INNOVATIVE SMART SYSTEMS

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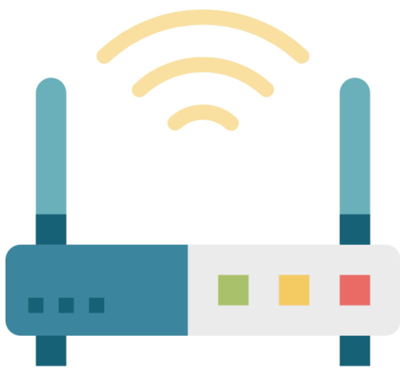
MAC layers

for Wireless Sensor Networks

Protocols for connected objects



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INTRODUCTION

The **M**edia **A**ccess **C**ontrol (**MAC**) layer is one of the two sublayers (with the Logical Link Layer or LLC) that together make up the **Data Link** Layer in the **OSI** model (cf. **Figure 1**).

MAC layer protocols have a very important role in the development of **Wireless sensor networks**, dealing with reliability and efficiency notions.

The main functions performed by the MAC layer are the following ones:

- Channel access policies
- Frame delimiting and identification (buffer management)
- Scheduling (Flow control)
- Frame error control

The **choice** of a MAC layer protocol, among other factors such as number of nodes, mobility or data/traffic rate, dictates how the wireless sensor network will perform.

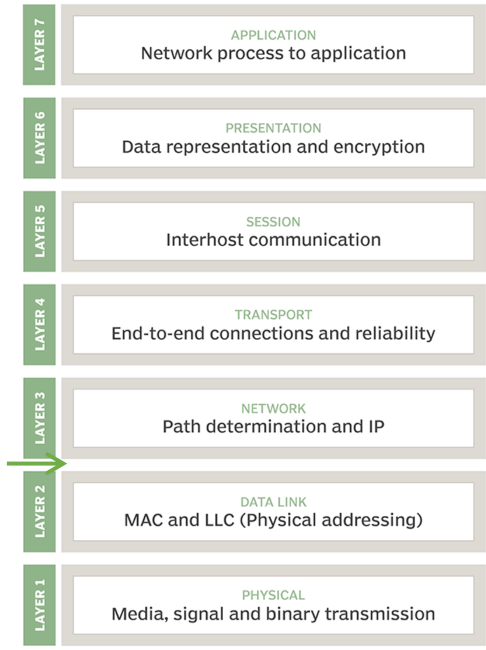

Figure 1: OSI Model

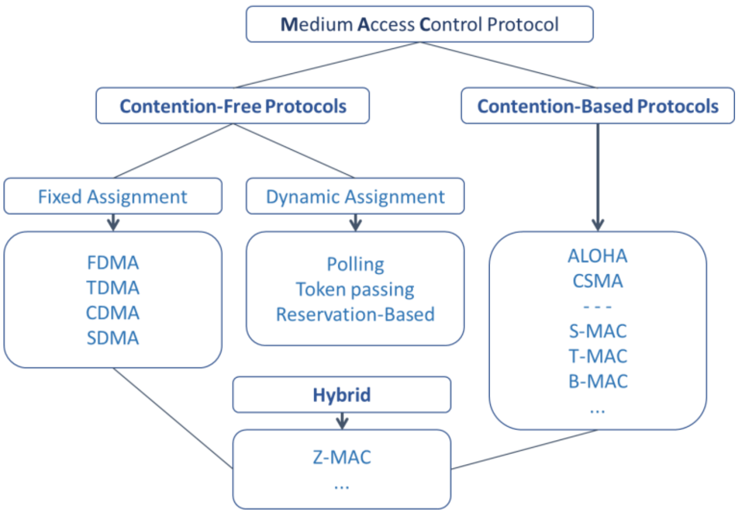

Figure 2: MAC protocols organisation

We can distinguish 3 types of MAC protocols (cf. **Figure 2**): **Contention-Free** (or Scheduled-Based), **Contention-Based** and **Hybrid** (mixing both). **IEEE 802.11** MAC protocol has been the standard for wireless LANs, but as the traffic goes up today, and in a different way (development of the **Internet of Things**), the standard **802.15.4** or **LR-WPAN** (**L**ow **R**ate **W**ireless **P**ersonal **A**rea **N**etwork) was specifically designed for this type of sensor networks to perform better in terms of latency and energy consumption.

