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Channel Access Methods and protocols used in Wireless Sensor Networks

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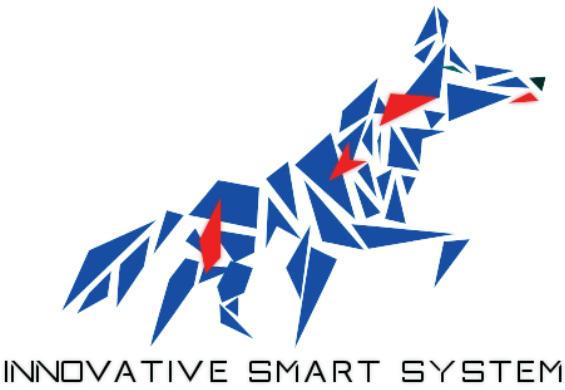

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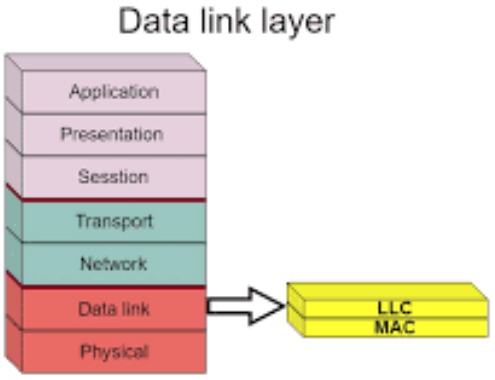
Introduction

The Medium Access Control (MAC) controls the hardware responsible for flow control and multiplexing for the transmission medium. In our study we will focus on the wireless transmission medium but it could also be wired or optical transmission medium. With another sublayer called Logical Link Control (LLC), they make up the Data Link layer of the OSI model.



In this report, we will firstly introduce various Channel Access Methods (FDMA - TDMA - CDMA - CSMA), explaining how they operate and what are their specifications. Then, we will present some of the existing MAC protocols and their characteristics. Finally, we will compare these protocols and conclude.

I. FDMA

Frequency-Division Multiple Access (FDMA) is a method that divides the channels by frequency. This is a contention-free method, which means that it avoids collision. Each node has an allocated frequency and bandwidth where it can communicate as long as it wants without clock synchronization, while it keeps emitting in its frequency range.

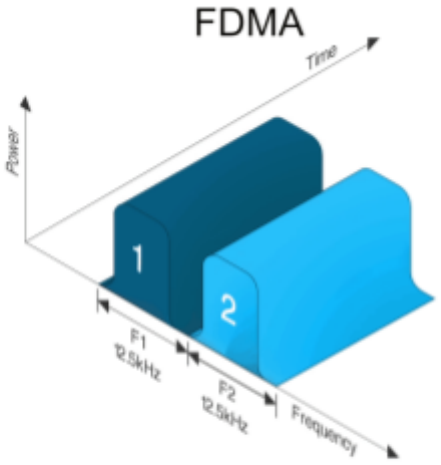


Figure 1 : FDMA

A small frequency gap is preserved between each allocated channel in order to limit interferences with the adjacent ones, this is called a guard band. Using this method, it is clear which user is emitting depending on the frequency. But the FDMA is a costly method because only one node can emit on a channel, and so the number of users is limited, and also because the transceiver must adapt to various frequencies. Thus, scalability is a problem for FDMA because it may not be adapted to a wireless sensor deployment due to the large amount of communicating nodes. This is why after being used in telephonics communication or even in aerospace telemetry, FDMA is now mainly replaced by TDMA.

Advantages of FDMA	Disadvantages of FDMA
• Channel bandwidth is relatively narrow (30kHz) • Simple algorithmically • Efficient when the number of user is reasonable and the traffic flow constant • No network timing • No restriction regarding the type of baseband or of modulation	• Loss of frequencies due to guard bands • Requires right filtering to avoid interferences • Maximum bite rate per channel is fixed

II. TDMA

TDMA stands for Time-Division Multiple Access, it is another channel access method that consists of dividing a single channel into time slots. This way, various nodes can emit on the same channel, their data are just slotted into one-byte-frames. As the previous one, this method is also contention-free and deterministic.

