Medium Access Control Sublayer (MAC sublayer)

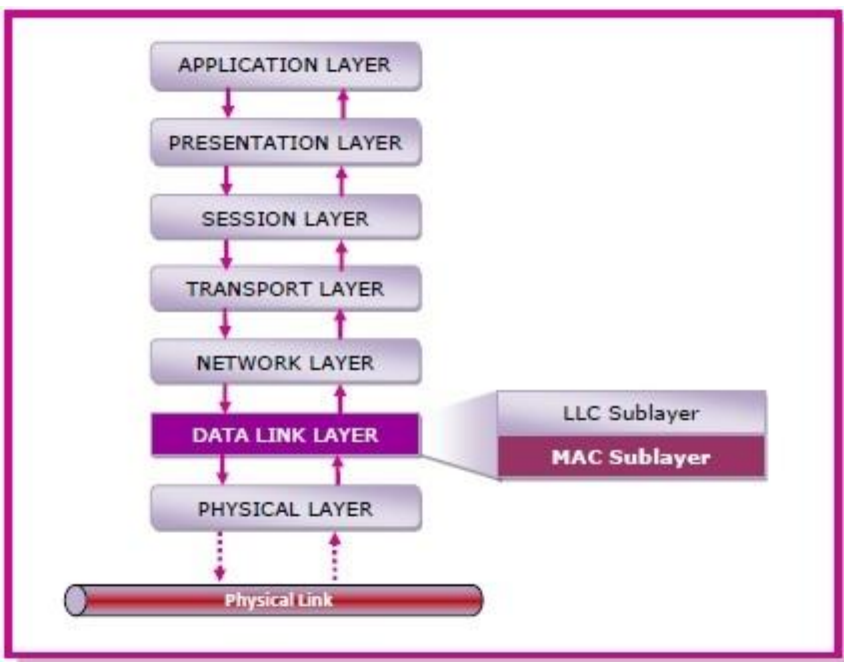
The medium access control (MAC) is a sublayer of the data link layer of the open system interconnections (OSI) reference model for data transmission. It is responsible for flow control and multiplexing for transmission medium. It controls the transmission of data packets via remotely shared channels. It sends data over the network interface card.

MAC Layer in the OSI Model

The Open System Interconnections (OSI) model is a layered networking framework that conceptualizes how communications should be done between heterogeneous systems. The data link layer is the second lowest layer. It is divided into two sublayers −

- The logical link control (LLC) sublayer
- The medium access control (MAC) sublayer

The following diagram depicts the position of the MAC layer −



Functions of MAC Layer

- It provides an abstraction of the physical layer to the LLC and upper layers of the OSI network.
- It is responsible for encapsulating frames so that they are suitable for transmission via the physical medium.
- It resolves the addressing of source station as well as the destination station, or groups of destination stations.
- It performs multiple access resolutions when more than one data frame is to be transmitted. It determines the channel access methods for transmission.
- It also performs collision resolution and initiating retransmission in case of collisions.
- It generates the frame check sequences and thus contributes to protection against transmission errors.

MAC Addresses

MAC address or media access control address is a unique identifier allotted to a network interface controller (NIC) of a device. It is used as a network address for data transmission within a network segment like Ethernet, Wi-Fi, and Bluetooth.

MAC address is assigned to a network adapter at the time of manufacturing. It is hardwired or hard-coded in the network interface card (NIC). A MAC address comprises of six groups of two hexadecimal digits, separated by hyphens, colons, or no separators. An example of a MAC address is 00:0A:89:5B:F0:11.

What is MAC Address?

- MAC address is the physical address, which uniquely identifies each device on a given network. To make communication between two networked devices, we need two addresses: **IP address and MAC address.** It is assigned to the NIC (Network Interface card) of each device that can be connected to the internet.
- It stands for **Media Access Control**, and also known as **Physical address, hardware address, or BIA (Burned In Address).**
- It is globally unique; it means two devices cannot have the same MAC address. It is represented in a hexadecimal format on each device, such as **00:0a:95:9d:67:16.**

- It is 12-digit, and 48 bits long, out of which the first *24 bits are used for **OUI**(Organization Unique Identifier)*, and *24 bits are for NIC/vendor-specific*.
- It works on the data link layer of the OSI model.
- It is provided by the device's vendor at the time of manufacturing and embedded in its NIC, which is ideally cannot be changed.
- The **ARP protocol** is used to associate a logical address with a physical or MAC address.

Reason to have both IP and MAC addresses.

As we already had the IP address to communicate a computer to the internet, why we need the MAC address. The answer to this question is that every mac address is assigned to the NIC of a hardware device that helps to identify a device over a network.

When we request a page to load on the internet, the request is responded and sent to our IP address.

Both MAC and IP addresses are operated on different layers of the internet protocol suite. The MAC address works on layer 2 and helps identify the devices within the same broadcast network (such as the router). On the other hand, the IP addresses are used on layer 3 and help identify the devices on different networks.

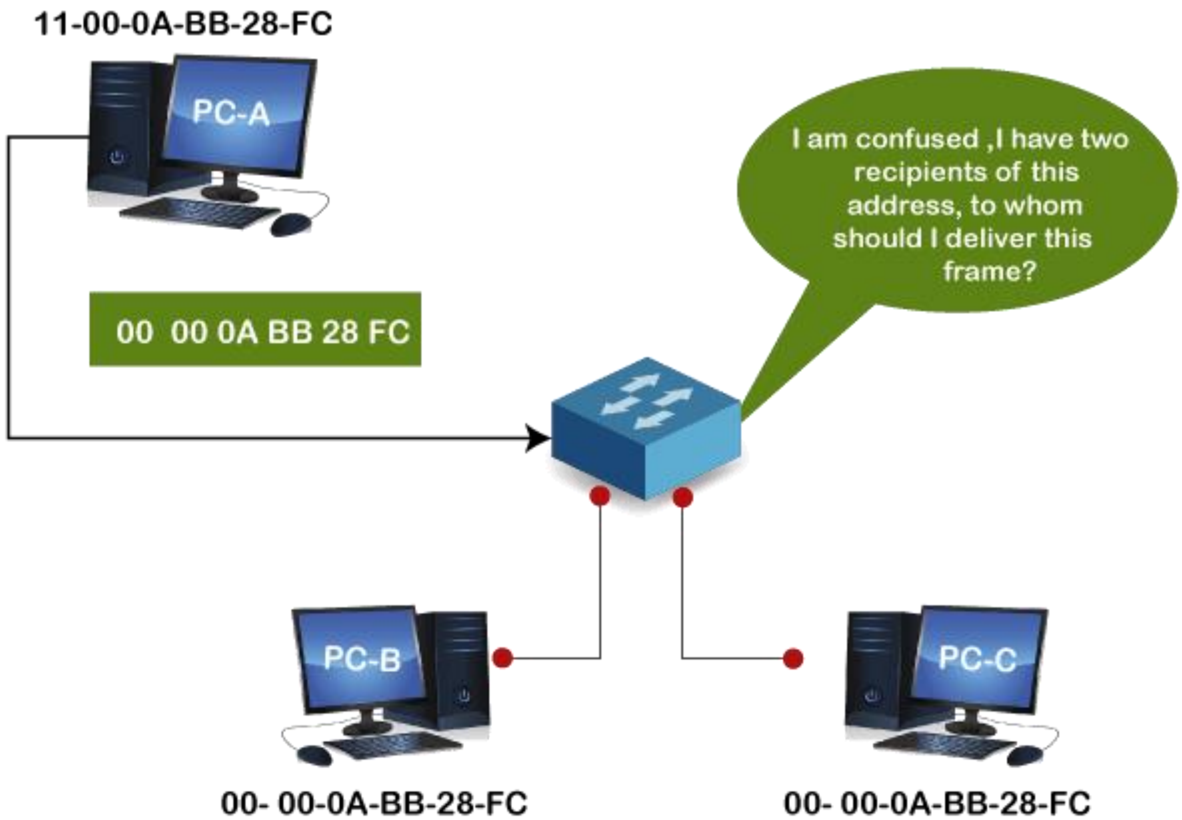
We have the IP address to identify the device through different networks, we still need a MAC address to find the devices on the same network.

Why should the MAC address be unique in the LAN network?

If a LAN network has two or more devices with the same MAC address, that network will not work.

Suppose three devices A, B, and C are connected to a network through a switch. The MAC addresses of these devices are 11000ABB28FC, 00000ABB28FC, and 00000ABB28FC, respectively. The NIC of devices B and C have the same MAC address. If device A sends a data frame to the address 00000ABB28FC, the switch will fail to deliver this frame to the destination, as it has two recipients of this data frame.

We can understand this example with the below image:



Format of MAC address

As we have already discussed in the above section, we cannot assign the MAC address to the device's NIC; it is preconfigured by the manufacturers. So, let's understand how it is configured and what format is selected.

