MOBILE COMPUTING (CS-417)

UNIT-2: Channel Allocation

Motivation for a specialized MAC: -

Let us consider **carrier sense multiple access with collision detection, (CSMA/CD)** which works as follows:

- A sender senses the medium (a wire or coaxial cable) to see if it is free.
- If the medium is busy, the sender waits until it is free.
- If the medium is free, the sender starts transmitting data and continues to listen into the medium.
- If the sender detects a collision while sending, it stops at once and sends a jamming signal.

This scheme fails in wireless networks because the signal should reach the receiver without collisions. But the sender is the one detecting collisions. This is not a problem using a wire, as more or less the same signal strength can be assumed all over the wire if the length of the wire stays within certain often standardized limits. If a collision occurs somewhere in the wire, everybody will notice it. The situation is different in wireless networks. As we know the strength of a signal decreases proportionally to the square of the distance to the sender. Obstacles attenuate the signal even further. The sender may now apply carrier sense and detect an idle medium. The sender starts sending – but a collision happens at the receiver due to a second sender.
Collision detection is very difficult in wireless scenarios as the transmission power in the area of the transmitting antenna is several magnitudes higher than the receiving power. So, this very common MAC scheme from wired network fails in a wireless scenario.

Hidden and Exposed Terminals: -

Consider the scenario with three mobile phones as shown in Fig. The transmission range of A reaches B, but not C (the detection range does not reach C either). The transmission range of C reaches B, but not A. Finally, the transmission range of B reaches A and C, i.e., A cannot detect C and vice versa. A starts sending to B, C does not receive this transmission. C also wants to send something to B and senses the medium. The medium appears to be free, the carrier sense fails. C also starts sending causing a collision at B. But A cannot detect this collision at B and continues with its transmission. A is hidden for C and vice versa.

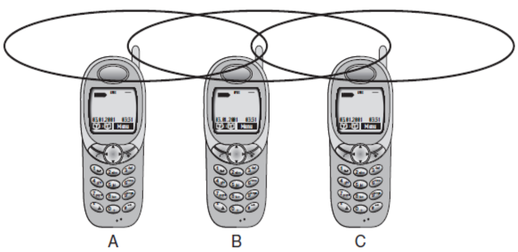


Figure 3.1
Hidden and exposed terminals

While hidden terminals may cause collisions, the exposed terminals only cause unnecessary delay. Now consider the situation that B sends something to A and C wants to transmit data to some other mobile phone outside the interference ranges of A and B. C senses the carrier and detects that the carrier is busy (B's signal). C postpones its transmission until it detects the medium as being idle again. But as A is outside the interference range of C, waiting is not necessary. Causing a 'collision' at B does not matter because the collision is too weak to propagate to A. In this situation, C is **exposed** to B.

Near and Far Terminals: -

Consider the situation as shown in Fig. A and B are both sending with the same transmission power. As the signal strength decreases proportionally to the square of the distance, B's signal drowns out A's signal. As a result, C cannot receive A's transmission.

Now think of C as being an arbiter for sending rights (e.g., C acts as a base station coordinating media access). In this case, terminal B would already drown out terminal A on the physical layer. C in return would have no chance of applying a fair scheme as it would only hear B.

The **near/far effect** is a severe problem of wireless networks using CDM. All signals should arrive at the receiver with more or less the same strength. Otherwise, a person standing closer to somebody could always speak louder than a person further away. Even if the senders were separated by code, the closest one would simply drown out the others. Precise power control is needed to receive all senders with the same strength at a receiver. For example, the UMTS system adapts power 1,500 times per second.

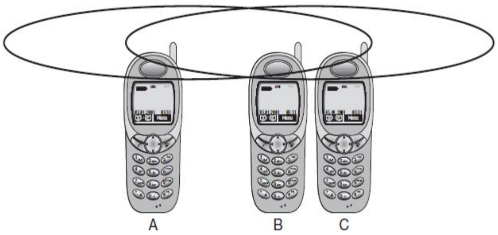


Figure 3.2
Near and far terminals

SDMA (Space Division Multiple Access): -

Space division multiple access (SDMA) is a channel access method that allows multiple users to share the same frequency band by spatially separating their signals. This is achieved using directional antennas, which can focus radio waves in a particular direction. SDMA is a key technology in many modern wireless communication systems, including cellular networks, satellite communication, and wireless local area networks (WLANs).