1. Contention-Free Protocols

1.1. FDMA

Frequency **D**ivision **M**ultiple **A**ccess (**FDMA**) is a very known channel access protocol, by its simplicity of deployment and lifespan, used in radio/TV broadcasting industries and satellite networks mainly. It separates channels by frequency, meaning that there is **only one conversation and one user at a time per channel**. The available system bandwidth $[W]$ is divided into several non-overlapping bands $[W_u]$ (cf. **Figure 3**).

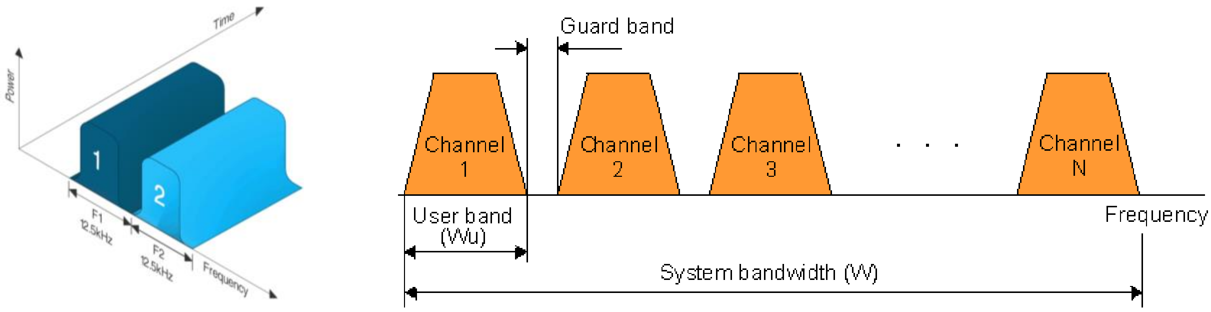

Figure 3: FDMA method

We can observe the presence of a **guard band** to avoid interference between the channels. Then, the bands $[W_u]$ are assigned to users who request the service. Once the service is no more needed and the transmission is terminated, and only at that point, the channel can be re-assigned to another user.

Thus, the number maximum of user is **predetermined**, and so not appropriate for Wireless Sensor Network application. Nevertheless, this method is efficient if the user has a steady flow of data to send.

1.2. TDMA

Time **D**ivision **M**ultiple **A**ccess, on the contrary, **divides the time axis into multiple slots**, grouped in **frames**. It is a scheduling data transmission protocol, used for instance in GSM (Global System for Mobile Communication). The principle is that each user occupied cyclically a time slot, which allows two or [M] users to occupy the same channel at what appears to them the same time (cf. **Figure 4**).

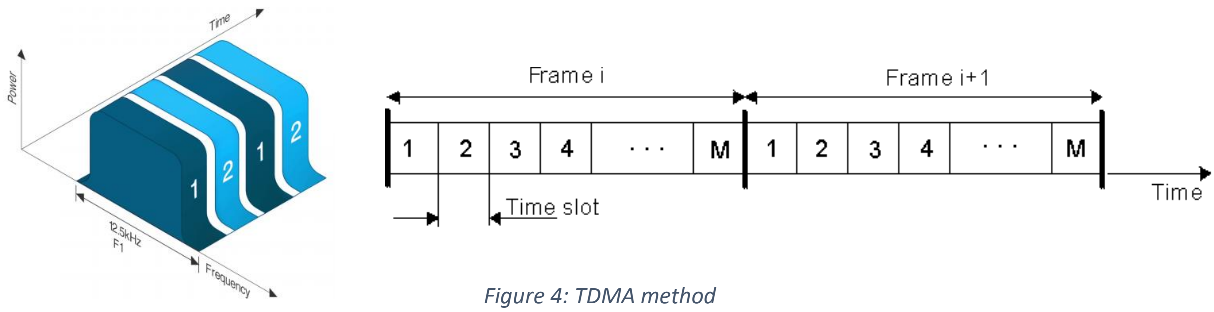

Figure 4: TDMA method

This process is so fast that user thinks he has the exclusivity of the frequency channel. However, TDMA requires a **synchronising** method to coordinate each node transmission. For example, this synchronisation can be achieved by sending periodically packets for this purpose, but it will mean a **costlier** solution if we want to apply it for sensor networks by the energy resources consumed.

1.3. CDMA

Code-**D**ivision **M**ultiple **A**ccess is another example of multiple channel access used in a lot of mobile phone standards (3G for example), where various sources can transmit simultaneously over a single communication channel. To avoid interference between users, CDMA uses **spread spectrum** technology with a special **coding scheme** generated for each data transmission.