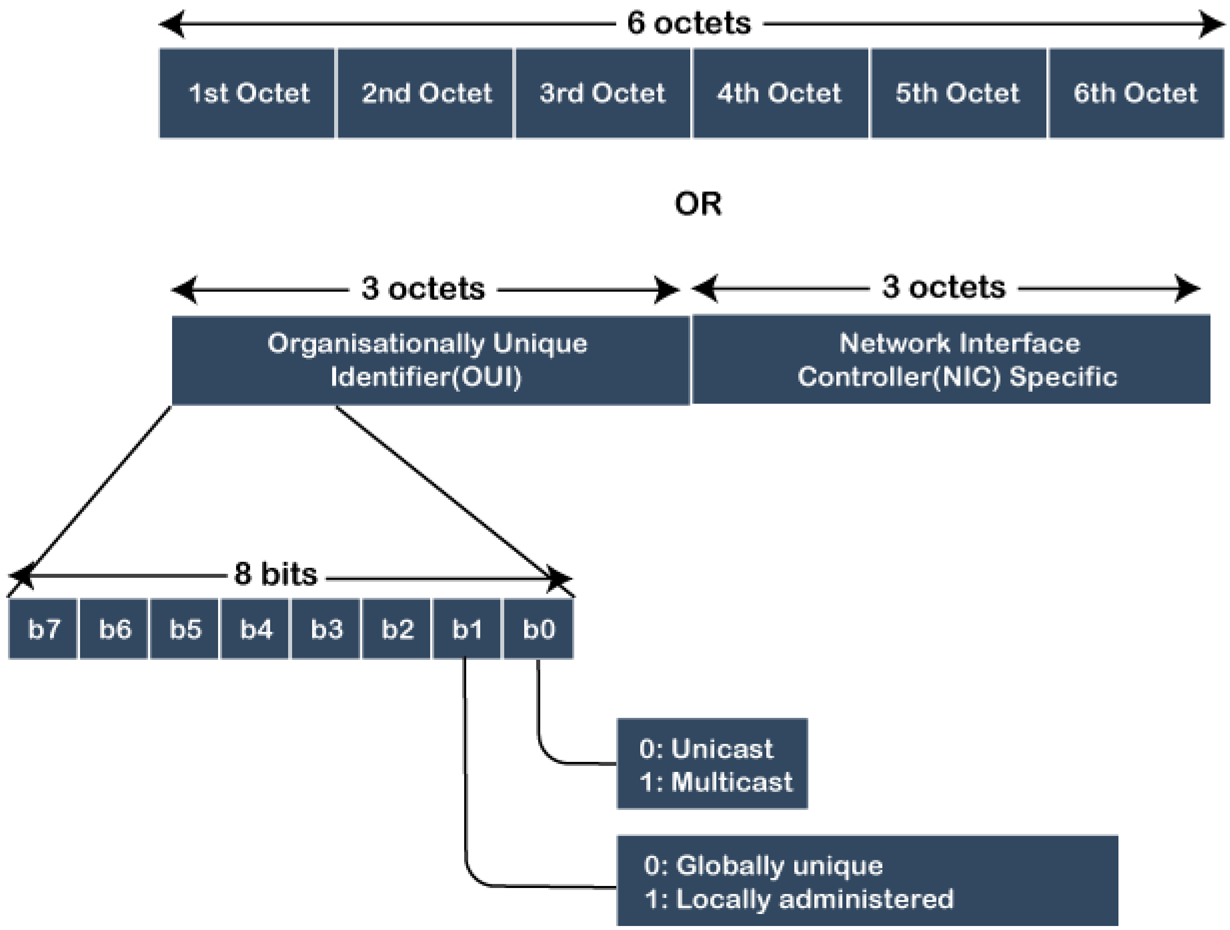
- It is 12 digits or 6-byte hexadecimal number, which is represented in colon-hexadecimal notation format. It is divided into six octets, and each octet contains 8 bits.
- The first three octets are used as the **OUI or Organisationally Unique Identifier**. These MAC prefixes are assigned to each organization or vendor by the IEEE Registration Authority Committee.
- Some example of OUI of known vendors are:

  CC:46:D6 - Cisco

  3C:5A:B4 - Google, Inc.

  3C:D9:2B - Hewlett Packard

  00:9A:CD - HUAWEI TECHNOLOGIES CO.,LTD



- The last three octets are NIC specific and used by the manufacturer to each NIC card. Vendors or manufacturers can use any sequence of digits to the NIC specific digits, but the prefix should be the same as provided by the IEEE.

- The MAC address can be represented in below three formats:

Hyphen-Hexadecimal notation

00-0b-56-b1-c0-6e

Colon-Hexadecimal notation

00:0b:56:b1:c0:6e

Period-separated hexadecimal notation

000.b56.b1c.06e

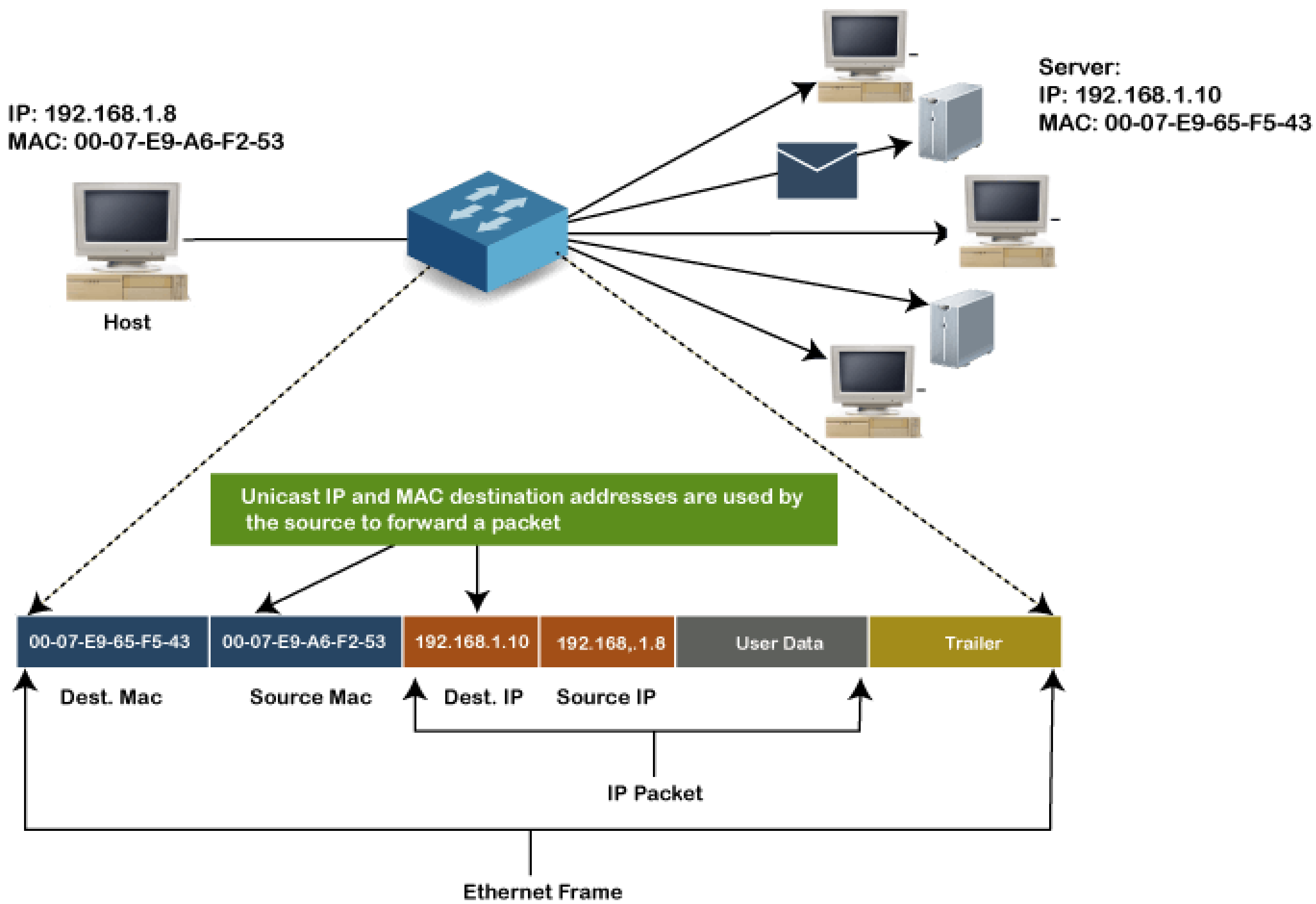
Types of MAC address

There are three types of MAC addresses, which are:

1. **Unicast MAC Address**
2. **Multicast MAC address**
3. **Broadcast MAC address**