SDMA works by dividing the coverage area of a base station into multiple sectors. Each sector is assigned a set of directional antennas, and each user is assigned to a particular sector. The base station then uses the directional antennas to focus its signal on the users in its assigned sector. This reduces interference between users in different sectors, allowing them to share the same frequency band.

Advantages of SDMA:

- **Increased capacity:** SDMA allows multiple users to access the same frequency channel at the same time, without interfering with each other. This can significantly increase the capacity of a wireless network.
- **Reduced interference:** SDMA reduces interference between users by focusing each user's signal in a specific direction.

- **Improved coverage:** SDMA can improve the coverage of a wireless network by extending the range of each base station.
- **Increased flexibility:** SDMA is a very flexible technique, and can be used in a variety of different applications, including cellular networks, satellite communications, and WLANs.

Disadvantages of SDMA:

- **Cost:** SDMA requires the use of smart antennas, which can be more expensive than traditional antennas.
- **Complexity:** SDMA is a more complex technology than other multiple access methods, such as TDMA and FDMA. This can make it more difficult to implement and manage.
- **Interference:** Although SDMA significantly reduces interference between users, it is not completely immune to interference. For example, interference can still occur if two users are too close together, or if there are obstacles in the path of the signal.
- **Capacity limit:** SDMA is not a silver bullet for increasing capacity. The number of users that can be supported by SDMA is limited by the number of spatial channels that can be created.

FDMA (Frequency Division Multiple Access): -

Frequency Division Multiple Access (FDMA) is a multiple access technique that divides the available frequency spectrum into multiple channels. Each user is assigned a unique frequency channel, and can transmit and receive data on that channel without interfering with other users.

FDMA was one of the first multiple access techniques to be used in mobile computing, and it was used in the first generation of analog cellular networks. Today, FDMA is still used in some mobile computing applications, such as satellite communications and narrowband IoT (NB-IoT).

Advantages of FDMA:

- Simple to implement and manage
- Efficient use of the available frequency spectrum
- Good support for voice and data traffic

Disadvantages of FDMA:

- Limited capacity
- Sensitive to interference from other users and devices
- Requires careful frequency planning

Duplex for FDMA: - FDM is often used for simultaneous access to the medium by base station and mobile station in cellular networks. Here the two partners typically establish a **duplex channel**, i.e., a channel that allows for simultaneous transmission in both directions. The two directions, mobile station to base station and vice versa are now separated using different frequencies. This scheme is then called **frequency division duplex (FDD)**. Again, both partners have to know the frequencies in advance; they cannot just listen into the medium. The two frequencies are also known as **uplink**, i.e., from mobile station to base station or from ground control to satellite, and as **downlink**, i.e., from base station to mobile station or from satellite to ground control.

TDMA (Time Division Multiple Access): -

Time Division Multiple Access (TDMA) is a multiple access technique that divides a frequency channel into a number of time slots. Each user is assigned a specific time slot, and can only transmit data during their assigned slot. This prevents interference between users.

TDMA was first used in mobile computing in the second generation (2G) cellular networks. It is now used in a variety of mobile communication systems, including 2G, 3G, and 4G networks.

Advantages of TDMA:

- **Increased capacity:** TDMA allows multiple users to share the same frequency channel, which increases the capacity of the network.
- **Reduced interference:** TDMA reduces interference between users by preventing them from transmitting at the same time.
- **Improved coverage:** TDMA can improve the coverage of a network by extending the range of each base station.

Disadvantages of TDMA:

- **Complexity:** TDMA is more complex to implement and manage than other multiple access techniques, such as FDMA.
- **Latency:** TDMA can introduce latency because users have to wait for their assigned time slot before they can transmit data.
- **Call setup overhead:** TDMA has higher call setup overhead than other multiple access techniques.

Fixed TDM: -

Fixed TDM is a type of time division multiplexing (TDM) that is used for point-to-point communication. In fixed TDM, the time slots are allocated in a fixed pattern and do not change over time. This contrasts with dynamic TDM, where the time slots are allocated to users on demand.

Fixed TDM is often used in applications where high reliability and low latency are required. For example, fixed TDM is used in digital subscriber line (DSL) systems and point-to-point microwave links.