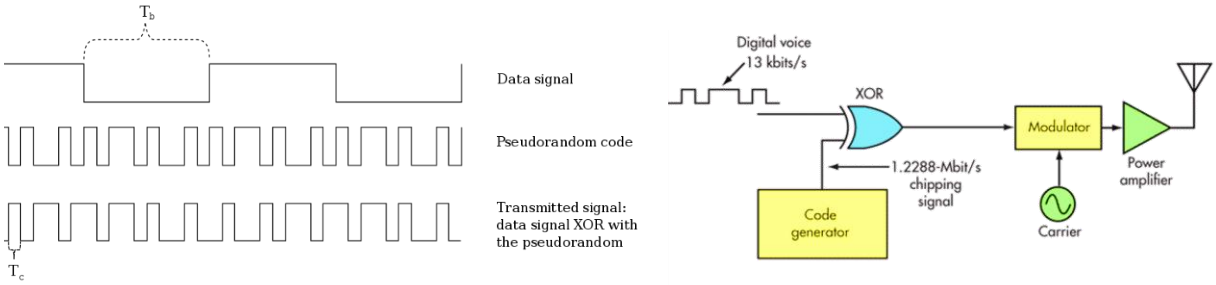

Figure 5: CDMA spread spectrum method

A generated **pseudorandom code** for each user runs at a higher rate than the data to transmit, and then is combined thanks to a **XOR** function with the data signal (cf. **Figure 5**).

Thus, all the signals assigned to the channel by the unique codes are transmitted through the transmission medium at the **same time** and in the **same frequency band**. Then the receiver, which known the code used to send the data, looks for the right broadband, and with a particular correlating circuit, synchronizes with the good transmitter and de-spreads the signal back to its original bandwidth.

This MAC protocol need more complex circuits/means to work and has also a soft **capacity limit**. Indeed, the system performance gradually degrades for each user while the number of these users increases. Nevertheless, CDMA signals are not sensitive to narrowband interferences.

1.4. SDMA

Space-**D**ivision **M**ultiple **A**ccess allows to share wireless channels too, based on the position of the users, if they are far enough to avoid interference.

In traditional mobile networks, the base antenna has no information on the mobile position and radiates the signal in all directions to provide radio coverage. Here, directional antennas or now **smart antennas**, allows frequency sharing with **dynamic beamforming** to shrink signals into **narrow beams** to focus specific users (cf. **Figure 6**).

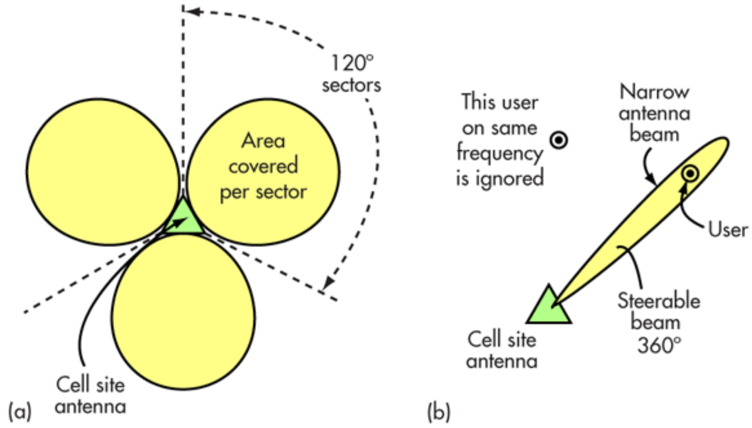

Figure 6: CDMA spread spectrum method

Therefore, SDMA offers very attractive performance enhancements.

As an example of use, besides of some GSM cellular networks, **5G** will be also focused on the position of devices compared to the base transceiver station, enabling **power savings and reducing the electromagnetic fields** around stations, which is important to consider for health and safety matters.

2. Contention-Based Protocols

2.1. CSMA

Carrier-**S**ense **M**ultiple **A**ccess is a contention-based media access control protocol, meaning that it *allows multiple users to share the same spectrum by defining the events that must occur when two or more transmitters attempt to simultaneously access the same channel* (Rules for Wireless Broadband Services). It is kind of "listen before talk" operating procedure of the **IEEE 802.11** standard.

There are 3 main different cases of CSMA, briefly described below:

- **Non-persistent**: 1. transmit immediately data once medium is idle – 2. back off operation (wait a certain amount of time before new attempt)
- **1-persistent**: 1 + 3. continuously sense of the medium to see if transmission is possible
- **p-persistent**: 3 + transmission with a probability p.