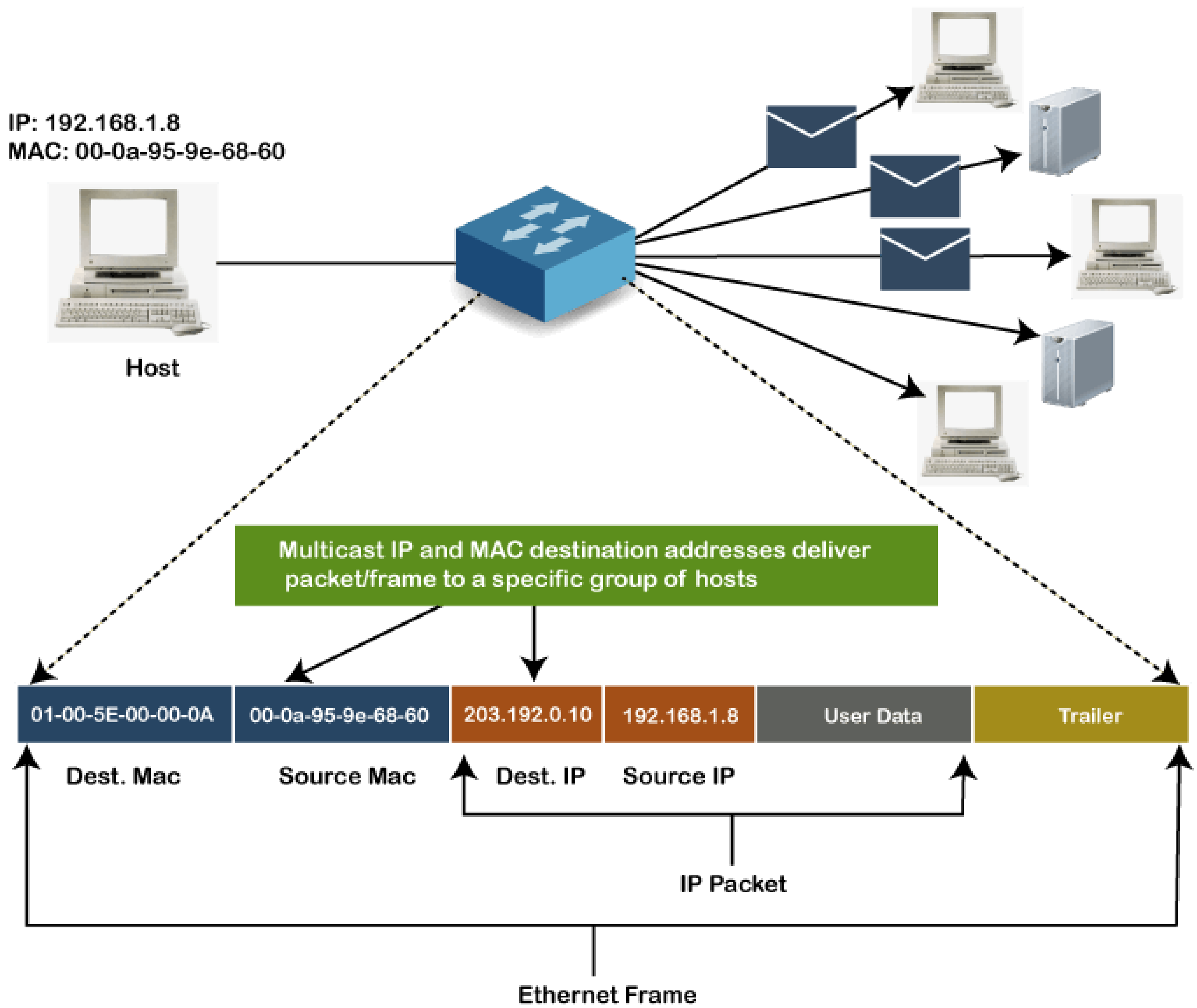
Unicast MAC address:

The Unicast MAC address represents the specific NIC on the network. A Unicast MAC address frame is only sent out to the interface which is assigned to a specific NIC and hence transmitted to the single destination device. If the LSB (least significant bit) of the first octet of an address is set to zero, the frame is meant to reach only one destination NIC.



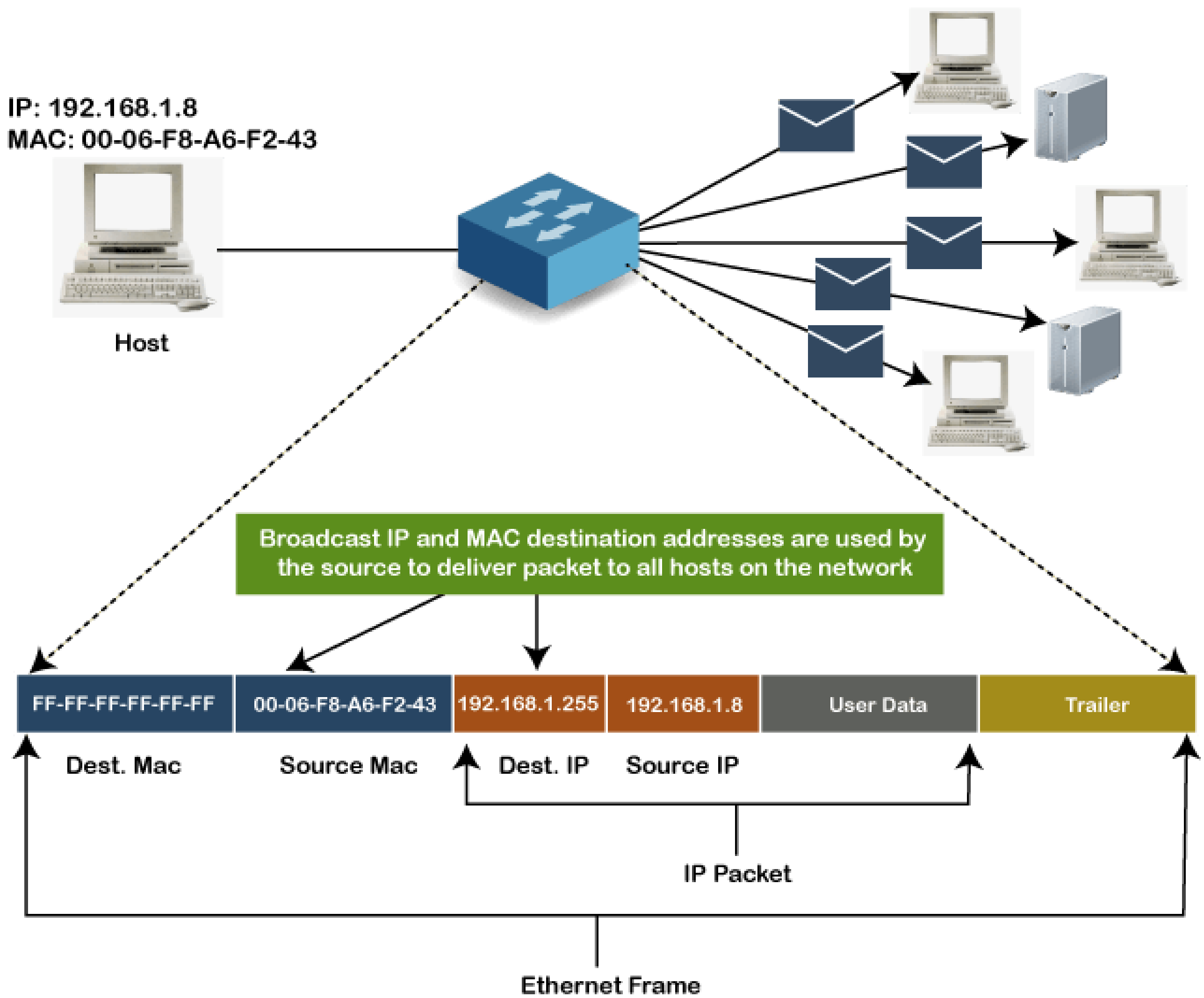
Multicast MAC Address:

Multicast addresses enables the source device to transmit a data frame to multiple devices or NICs. In Layer-2 (Ethernet) Multicast address, LSB (least significant bit) or first 3 bytes of the first octet of an address is set to one and reserved for the multicast addresses. The rest 24 bits are used by the device that wants to send the data in a group. The multicast address always starts with the prefix 01-00-5E.



Broadcast MAC address

It represents all devices within a Network. In broadcast MAC address, Ethernet frames with ones in all bits of the destination address (FF-FF-FF-FF-FF-FF) are known as a b**roadcast address**. All these bits are the reserved addresses for the broadcast. Frames that are destined with MAC address FF-FF-FF-FF-FF-FF will reach every computer belong to that LAN segment. Hence if a source device wants to send the data to all the devices within a network, that can use the broadcast address as the destination MAC address.