Here is a simplified example of how fixed TDM works:

1. The TDM system is configured with a fixed number of time slots.
2. Each time slot is assigned to a specific user.
3. At the start of each time slot, the user is allowed to transmit data.
4. After the time slot expires, the next user is allowed to transmit data.
5. This process continues until all of the users have transmitted their data.

Advantages of Fixed TDM:

- **High reliability:** Fixed TDM is very reliable because the time slots are allocated in a fixed pattern. This means that users can always expect to have access to their assigned time slot.
- **Low latency:** Fixed TDM has low latency because users do not have to wait for their assigned time slot to be allocated. This is because the time slots are pre-allocated.
- **Simplicity:** Fixed TDM is relatively simple to implement and manage.

Disadvantages of Fixed TDM:

- **Inefficiency:** Fixed TDM can be inefficient because users may not always need their entire time slot. This is because the time slots are allocated in a fixed pattern.
- **Limited flexibility:** Fixed TDM is not very flexible because the time slots cannot be changed to accommodate changes in user demand.

Duplex for Fixed TDM: Fixed TDM patterns are used to implement multiple access and a duplex channel between a base station and mobile station. Assigning different slots for uplink and downlink using the same frequency is called **time division duplex (TDD)**. As shown in the figure, the base station uses one out of 12 slots for the downlink, whereas the mobile station uses one out of 12 different slots for the uplink. Uplink and downlink are separated in time. Up to 12 different mobile stations can use the same frequency without interference using this scheme. Each connection is allotted its own up- and downlink pair.

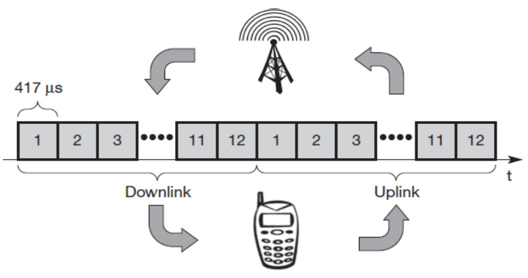
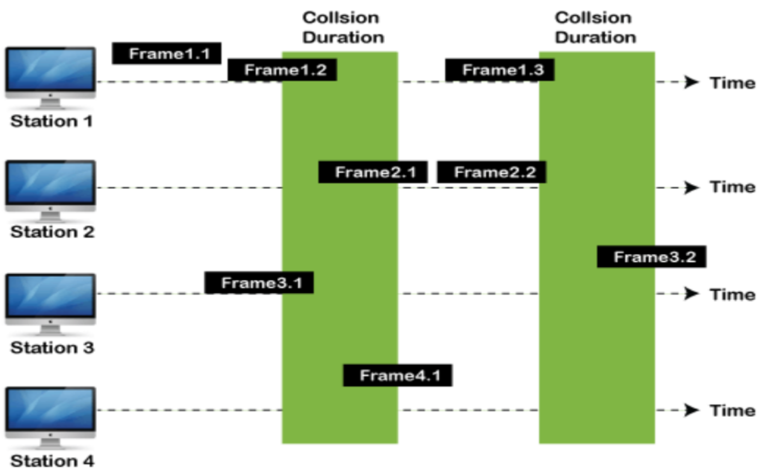


Figure 3.4 Time division multiplexing for multiple access and duplex

Classical/Pure ALOHA: - Classical Aloha is a random access protocol for wireless networks. It is a scheme which was invented at the University of Hawaii and was used in the ALOHANET for wireless connection of several stations. In Classical Aloha, any station can transmit data at any time. If two or more stations transmit at the same time, their packets will collide and be destroyed. In this case, the stations must wait a random amount of time and then retransmit their packets.

Here is an example of how Classical Aloha works:

- Station A has a packet to transmit.
- Station A transmits the packet at a random time.
- If no other stations are transmitting at the same time, the packet will be successfully received.
- If another station is transmitting at the same time, the packets will collide and be destroyed.
- If the packet collides, Station A waits a random amount of time and then retransmits the packet.
- This process continues until the packet is successfully received.



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.