We then distinguish 2 variations of CSMA protocol: Carrier-sense multiple access with **collision detection** (CSMA/CD) and Carrier-sense multiple access with **collision avoidance** (CSMA/CA).

2.1.1. CSMA/CD terminates a transmission as soon as collision is detected (used by **Ethernet**). It requires that sender aware of collisions.

2.1.2. CSMA/CA attempts to avoid collisions directly, by a shift of the transmission with a random interval of time (used by **WIFI**). Both protocol modifications tend to improve the performance of CSMA.

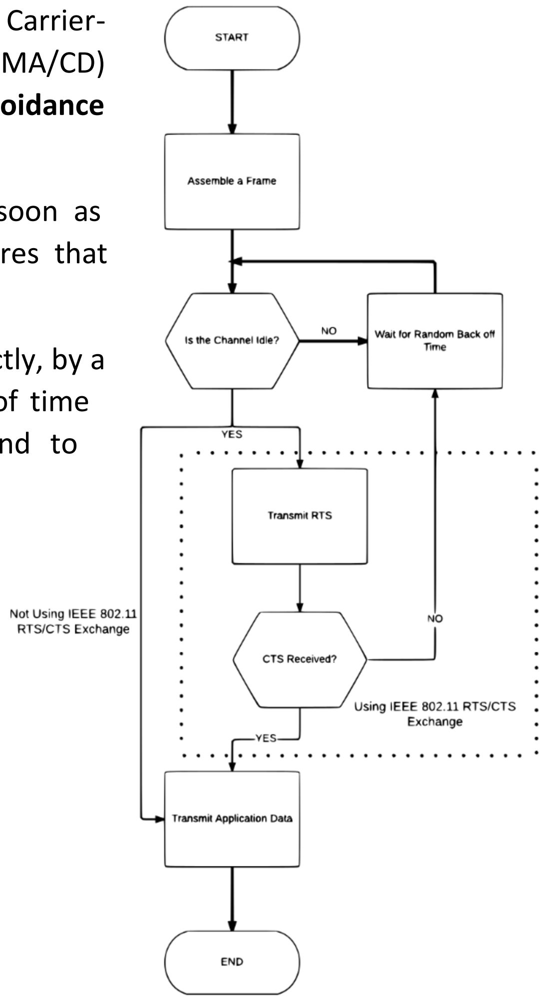

Figure 7: CSMA/CA method

2.2. ALOHA

ALOHA is a very simple media access shared channel protocol (developed in Hawaii), in which collisions are treated by **repeating** the transmission in a specific way.

2.2.1. Pure ALOHA

It relies on **acknowledgment** from the receiver, **repetition** of the transmission in case of collisions, and **waiting** random intervals when time-out is passed.

To prevent from congesting the channel, the method given below is used (cf. **Figure 8**), based on the previous notions:

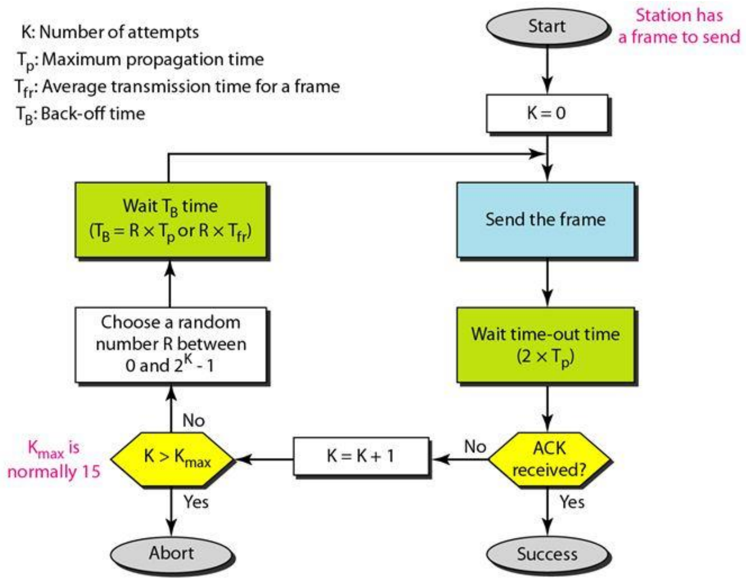

Figure 8: ALOHA transmission procedure

2.2.2. Slotted ALOHA

With the previous method, ALOHA has a non-negligible vulnerable time. Now, with this method, **slots are defined** to force the station to send only at the beginning of these slots. As a consequence, vulnerability time is **divided by 2**.