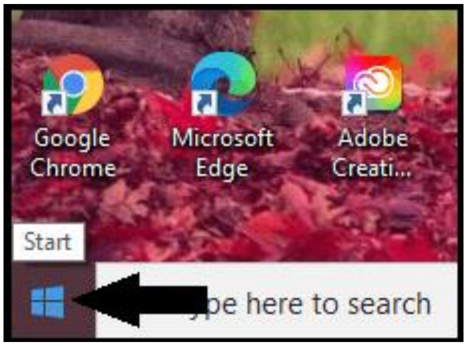
How to find the MAC address of a device

We can easily find or check the address of our computer device with any operating device. Every device connected to the home network contains a unique MAC address, but if your system has multiple network adapters, such as an Ethernet adapter or wireless adapter, each adapter or NIC has its own MAC address or physical address.

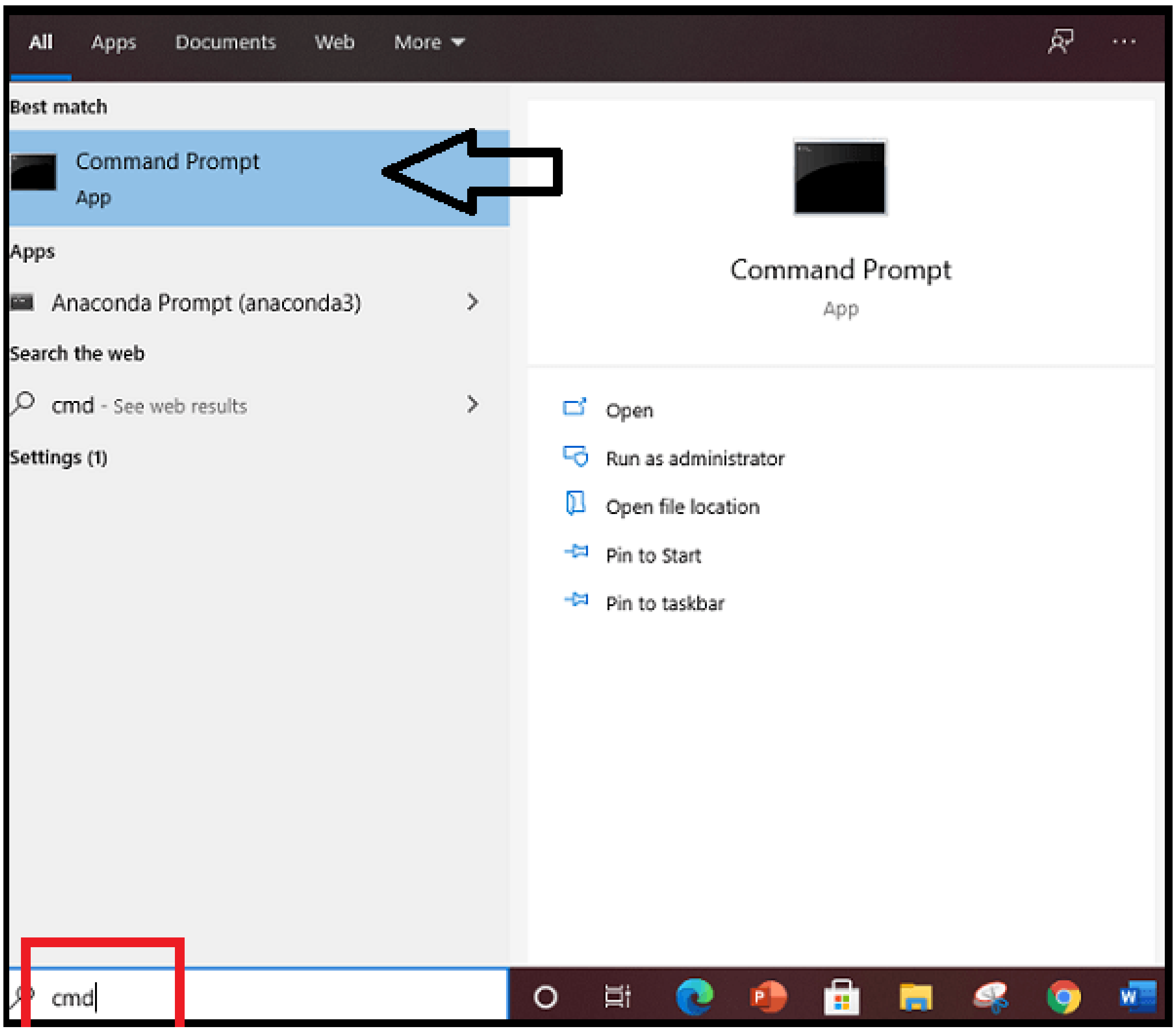
Follow the below steps to find the MAC addresses of a device on a different OS.

MAC address on Windows:

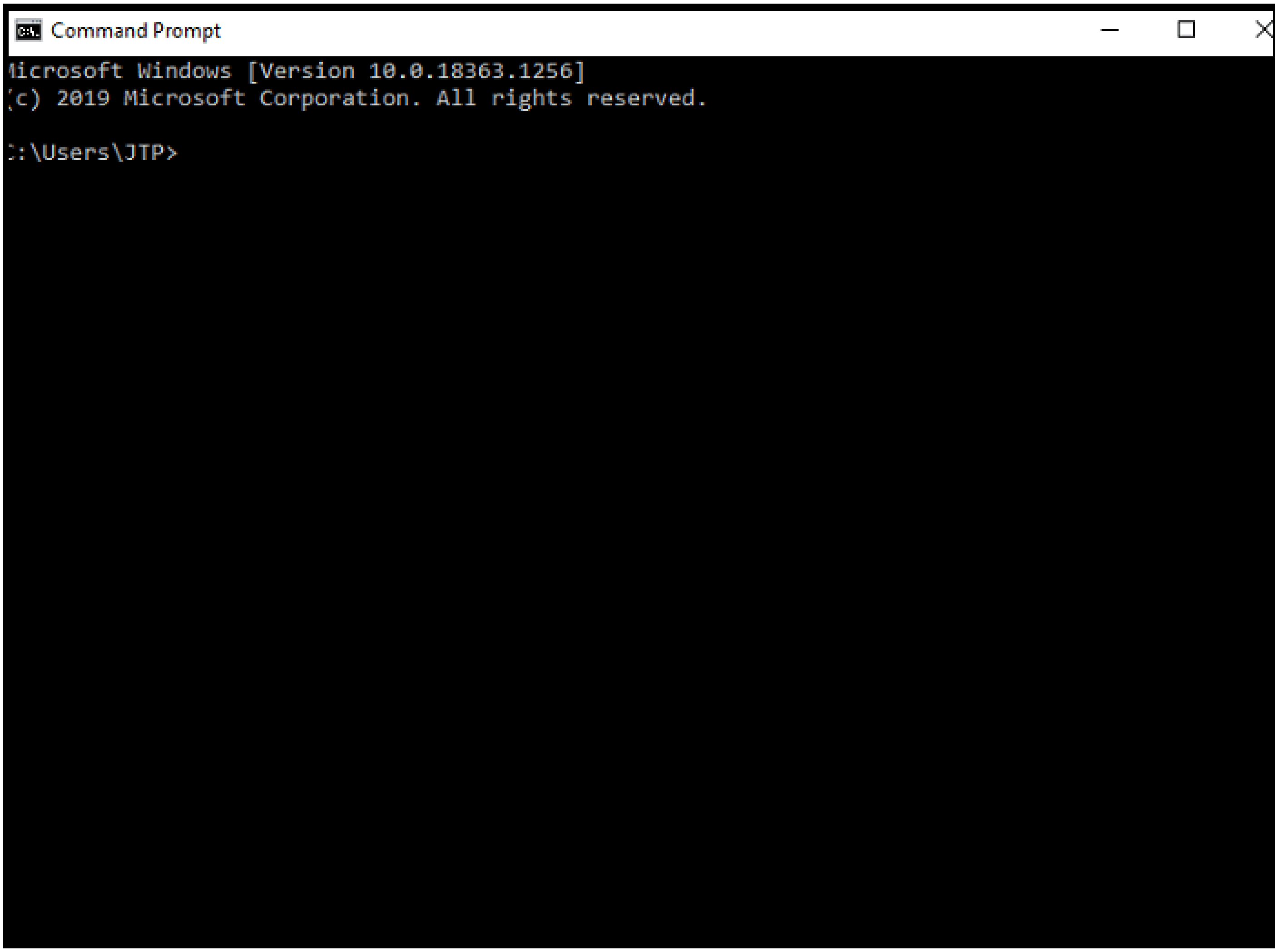
1. Click **Window Start** or Press the Windows Key.