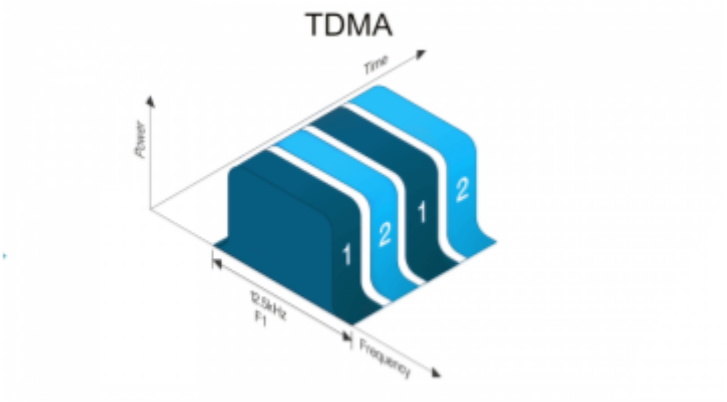


Figure 2 : TDMA

The Global System of Mobile Communication (GSM) is based on the TDMA method. In this case it divides a single channel of 200kHz then uses the time division technique in order to put eight mobile calls into this only channel. The multiplexing and demultiplexing is so fast that it is not even perceptible. The frame is transmitted at a 270-kbit/s rate using Gaussian minimum shift keying (GMSK), which is a form of frequency shift keying (FSK) modulation.

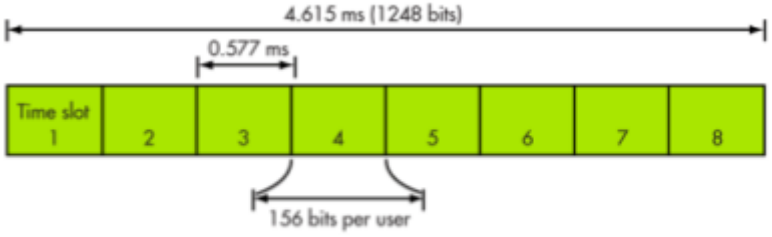


Figure 3 : Time division in TDMA

In WSN, algorithms for scheduling TDMA transmissions in multi-hop networks usually try to calculate the smallest conflict-free assignment of slots in which each link or node is activated at least once. In sensor networks however data is often transferred from the sensor nodes to a few central data collectors so there are enough independent point-to-point flows in the network to use this method. The scheduling problem is therefore to determine the smallest length conflict-free assignment of slots during which the packets generated at each node reach their destination.

Efficient scheduling of time slots in a TDMA is essential for low power wireless sensor networks, if not the synchronization may cost a lot of energy for sensor networks.

Advantages of TDMA	Disadvantages of TDMA
• Data rates of 64 kbps to 120 Mbps • Low energy needed if well designed • No interferences thanks to time separation	• Does need synchronization • Multipath distortion can be a problem and cause interferences • Possible loss of data if too much users are sending data on the same channel

III. CDMA

There is another digital channel access method called Code-Division Multiple Access (CDMA) that uses spread spectrum to control the medium access. CDMA algorithm digitizes an analog signal before spreading it out over a wider bandwidth with a lower power. As represented in the figure 4, the compressed signal is spread in an XOR circuit along with a chipping signal at a much higher frequency. The chipping signal is generated by a code and each node uses a different and unique code.