3. Protocols For Wireless Sensor Networks

Wireless Sensor Networks (WSN), in addition to basic MAC layers functions (avoid collisions and interference for example), needs more improvement in several domains to consume less power and energy: control packet overhead, overhearing unnecessary traffic, long idle time, synchronization overhead… That is why several methods using exiting protocols have seen the day. Let’s have a look at some of these technologies.

3.1. CSMA based (Contention-based)

3.1.1. S-MAC

Sensor-MAC is designed for sensor networks operations. It minimizes the losses of power due to collisions and idle listening. The idea is to limit this state pushing the nodes in **sleep mode**.

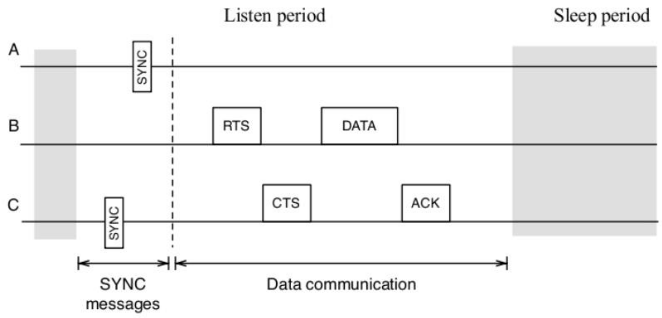

Figure 9: S-MAC behaviour

It uses flow control (**RTS**: Request to Send / **CTS**: Clear to Send / Data / **ACK**: Acknowledgement) with CSMA/CA mode to limit collisions and power consumption. Nodes wake up periodically to listen (**LPL: Low-Power Listening**) and synchronize by broadcasting SYNC packets with their neighbouring nodes (cf. **Figure 9**).

S-MAC protocol can be called a ‘low power’ protocol because it eliminates a large part of unnecessary active listening time. However, the throughput is **reduced** because of these periodic sleeping intervals. Therefore, this protocol is **not adapted for time-critical** applications but works very well for data sensor periodic updates for example.

3.1.2. T-MAC

Timeout-MAC is quite like S-MAC protocol. The duty-cycle active/sleeping is not fixed anymore but depends on the traffic of the channel. Indeed, when it is in the listening mode, trace of the traffic is kept so the active time is **dynamically adjusted** when traffic is high or low (cf. **Figure 10**). It also adds **FRTS** (Future RTS) to prevent early sleep.

This system is more adapted for data with **limited size**. Nevertheless, nodes tend to enter in sleeping state too soon with larger packets, causing **data losses**.

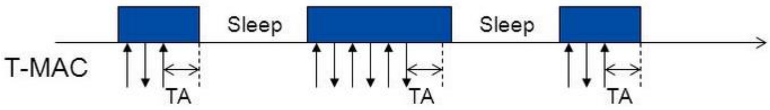

Figure 10: T-MAC behaviour

3.1.3. B-MAC

Berkley-MAC protocol has various objectives: low power operation, effective collision avoidance and efficient channel utilization (low AND high data rate). With this protocol, the transmitter sends a long **preamble** to overlap with the receivers sleeping cycle duration (cf. **Figure 11**).

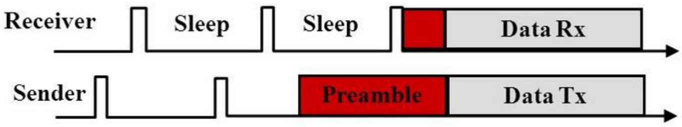

Figure 11: B-MAC behaviour

The checking interval is adjusted to at least equals the frame preamble size. This technology solves therefore problems of **idle listening** too but needs less synchronisation than S-MAC and is much more simple and scalable: the overall performance is better. However, the overhearing problem is not really solved compared to S-MAC.