2. In the given search box, type **cmd** to open the command prompt.

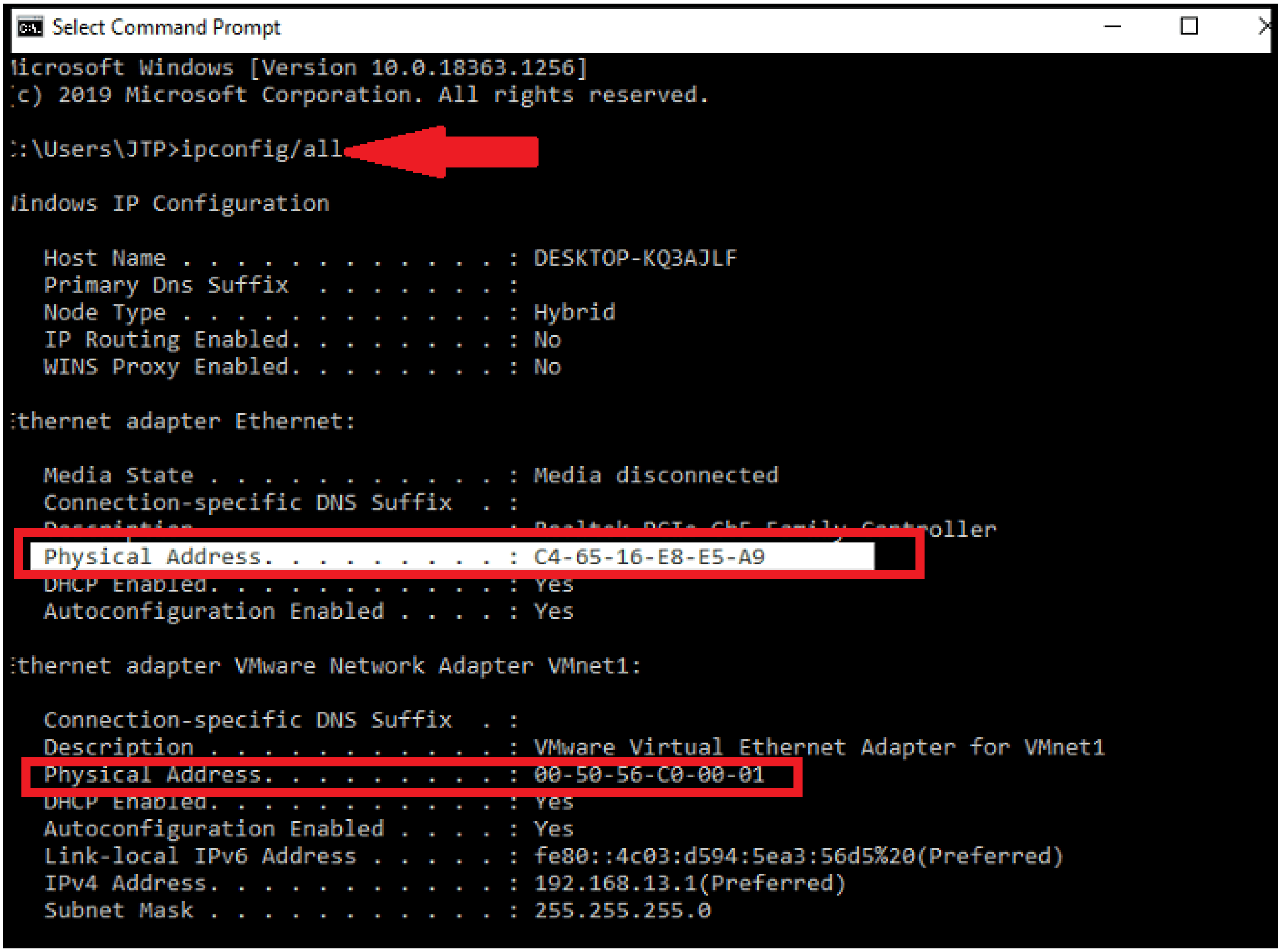


3. Press the Enter key, and the command prompt window will display, as shown below image:



4. Type ipconfig/all command and press enter.

5. It will show different information, scroll down and look for the physical address. Each physical address is the MAC address of your device.



As we can see in the above image, there are two physical addresses shown with different values, one is for the Ethernet adapter, and the other one is for the VMware network adapter.

MAC address on Macintosh OS:

Follow the below steps to find the MAC address on the Macintosh OS:

1. Select the Apple icon or open the Apple Menu, and click on System Preferences.
2. Under system preferences → Select Network →
3. The above path will open a network box.
4. Select the Wi-Fi option from here. It will show the Wi-Fi address or Airport Address displays; it is the MAC address of your device.

Cloning of MAC address

MAC cloning is a way to fix the connectivity issues of the device with ISP. In this method, we need to set the MAC address of a device WAN port to be the similar MAC address of your PC or another device.

The connectivity issue arises mainly when we add new MAC address to a network, and this issue can be fixed with the help of MAC cloning.

For example, Some ISPs use the MAC address of your device when the service is installed. Now, if we place a router behind the cable modem or DSL modem, the ISP will not recognize the MAC address from the device's WAN port. For such a case, either you can call to ISP provider to register the MAC of your device, or you can clone the MAC address of the WAN port to the same as the computer MAC address.

Difference between MAC address and IP address

Both the MAC address and IP address are the way to identify the device on the network. Following are some important differences between both:

MAC address	IP address
It stands for Media Access Control.	It stands for Internet Protocol.
It is the unique address provided by the manufacturer.	It is the logical address provided by the ISP or Internet Service Provider.
It is the physical address of the device's NIC that is used to identify a device within a network.	It is the logical address that identifies a network or device on the internet.
It operates on the data link layer.	It operates on a network Layer.
It is the 6 -bytes hexadecimal address.	It is of 4 bytes for IPv4 and 8 bytes for IPv6 addresses.

Controlled Access Protocols

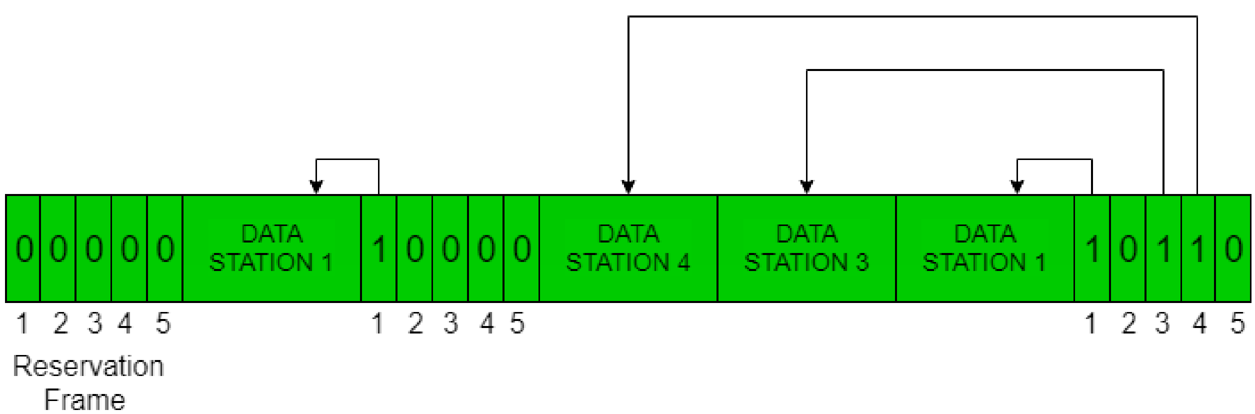
In controlled access, the stations seek information from one another to find which station has the right to send. It allows only one node to send at a time, to avoid the collision of messages on a shared medium. The three controlled-access methods are:

1. Reservation
2. Polling
3. Token Passing

Reservation

- In the reservation method, a station needs to make a reservation before sending data.
- The timeline has two kinds of periods:
  1. Reservation interval of fixed time length
  2. Data transmission period of variable frames.
- If there are M stations, the reservation interval is divided into M slots, and each station has one slot.
- Suppose if station 1 has a frame to send, it transmits 1 bit during the slot 1. No other station is allowed to transmit during this slot.
- In general, i th station may announce that it has a frame to send by inserting a 1 bit into i th slot. After all N slots have been checked, each station knows which stations wish to transmit.
- The stations which have reserved their slots transfer their frames in that order.
- After data transmission period, next reservation interval begins.
- Since everyone agrees on who goes next, there will never be any collisions.

The following figure shows a situation with five stations and a five-slot reservation frame. In the first interval, only stations 1, 3, and 4 have made reservations. In the second interval, only station 1 has made a reservation.