Advantages of Classical Aloha:

- **Simple:** Classical Aloha is a very simple protocol to implement. There is no need for any coordination between the stations.
- **Robust to interference:** Classical Aloha is relatively robust to interference. If a packet is corrupted by interference, it will simply be retransmitted.
- **Flexible:** Classical Aloha is a very flexible protocol. It can be used in a variety of different wireless networks, including ad hoc networks, sensor networks, and satellite networks.

Disadvantages of Classical Aloha:

- **Inefficient:** Classical Aloha is a very inefficient protocol. If the number of stations is high, the probability of collisions is high, which can lead to significant delays.
- **Unfair:** Classical Aloha is unfair to stations that generate a lot of traffic. These stations are more likely to have their packets collide, which can lead to even more delays.
- **Not scalable:** Classical Aloha does not scale well to large networks. As the number of stations increases, the probability of collisions increases, which can lead to even more delays.

Slotted ALOHA: -

Slotted Aloha is a random access protocol for wireless networks. It is a modification of the Classical Aloha protocol that improves efficiency by reducing the number of collisions.

In Slotted Aloha, time is divided into fixed-length slots. Stations can only transmit data at the beginning of a slot. If two or more stations transmit at the same time, their packets will collide and be destroyed. In this case, the stations must wait a random amount of time and then retransmit their packets.

Slotted Aloha is more efficient than Classical Aloha because it reduces the number of collisions. This is because stations cannot transmit data at any time. They can only transmit data at the beginning of a slot. This reduces the probability of two or more stations transmitting at the same time.

Here is an example of how Slotted Aloha works:

- Station A has a packet to transmit.
- Station A waits for the beginning of the next slot.
- At the beginning of the slot, Station A transmits the packet.
- If no other stations are transmitting at the same time, the packet will be successfully received.

- If another station is transmitting at the same time, the packets will collide and be destroyed.
- If the packet collides, Station A waits a random amount of time and then retransmits the packet.
- This process continues until the packet is successfully received.

Frames in Slotted ALOHA

Advantages of Slotted Aloha:

- **Reduced collisions:** Slotted Aloha reduces the number of collisions by only allowing stations to transmit at the beginning of a slot. This is in contrast to Classical Aloha, where stations can transmit at any time.
- **Increased throughput:** The reduced number of collisions in Slotted Aloha leads to increased throughput.
- **Improved fairness:** Slotted Aloha is more fair to stations that generate a lot of traffic than Classical Aloha. This is because stations cannot transmit their packets until the beginning of the next slot. This gives all stations an equal chance to transmit their packets.

Disadvantages of Slotted Aloha:

- **Still inefficient:** Slotted Aloha is still not as efficient as other random access protocols, such as CSMA/CD. This is because there is still a chance of collisions, even though stations can only transmit at the beginning of a slot.
- **Requires synchronization:** Slotted Aloha requires all stations to be synchronized. This can be difficult to achieve in some wireless networks.
- **Not scalable:** Slotted Aloha does not scale well to large networks. As the number of stations increases, the probability of collisions increases.

Difference between Classical/Pure Aloha and Slotted Aloha: -

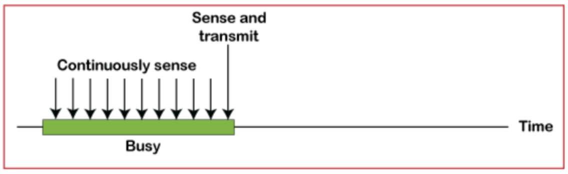
Pure Aloha	Slotted Aloha
In this Aloha, any station can transmit the data at any time.	In this, any station can transmit the data at the beginning of any time slot.
In this, the time is continuous and not globally synchronized.	In this, the time is discrete and globally synchronized.
Vulnerable time for Pure Aloha = $2 \times T_t$	Vulnerable time for Slotted Aloha = T_t
In Pure Aloha, the Probability of successful transmission of the data packet $= G \times e^{-2G}$	In Slotted Aloha, the Probability of successful transmission of the data packet $= G \times e^{-G}$
In Pure Aloha, Maximum efficiency = 18.4%	In Slotted Aloha, Maximum efficiency = 36.8%
Pure Aloha doesn't reduce the number of collisions to half.	Slotted Aloha reduces the number of collisions to half and doubles the efficiency of Pure Aloha.

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.

