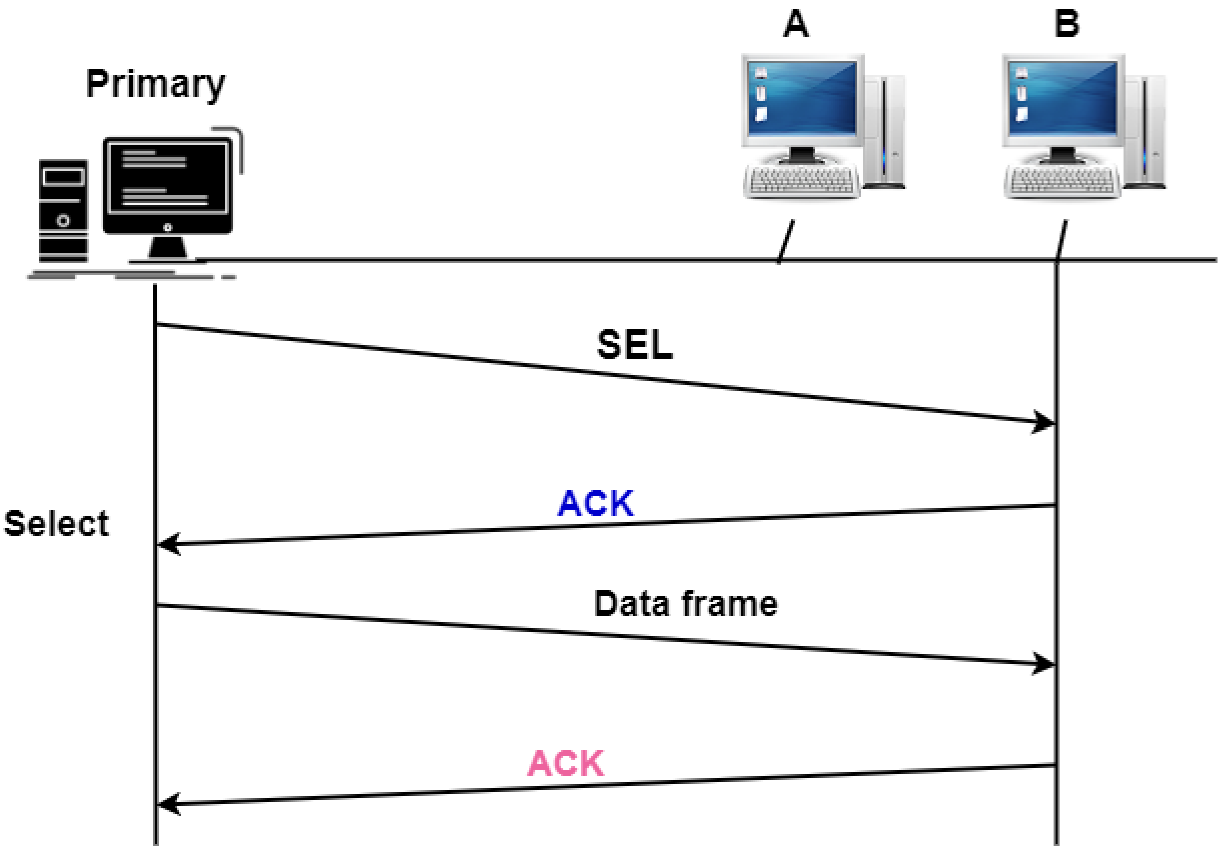


Select Function

In case, if the primary device wants to send the data then it tells the secondary devices in order to get ready to receive the data. This is commonly known as the **Select function**.

- Thus the **select function** is used by the primary device when it has something to send.
- We had already told you that the **primary device** always **controls the link.**
- Before sending the data frame, a select **(SEL) frame is** created and transmitted by the primary device, and one field of the SEL frame includes the address of the intended secondary.

- The primary device alerts the secondary devices for the upcoming transmission and after that wait for an acknowledgment (ACK) of the secondary devices.



Advantages of Polling

Given below are some benefits of the Polling technique:

1. The minimum and maximum access times and data rates on the channel are predictable and fixed.
2. There is the assignment of priority in order to ensure faster access from some secondary.

Drawbacks

There are some cons of the polling method and these are as follows:

- There is a high dependency on the reliability of the controller
- The increase in the turnaround time leads to the reduction of the data rate of the channel under low loads.

3. Token Passing

In the token passing methods, all the stations are organized in the form of a logical ring. We can also say that for each station there is a predecessor and a successor.

- The predecessor is the station that is logically before the station in the ring; while the successor is the station that is after the station in the ring. The station that is accessing the channel now is the **current station**.
- Basically, a special bit pattern or a small message that circulates from one station to the next station in some predefined order is commonly known as a **token**.
- Possessing the token mainly gives the station the right to access the channel and to send its data.
- When any station has some data to send, then it waits until it receives a token from its predecessor. After receiving the token, it holds it and then sends its data. When any station has no more data in order to send then it releases the token and then passes the token to the next logical station in the ring.
- Also, the station cannot send the data until it receives the token again in the next round.
- In Token passing, when a station receives the token and has no data to send then it just passes the token to the next station.
- The problem that occurs due to the Token passing technique is the duplication of tokens or loss of tokens. The insertion of the new station, removal of a station, also needs to be tackled for correct and reliable operation of the token passing technique.