3.1.4. Comparison table

Name of protocol	Scheme used	Energy Saving	Advantages	Disadvantages
S-MAC	Fixed duty cycle Virtual cluster CSMA	Power savings Over standard CSMA	Low energy consumption when traffic is low	Sleep latency, problem with broadcast
B-MAC	LPL, channel assessment, software interface	Better power Savings, latency and throughput than S-MAC	Low overhead when network is idle, simple to implement Consume less power	Overhearing, bad performance at heavy traffic. Long transmission latency
T-MAC	Adaptive duty cycle, overhearing, FRTS	Uses 20% of energy used in S-MAC	Adaptive active time	Early sleeping problem

3.2. Hybrid (CSMA & TDMA)

3.2.1. Z-MAC

Zebra-MAC is a hybrid solution based on **CSMA** and **TDMA**, in order to have a good network at low data load and high traffic. Indeed, slots are assigned over time for users like in TDMA protocol. Nevertheless, each node is owner of one or more slots, and can transmit during **any time slot** to maximize channel utilization, and not necessarily at the beginning of the slot. It always performs carrier-sensing operation (CSMA based-contention) and transmits the packet when the channel is clear. However, the user of that slot has a higher priority than other users who may use this particular slot at a given moment.

Therefore, by using this method of reassigning unused slots, the channel is **optimised**. On one side, when the **traffic is low** (meaning few users), ‘competition’ for unused slots looks more like CSMA style. On the other side, when a **lot of users** are sending data, the slots are naturally more restricted for their own user, which is assimilated as the TDMA behaviour.

This technique allows a very **efficient maximization** of the channel and resources sharing between users/nodes.

CONCLUSION

To conclude, it exists a lot of MAC protocols following **two main standards**, using various methods and concepts, and each one **adapted** for a specific utilization.

However, it seems that the perfect protocol does not exist yet, and that the development of the new technologies of the **Internet of Things** needs the creation of new protocols: that is the case for the new **Hybrid** Medium Access Protocols, which try to mix the best of the already known methods (often CSMA and TDMA concepts) to be able to save power consumption, and maximize the channel access and use, while keeping security solutions.

SOURCES

- A Survey : MAC Layer Protocol for Wireless Sensor Networks: https://pdfs.semanticscholar.org/cf88/f1f44a4a8508fafb73b49ccfaf7216ab40a4.pdf?fbclid=IwAR3QA0QbLdMW6cKL4ESHka1t7ROFIu8OWOLf1LM8wWz6ZG3EVYbjaVMyCtg
- Comparison of CSMA based and MAC protocols of Wireless Sensor Networks: https://arxiv.org/ftp/arxiv/papers/1205/1205.1701.pdf
- Performance Analysis of MAC Layer Protocols in Wireless Sensor Network: https://pdfs.semanticscholar.org/8307/ccb80c4fbcfe32393c9aab7902c142c82e5d.pdf
- Medium access control: https://en.wikipedia.org/wiki/Medium_access_control
- IEEE 802.15.4: https://fr.wikipedia.org/wiki/IEEE_802.15.4
- Medium Access Control Layer: https://www3.nd.edu/~cpoellab/teaching/cse40815/Chapter6.pdf?fbclid=IwAR3IG7WUMK6lb-2o8nD_U2POxiAPF8Opf0k8pEVvvlo3MncV24hWN4nIvYk
- Space-division multiple access: https://en.wikipedia.org/wiki/Space-division_multiple_access
- Carrier-sense multiple access with collision avoidance: https://en.wikipedia.org/wiki/Carrier-sense_multiple_access_with_collision_avoidance
- Contention-based protocol: https://en.wikipedia.org/wiki/Contention-based_protocol
- ALOHAnet: https://fr.wikipedia.org/wiki/ALOHAnet
- Aloha Protocols : http://www.myreadingroom.co.in/notes-and-studymaterial/68-dcn/819-aloha-protocols.html
- Performance of wireless LANs based on IEEE 802.11 MAC protocols: https://ieeexplore.ieee.org/document/1259194
- Zebra Media Access Control: https://en.wikipedia.org/wiki/Zebra_Media_Access_Control
- The difference between FDMA and TDMA: https://www.taitradioacademy.com/topic/the-difference-between-fdma-and-tdma-1/
- Frequency-division multiple access: https://en.wikipedia.org/wiki/Frequency-division_multiple_access
- Time-division multiple access: https://en.wikipedia.org/wiki/Time-division_multiple_access
- Code-division multiple access: https://en.wikipedia.org/wiki/Code-division_multiple_access#Example
- Multiple access techniques : http://www.invocom.et.put.poznan.pl/~invocom/C/P1-4/p1-4_en/p1-4_2_2.htm
- Fundamentals of Communications Access Technologies: FDMA, TDMA, CDMA, OFDMA, AND SDMA: https://www.electronicdesign.com/communications/fundamentals-communications-access-technologies-fdma-tdma-cdma-ofdma-and-sdma#%E2%80%9DSDMA%E2%80%9D