Advantages of Reservation:

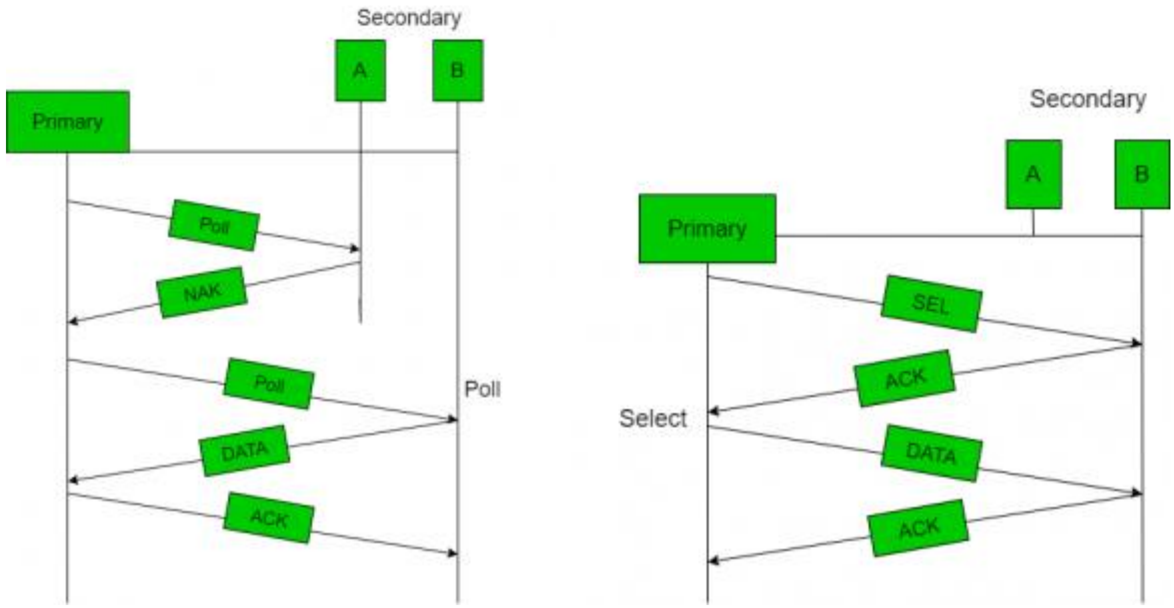
- The main advantage of reservation is *high rates and low rates of data accessing* time of the respective channel can be predicated easily. Here time and rates are fixed.
- Priorities can be set to provide speedier access from secondary.
- Predictable network performance: Reservation-based access methods can provide predictable network performance, which is important in applications where latency and jitter must be minimized, such as in real-time video or audio streaming.
- **Reduced contention:** Reservation-based access methods can reduce contention for network resources, as access to the network is pre-allocated based on reservation requests. This can improve network efficiency and reduce packet loss.
- **Quality of Service (QoS) support**: Reservation-based access methods can support QoS requirements, by providing different reservation types for different types of traffic, such as voice, video, or data. This can ensure that high-priority traffic is given preferential treatment over lower-priority traffic.
- **Efficient use of bandwidth**: Reservation-based access methods can enable more efficient use of available bandwidth, as they allow for time and frequency multiplexing of different reservation requests on the same channel.
- **Support for multimedia applications:** Reservation-based access methods are well-suited to support multimedia applications that require guaranteed network resources, such as bandwidth and latency, to ensure high-quality performance.

Disadvantages of Reservation:

- Highly trust on controlled *dependability*.
- *Decrease in capacity* and channel data rate under light loads; increase in turn-around time.

Polling

- Polling process is similar to the roll-call performed in class. Just like the teacher, a controller sends a message to each node in turn.
- In this, one acts as a primary station(controller) and the others are secondary stations. All data exchanges must be made through the controller.
- The message sent by the controller contains the address of the node being selected for granting access.
- Although all nodes receive the message the addressed one responds to it and sends data if any. If there is no data, usually a “poll reject”(NAK) message is sent back.
- Problems include high overhead of the polling messages and high dependence on the reliability of the controller.



Advantages of Polling:

- The maximum and minimum access time and data rates on the channel are fixed predictable.
- It has maximum *efficiency*.
- It has maximum *bandwidth*.
- No slot is wasted in polling.
- There is assignment of priority to ensure faster access from some secondary.

Disadvantages of Polling:

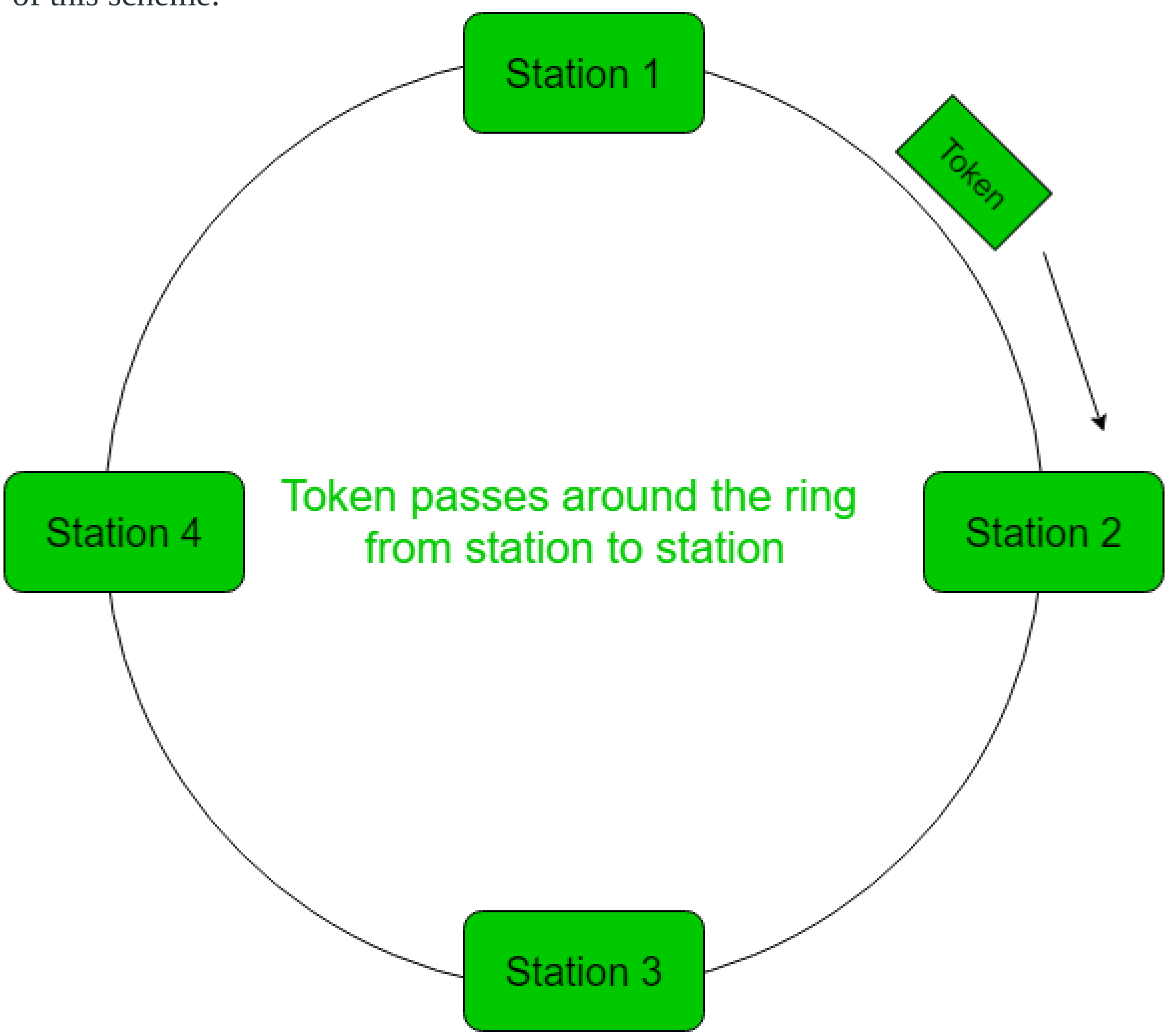
- It consume *more time*.
- Since every station has an equal chance of winning in every round, link sharing is *biased*.
- Only some station might run out of data to send.
- An increase in the turnaround time leads to a drop in the data rates of the channel under low loads.

Efficiency Let T_{poll} be the time for polling and T_t be the time required for transmission of data. Then,

$$Efficiency = T_t/(T_t + T_{poll})$$

Token Passing

- In token passing scheme, the stations are connected logically to each other in form of ring and access to stations is governed by tokens.
- A token is a special bit pattern or a small message, which circulate from one station to the next in some predefined order.
- In Token ring, token is passed from one station to another adjacent station in the ring whereas incase of Token bus, each station uses the bus to send the token to the next station in some predefined order.
- In both cases, token represents permission to send. If a station has a frame queued for transmission when it receives the token, it can send that frame before it passes the token to the next station. If it has no queued frame, it passes the token simply.
- After sending a frame, each station must wait for all N stations (including itself) to send the token to their neighbours and the other N – 1 stations to send a frame, if they have one.
- There exists problems like duplication of token or token is lost or insertion of new station, removal of a station, which need be tackled for correct and reliable operation of this scheme.