The performance of a token ring is governed by 2 parameters, which are delay and throughput.

Delay is a measure of the time; it is the time difference between a packet ready for transmission and when it is transmitted. Hence, the average time required to send a token to the next station is a/N.

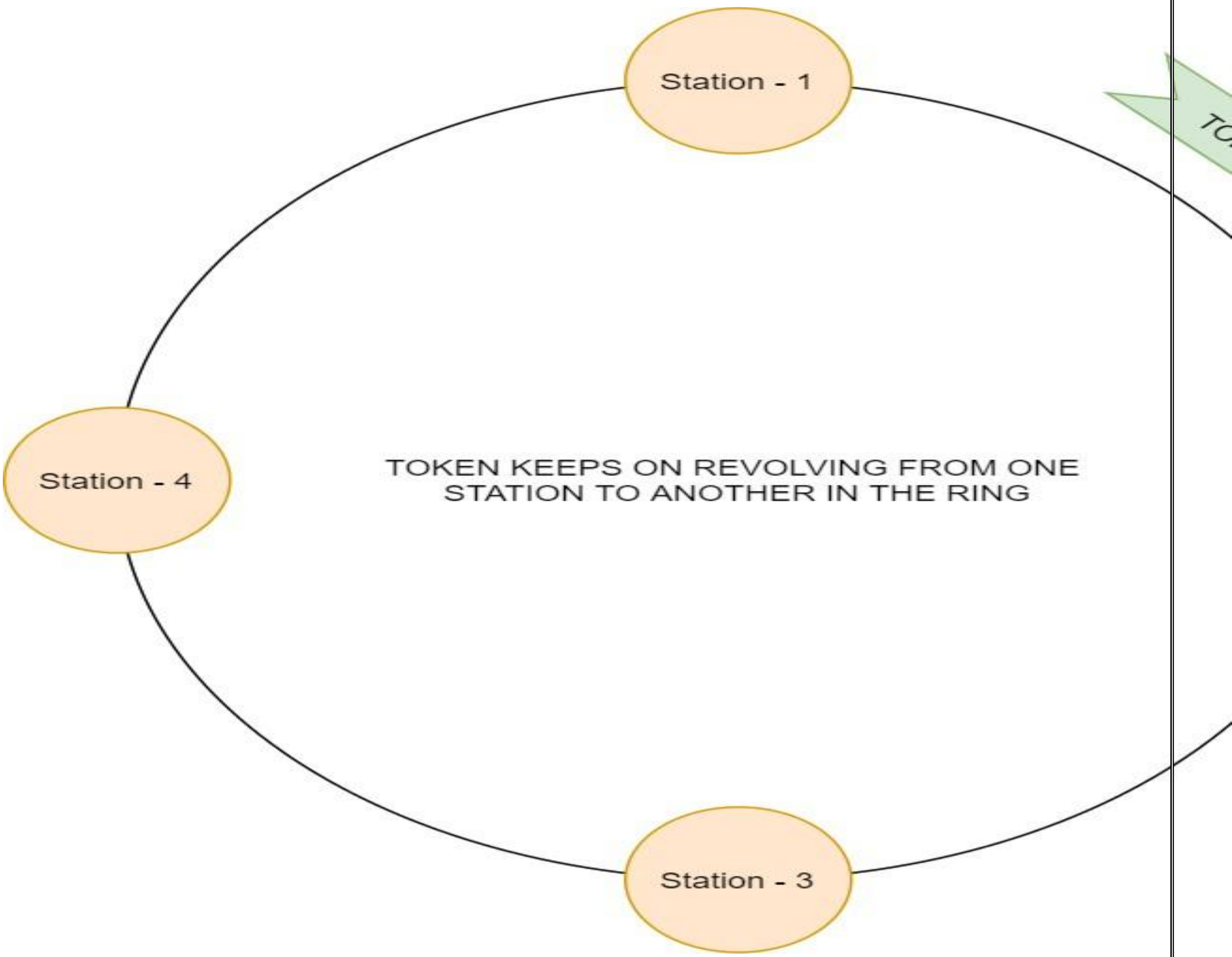
Throughput is a measure of the successful traffic in the communication channel.

Throughput, $S = 1/(1 + a/N)$ for $a<1$

$S = 1/[a(1+1/N)]$ for $a>1$, here N = number of stations & $a = T_p/T_t$

T_p = propagation delay & T_t = transmission delay

In the diagram below when station-1 posses the token, it starts transmitting all the data-frames which are in its queue. now after transmission, station-1 passes the token to station-2 and so on. Station-1 can now transmit data again, only when all the stations in the network have transmitted their data and passed the token.



Note: It is important to note that A token can only work in that channel, for which it is generated, and not for any other.