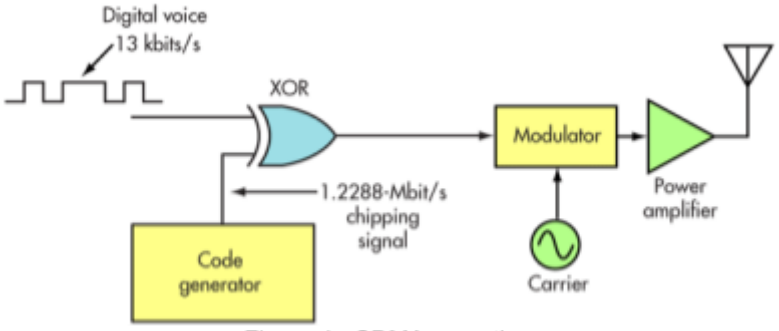


Figure 4 : CDMA operation

The resulting signal is spread on a much reduced bandwidth and appears like some noise. This way, the channel of 1,25 MHz can be shared by even more users than with TDMA. As the previous ones, this method is contention-free and deterministic.

The 3G cell phones use an extended version of CDMA called Wideband CDMA (W-CDMA) is the same method but using a 3.84-Mbit/s chipping signal and spreading the final signal on a 5 MHz channel in order to allow even more nodes to use the same channel.

Advantages of CDMA	Disadvantages of CDMA
● Large band capacity (many users can use the same channel, especially with W-CDMA) ● Easy addition of new nodes ● Secured ● Increases efficiency when serving more users ● Does not need synchronisation	● The quality decreases with the number of users ● Self jamming arises from the fact that the spreading sequences of different users are not exactly orthogonal. ● The near-far problem occurs if an undesired user has a high detected power as compared to the desired powers

IV. CSMA

Carrier Sense Multiple Access or CSMA is another Media Access Method which interrogates the receiver in order to make sure it is free to receive data. If so it initiates the data transfer otherwize it waits. However, many nodes can sense the medium at the same time so this method is contention based (does not avoid collisions).

However it exists CSMA-CD (CSMA-Collision Detection), that is used in Ethernet Local Area Networks (LAN). In this method, if a node wishes to send data, it first waits and listens, then sends its frames one by one making sure that it does not receive any alert from the collision detector. If this happens, it sleeps during a random time then keeps transmitting.

Another alternative is CSMA-CA (CSMA-Collision Avoidance) that uses a scheduling algorithm to determine the appropriate moment to transmit on the shared channel. CSMA-CD is more used for wired networks and CSMA-CA will be preferred for wireless networks.

Advantages of CSMA	Disadvantages of CSMA
● Low overhead ● utilizes all available bandwidth when possible	● Collision degrades QoS ● Priorities can not be assigned to certain nodes ● QoS decreases while adding users

V. MAC protocols

With the development of sensor networks and especially wireless sensor networks, some new protocols, more adapted to the sensor type of communication were developed starting from the Channel Access Methods we have seen previously. These are energy efficient MAC protocols. As an example, the LoRaWAN network which is deployed on the INSA's campus is a hybrid solution using ALOHA structure and TDMA.

a. S-MAC

Sensor-MAC (S-MAC) is a protocol based on periodic "sleep" or "listen" schedules which are handled locally by the sensor network. Nodes that are close to each other form a virtual cluster and they share the same schedule. After transmitting data, a node will fall in a sleep mode. That way, S-MAC is a low energy protocol because sleeping nodes are consuming less energy, this way it enables a large number of nodes on the network. Even if nodes periodically wake up to synchronize or to listen to transmission even if they do not have any data to send, S-MAC enables do remove unnecessary active listening time. S-MAC also saves energy by dividing large data into small packets before transmitting.

During the listening period, the node will firstly synchronize with the nodes of its cluster (TX SYNC), then it will send a transmission request using CSMA (TX RTS) and finally it receives the acknowledge (CTS), and so it can send data.

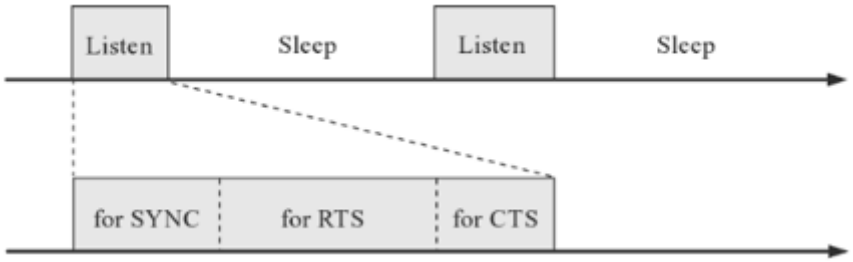


Figure 5 : S-MAC Sleep and Listen schedule

However, it can happen that two nodes are close but not part of the same cluster, they will wake up following the schedule of both clusters. Moreover, the sleep delay can result in latency which will be significant in case of multi-hop routing algorithms. Anyway this delay can be reduced by using another listening technique proposed by T-MAC.