Performance of token ring can be concluded by 2 parameters:-

1. **Delay**, is a measure of time between when a packet is ready and when it is delivered. So, the average time (delay) required to send a token to the next station = a/N.
2. **Throughput**, which is a measure of successful traffic.

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

and

```
S = 1/{a(1 + 1/N)} for a>1.

where N = number of stations

a = Tp/Tt
(Tp = propagation delay and Tt = transmission delay)
```

Advantages of Token passing:

- It may now be applied with routers cabling and includes built-in debugging features like *protective relay and auto reconfiguration.*
- It provides *good throughput* when conditions of high load.

Disadvantages of Token passing:

- Its cost is *expensive.*
- Topology components are more expensive than those of other, more widely used standard.
- The hardware element of the token rings are designed to be tricky. This implies that you should choose on manufacture and use them exclusively.

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

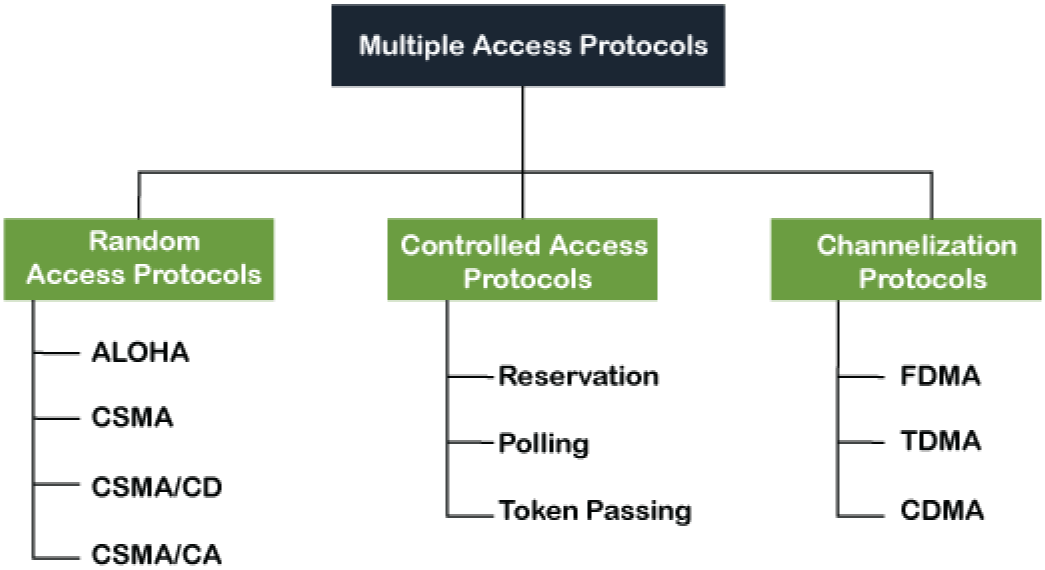
A data link control is a reliable channel for transmitting data over a dedicated link using various techniques such as framing, error control and flow control of data packets in the computer network.

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.

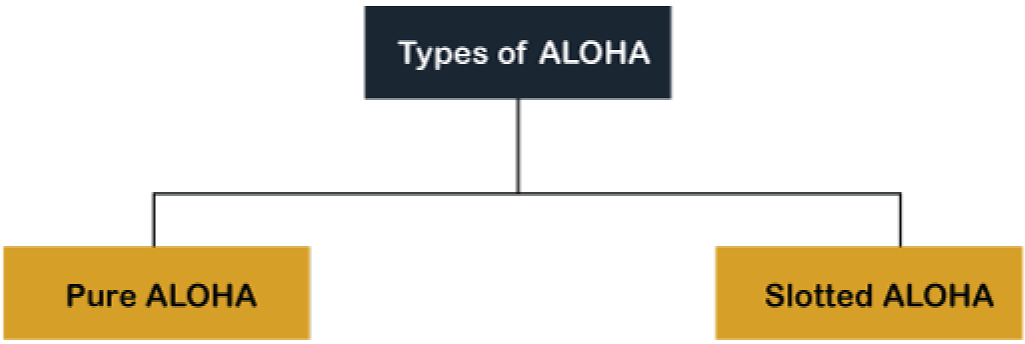
- Aloha
- CSMA
- CSMA/CD
- CSMA/CA

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

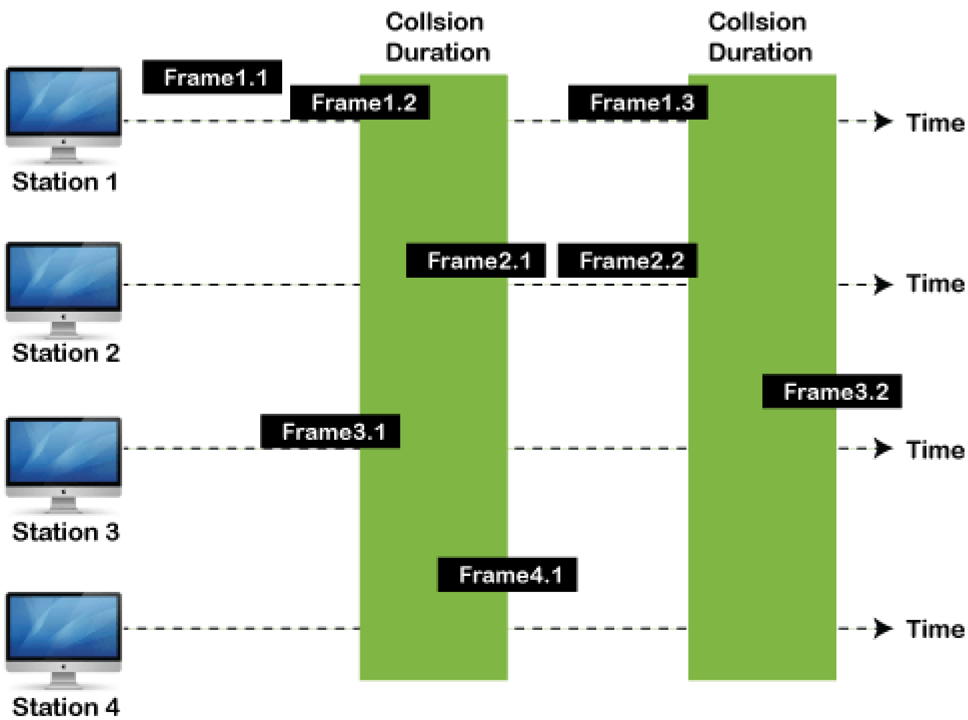
1. Any station can transmit data to a channel at any time.
2. It does not require any carrier sensing.
3. Collision and data frames may be lost during the transmission of data through multiple stations.
4. Acknowledgment of the frames exists in Aloha. Hence, there is no collision detection.
5. It requires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

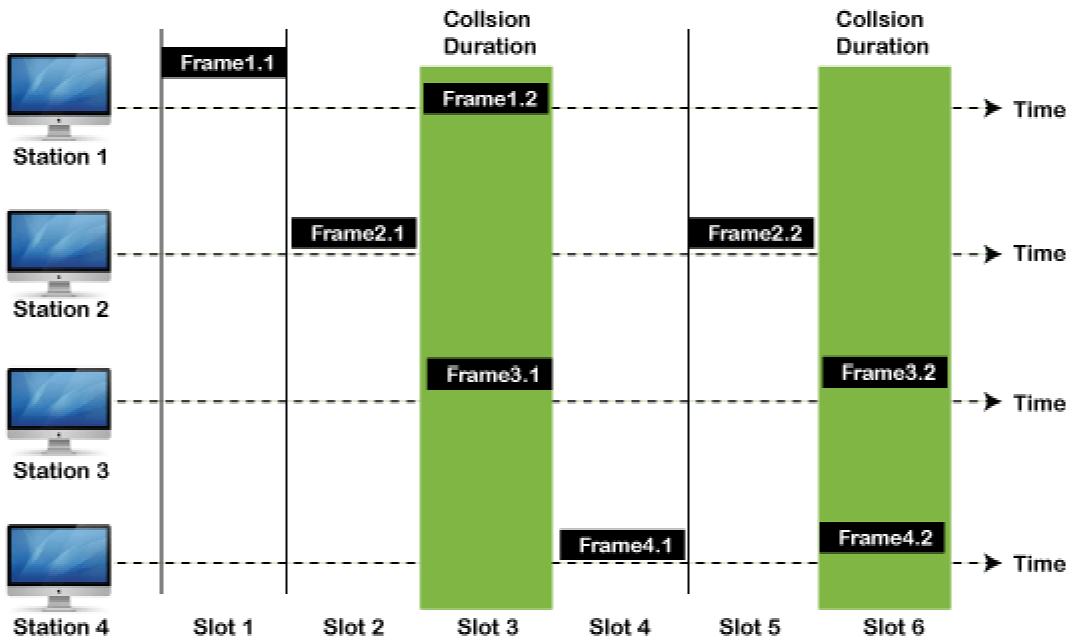
As we can see in the figure above, there are four stations for accessing a shared channel and transmitting data frames. Some frames collide because most stations send their frames at the same time. Only two frames, frame 1.1 and frame 2.2, are successfully transmitted to the receiver end. At the same 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.