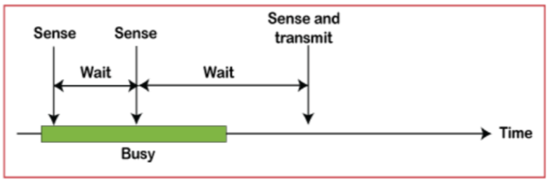
CSMA Access Modes: -

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.



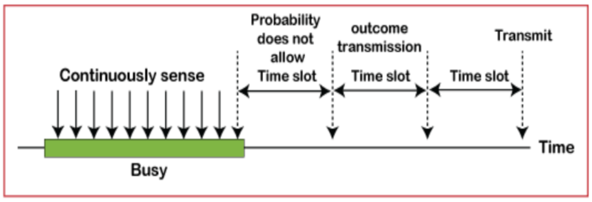
a. 1-persistent

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.



b. Nonpersistent

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.



c. p-persistent

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.

Career Sense Multiple Access with Collision Detection (CSMA/CD): -

Carrier Sense Multiple Access with Collision Detection (CSMA/CD) is a medium access control (MAC) method used in Ethernet networks. It allows multiple devices to share a single transmission medium without interfering with each other.

CSMA/CD works by having each device listen to the network before transmitting data. If the network is idle, the device can transmit its data. However, if the network is busy, the device must wait until the network is idle before transmitting.

If two devices transmit data at the same time, a collision will occur. When a collision occurs, both devices stop transmitting and wait a random amount of time before retransmitting their data.

Working of CSMA/CD: -

- A sender senses the medium (a wire or coaxial cable) to see if it is free.
- If the medium is busy, the sender waits until it is free.
- If the medium is free, the sender starts transmitting data and continues to listen into the medium.

- If the sender detects a collision while sending, it stops at once and sends a jamming signal.

Advantages of CSMA/CD:

- **Simple and widely used:** CSMA/CD is a widely used protocol for Ethernet networks, and its simplicity makes it easy to implement and use.
- **Fairness:** In a CSMA/CD network, all devices have equal access to the transmission medium, which ensures fairness in data transmission.
- **Efficiency:** CSMA/CD allows for efficient use of the transmission medium by preventing unnecessary collisions and reducing network congestion.

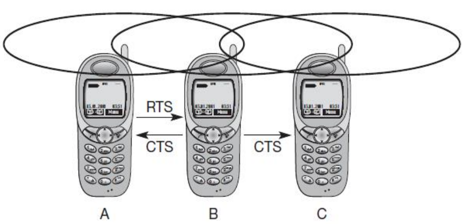
Disadvantages of CSMA/CD:

- **Limited scalability:** CSMA/CD has limitations in terms of scalability, and it may not be suitable for large networks with a high number of devices.
- **Vulnerability to collisions:** While CSMA/CD can detect collisions, it cannot prevent them from occurring. Collisions can lead to data corruption, retransmission delays, and reduced network performance.
- **Inefficient use of bandwidth:** CSMA/CD uses a random backoff algorithm that can result in inefficient use of network bandwidth if a device continually experiences collisions.
- **Susceptibility to security attacks:** CSMA/CD does not provide any security features, and the protocol is vulnerable to security attacks such as packet sniffing and spoofing.

Multiple Access with Collision Avoidance (MACA): -

Multiple access with collision avoidance (MACA) presents a simple scheme that solves the hidden terminal problem, does not need a base station, and is still a random access Aloha scheme – but with dynamic reservation.
Figure shows the same scenario as with the hidden terminals.
Remember, A and C both want to send to B. A has already started the transmission, but is hidden for C, C also starts with its transmission, thereby causing a collision at B.

Figure 3.10
MACA can avoid hidden terminals



- With MACA, A does not start its transmission at once, but sends a **request to send (RTS)** first.
- B receives the RTS that contains the name of sender and receiver, as well as the length of the future transmission.

- This RTS is not heard by C, but triggers an acknowledgement from B, called **clear to send (CTS)**. The CTS again contains the names of sender (A) and receiver (B) of the user data, and the length of the future transmission.
- This CTS is now heard by C and the medium for future use by A is now reserved for the duration of the transmission.
- After receiving a CTS, C is not allowed to send anything for the duration indicated in the CTS toward B.
- A collision cannot occur at B during data transmission, and the hidden terminal problem is solved – provided that the transmission conditions remain the same.