In terms of security, S-MAC was not careful enough so a secured version SSMAC was created in order to ensure data integrity, identity authenticity and anti-deny of communicating packets by using NTRU encryption.

b. T-MAC

Time-out MAC (T-MAC) is almost the same protocol as S-MAC except that it introduces a dynamical end to the active period. Sleep and listen cycles have no more fixed size, messages are transmitted by brusts of variable length and nodes are sleeping between active brusts. Thanks to this adaptive duty cycle, T-MAC reduces the amount of energy wasted during the listening period.

c. Z-MAC

Zebra-MAC (Z-MAC) is a hybrid protocol that alternates between CSMA and TDMA. In low channel contention it uses CSMA but switches to TDMA for uper channel contention. Z-MAC enables nodes to communicate on channel on the one they are not assigned. This helps when some channels are overloaded and others are free. But in case of conflict, the nodes that own the channel always have a priority on the others. On one hand, when few nodes are transmitting, Z-MAC presents the advantages of CDMA because unused channels are borrowed by other nodes, on the other hand, when many nodes are activated, Z-MAC is using a TDMA-style protocol because nodes are sharing channels. This way, Z-MAC is saving energy and adapts to the level of contention of the network in order to provide the best quality of service. Z-MAC is commonly used and is implemented in TinyOS.

d. B-MAC

Berkeley-MAC (B-MAC) is much used in WSN and is part of the standard distribution of TinyOS. This protocol is very powerful and is able to save energy when the traffic is low. The protocol lets the sensor nodes sleep for quite a long period, waking them up at fixed intervals. During this active period, the nodes check the traffic and if a packet needs to be transmitted to its neighbor it first sends short words called ”preambles” during one sleeping cycle. That way, when waking up, the adjacent nodes will receive this alert and stay up, waiting for the data packet. After transfering the packet, the sender node goes back to sleep.

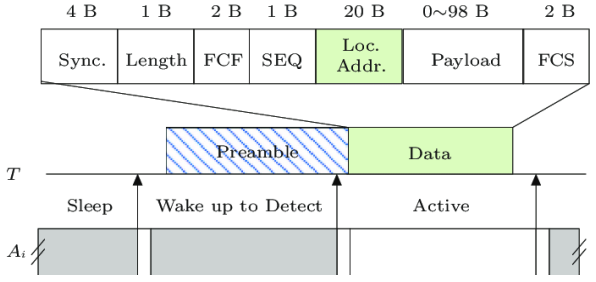


Figure 6 : B-MAC schedule

Conclusion

In the first part of this study, we have presented the existing Channel Access Methods. We have seen their advantages and drawbacks, and exposed the best conditions to use each one of them. In a second part, we focused on some of the protocols used by these methods. Because of the large number of existing protocols, we had to select some of them in order to make our study. To conclude this report here is a final comparison table of the presented protocols for WSN :

Protocol	Throughput	Energy conservation	Latency	Overhead	Scalability	Security
S-MAC	Low	Low	High	Low	Low	Low (Jamming Attack)
T-MAC	Low	High	Low	Moderate	Low	Low (Jamming Attack, Adaptive Timeout Attack)
Z-MAC	High	High	Low	Moderate	Low	Low
B-MAC	High	Moderate	Moderate	High	Low	Low (Jamming Attack, Broadcast Attack)

We can conclude on the fact that for all these protocols, the main improvements that still need to be done are on scalability and on security. But many new protocols are being developed and the new generation of networks like 5G will maybe help with these enhancements.

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