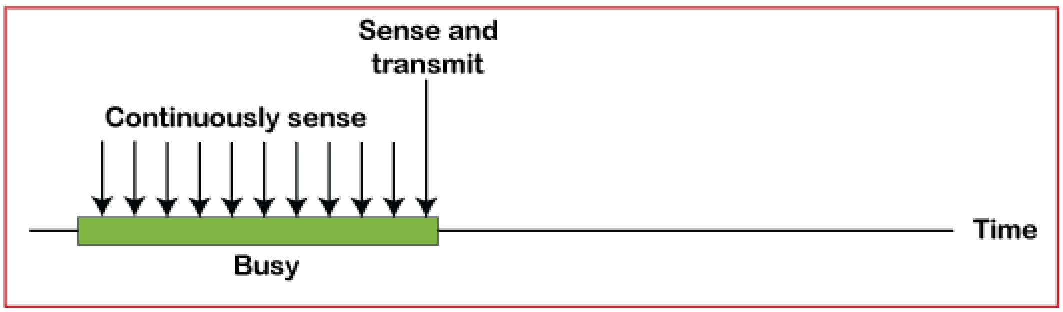
CSMA Access Modes

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.

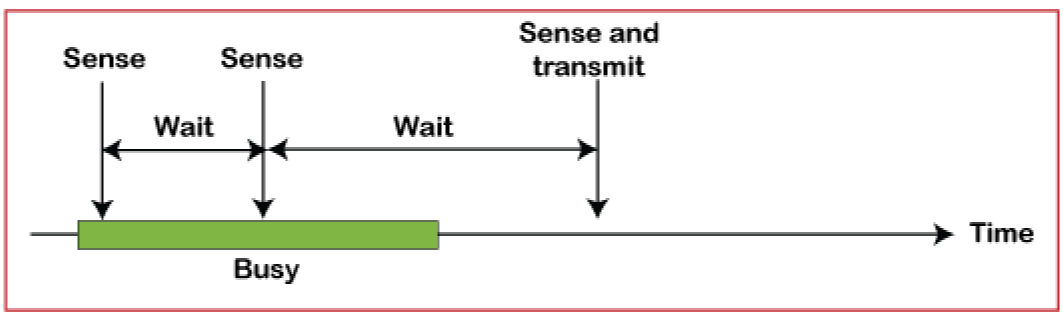
Non-Persistent: It is the access mode of CSMA that defines before transmitting the data, each node must sense the channel, and if the channel is inactive, it immediately sends the data. Otherwise, the station must wait for a random time (not continuously), and when the channel is found to be idle, it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

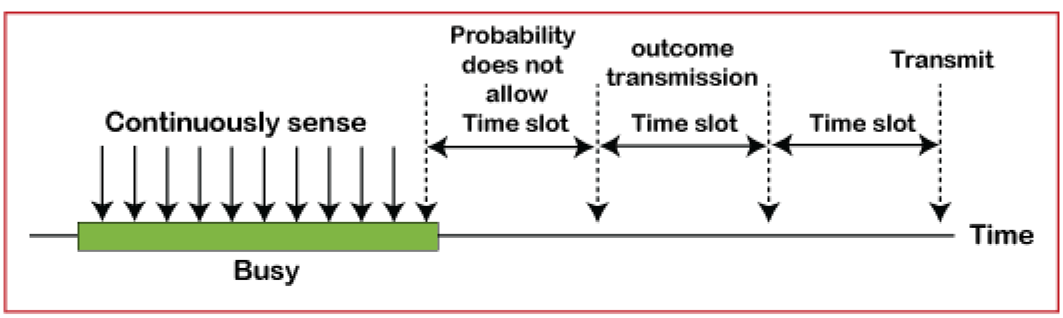
O- Persistent: It is an O-persistent method that defines the superiority of the station before the transmission of the frame on the shared channel. If it is found that the channel is inactive, each station waits for its turn to retransmit the data.



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**.

C. Channelization Protocols

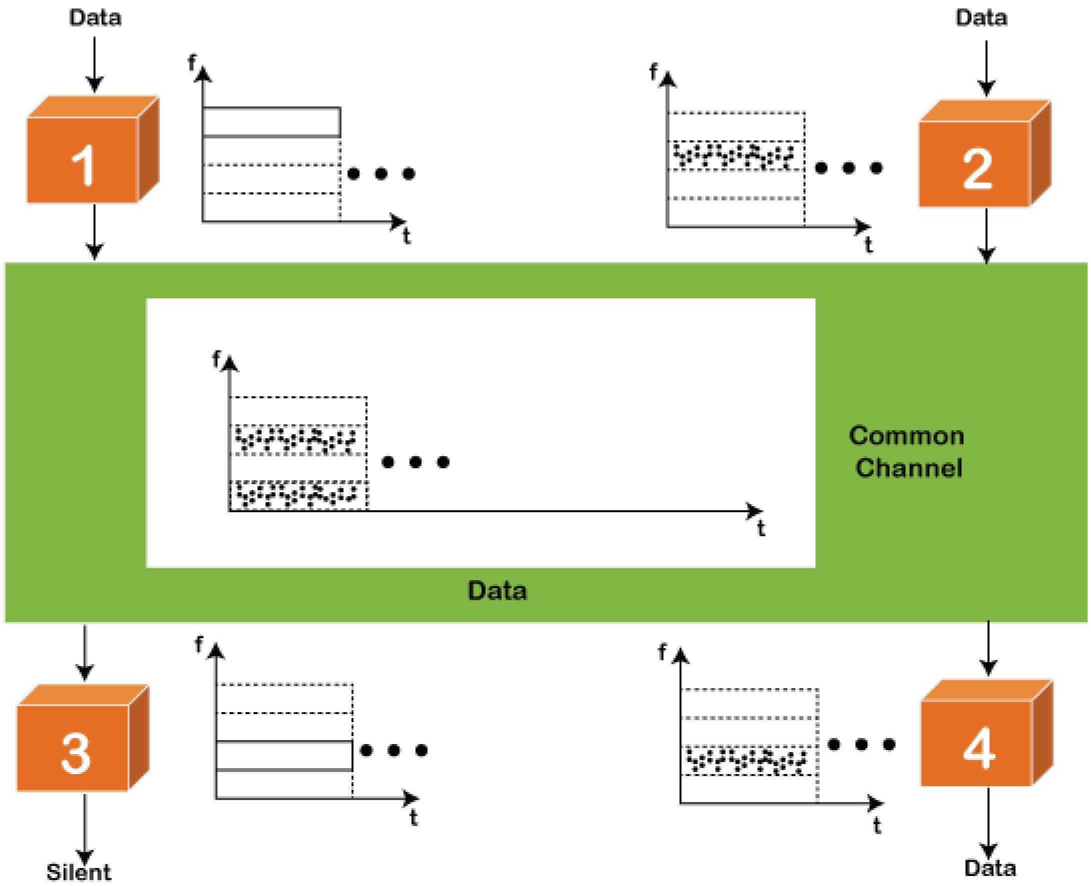
It is a channelization protocol that allows the total usable bandwidth in a shared channel to be shared across multiple stations based on their time, distance and codes. It can access all the stations at the same time to send the data frames to the channel.

Following are the various methods to access the channel based on their time, distance and codes:

1. FDMA (Frequency Division Multiple Access)
2. TDMA (Time Division Multiple Access)
3. CDMA (Code Division Multiple Access)

FDMA

It is a frequency division multiple access (**FDMA**) method used to divide the available bandwidth into equal bands so that multiple users can send data through a different frequency to the subchannel. Each station is reserved with a particular band to prevent the crosstalk between the channels and interferences of stations.



TDMA

Time Division Multiple Access (**TDMA**) is a channel access method. It allows the same frequency bandwidth to be shared across multiple stations. And to avoid collisions in the shared channel, it divides the channel into different frequency slots that allocate stations to transmit the data frames. The same **frequency** bandwidth into the shared channel by dividing the signal into various time slots to transmit it. However, TDMA has an overhead of synchronization that specifies each station's time slot by adding synchronization bits to each slot.

CDMA

The code division multiple access (CDMA) is a channel access method. In CDMA, all stations can simultaneously send the data over the same channel. It means that it allows each station to transmit the data frames with full frequency on the shared channel at all times. It does not require the division of bandwidth on a shared channel based on time slots. If multiple stations send data to a channel simultaneously, their data frames are separated by a unique code sequence. Each station has a different unique code for transmitting the data over a shared channel. For example, there are multiple users in a room that are continuously speaking. Data is received by the users if only two-person interact with each other using the same language. Similarly, in the network, if different stations communicate with each other simultaneously with different code language.