MACA also help to solve the 'exposed terminal' problem. Consider the scenario of exposed terminal in which B wants to send data to A, C to someone else. But C is polite enough to sense the medium before transmitting, sensing a busy medium caused by the transmission from B. C defers, although C could never cause a collision at A.

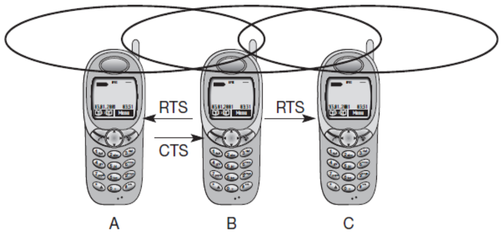


Figure 3.11
MACA can avoid exposed terminals

- With MACA, B has to transmit an RTS first containing the name of the receiver (A) and the sender (B).
- C does not react to this message as it is not the receiver, but A acknowledges using a CTS which identifies B as the sender and A as the receiver of the following data transmission.
- C does not receive this CTS and concludes that A is outside the detection range.
- C can start its transmission assuming it will not cause a collision at A. The problem with exposed terminals is solved without fixed access patterns or a base station.

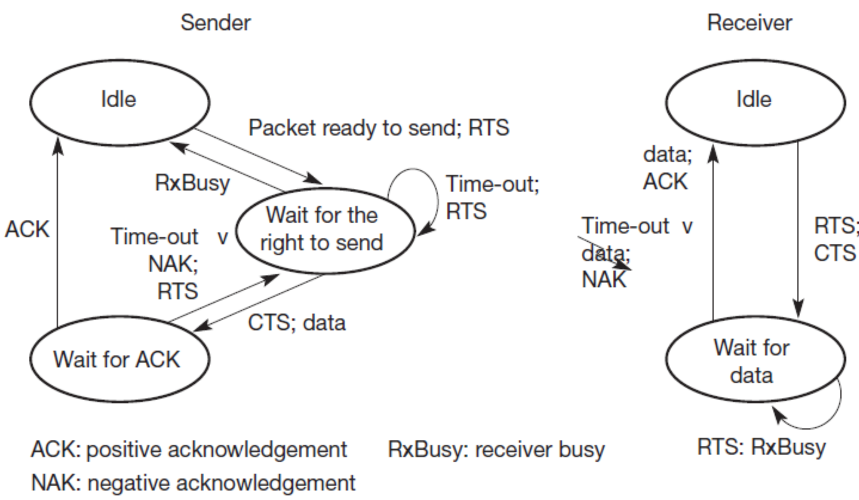


Figure 3.12
Protocol machines for multiple access with collision avoidance

Above Fig. shows simplified state machines for a sender and receiver. The sender is idle until a user requests the transmission of a data packet. The sender then issues an RTS and waits for the right to send. If the receiver gets an RTS and is in an idle state, it sends back a CTS and waits for data. The sender receives the CTS and sends the data. Otherwise, the sender would send an RTS again after a time-out (e.g., the RTS could be lost or collided). After transmission of the data, the sender waits for a positive acknowledgement to return into an idle state. The receiver sends back a positive acknowledgement if the received data was correct. If not, or if the waiting time for data is too long, the receiver returns into idle state. If the sender does not receive any acknowledgement or a negative acknowledgement, it sends an RTS and again waits for the right to send. Alternatively, a receiver could indicate that it is currently busy via a separate RxBusy.

Advantages of MACA:

- **Reduces collisions:** MACA reduces collisions by using RTS and CTS packets to coordinate transmissions.
- **Improves throughput:** The reduced number of collisions in MACA leads to improved throughput.
- **Reduced interference:** MACA reduces interference by using RTS and CTS packets to prevent stations from transmitting at the same time.
- **Improved fairness:** MACA is more fair to stations that generate a lot of traffic than CSMA/CD. This is because stations cannot transmit their packets until they have received a CTS packet.

Disadvantages of MACA:

- **More complex:** MACA is more complex to implement than CSMA/CD. This is because MACA requires stations to send RTS and CTS packets before transmitting data.
- **Requires synchronization:** MACA requires all stations to be synchronized. This can be difficult to achieve in some wireless networks.
- **Not scalable:** MACA does not scale well to large networks. As the number of stations increases, the overhead of RTS and CTS packets increases.