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# MAC protocols dedicated to WSN / IoT

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## Introduction:

In the last few years, we have been affected by a very dynamic development of techniques and technologies in the fields of electronics, mechanics, and wireless communication technologies. These innovations have led to the creation of small communicating objects equipped with sensors at an affordable cost... This technology is called Wireless Sensor Network, and we can define it as a network of many small computing nodes.

These sensor networks are composed of many nodes or sensors communicating with each other and deployed over a given area in order to measure and record the physical environment and to communicate together. It can measure a few physics data such as temperature, humidity etc… [4]
As these electronic devices are strongly minimized in size, this impacts their processing capacity (limited memory and processor resources) and even their autonomy if they are powered by a limited energy source. That is why, these nodes are organized in a network and collaborate in a coordinated way to overcome their limited capacity.

In order to be efficient, effective, and well-used, the hardware and software elements that make up the network must be optimal. Moreover, these sensors are powered with a battery and are energy self-sufficient devices over a long period of time. They must therefore consume very low levels of energy. However, radio communication requires a lot of energy, which is in contradiction with their need. It is also not that easy to change the battery of a sensor network compared to other wireless devices such as mobile phones or laptops.

Therefore, MAC layer protocols have been developed to overcome these problems. As mentioned before, radio communication is the principal source of energy consumption, and this is the layer MAC, which is in charge to optimize this, for example by optimizing losses due to collisions.

The main strategy for saving energy is to keep the radio device off as often as possible. This is done by alternating periods of activity (radio component on) and sleep (component off to save energy). There is a huge number of protocols, so in this report we will only list the most important ones. Some protocols are very similar and differ only in one aspect. We can classify them as shown in figure 1 in different categories. In this report, we will study Contention Based protocol, Scheduling based and Hybrid.

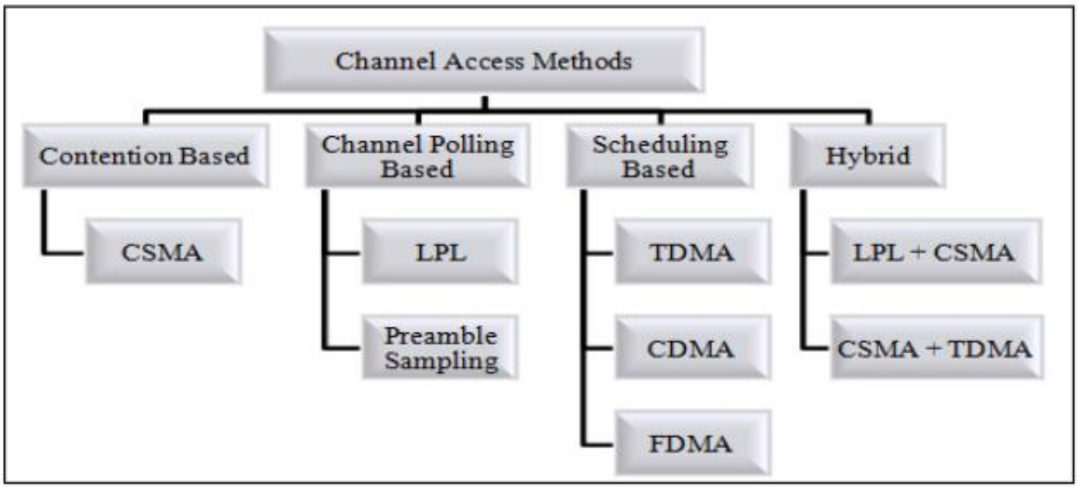


*Figure 1 Classification of MAC Protocol*

## I- Principal causes of Energy waste

There are several causes of wasted energy for WSNs, there are for example:

***COLLISION***
This phenomenon occurs when there are two nodes that wish to access the medium at the same time. This leads to a waste of energy as data is discarded and retransmitted.

***OVERHEARING***
It happens when a node receives a paquet whose destination is another node.

***OVER EMITTING***
This problem can occur when sending information to a node which is idle mode.

***IDLE LISTENING***
This happens when a node transmits a carrier without transmitting data, there may be other nodes waiting for that data and keeps listening to the medium.

## II- Contention based protocol

Contention-based protocols are one of the main kinds of protocols used in Wsn. When one node has a packet to send, it will have to struggle with other nodes to get permitted to use the medium. The selected node is in some way randomized. If the carrier signal is configured in idle mode, then the node will start its transmission, otherwise the node will defer the transmission for some time randomly. These protocols do not offer a bounded time delay as they do not guarantee access to the medium as the network load increases. On the other hand, the strong point of this type of protocol is certainly its scalability. [12][2]

This protocol is usually based on CSMA. It is a set of methods for accessing a medium. They check that the medium is available before starting to send a message.[1] They

also detect or avoid message collisions in transmissions. There are several types of CSMA, the most used are:
-CSMA/CD: Collision Detection
-CSMA/CA: Collision Avoidance

### a) Synchronous protocol

Synchronized protocols are used to coordinate sensor nodes between them to synchronize the phases of waking and sleeping sleep phases in order to exchange their data. Synchronization with adjacent nodes to ensure they wake up at the same time, thus saving energy

***S-MAC Protocol***

The S-MAC protocol uses the CSMA/CA medium access algorithm which avoids collision problems. This protocol is conceived to ensure a method of access to the medium in order to save energy. The principle is simple: the nodes go into sleep mode for a period and wake up to listen to the medium for another period. While the listening session allows sensor nodes to interact with other nodes to share some control packages, the sleep session turns off their radios in order to save energy.

The nodes exchange their listening period schedule between neighbours. Thus, each node knows the schedule of its neighbour and can know when it will wake up to communicate with another node. Multiple nodes can have the same time interval as a listening period. To keep the clocks synchronized, the sending nodes send a SYNC packet with a schedule defining listen and sleep periods, at the beginning of the listening period of their neighbours.[13] Once a node has received the schedule from its neighbour, if it wants to send a data it will first have to send an RTS packet and waits for neighbour's answer. If the neighbour is ready to receive it sends a CTS packet and the data transmission can start immediately. Nodes which are not participating in any data transmission change to sleep mode to save energy.

Here is a summary of the different characteristics of the S-mac protocol

| | |
|---|---|
| Clock Synchronisation | Yes, it contains clock synchronisation through a SYNC Packet |
| Localization capability | Standard CSMA protocol like S-MAC is not appropriate in localization systems |
| Nodes mobility | Not optimized for nodes mobility |

### b) Asynchronous protocol

***B-MAC***

B-MAC (Berkeley MAC) is one of the first approaches to reduce idle listening by introducing a period of inactivity at the physical layer. The idea is to penalize the transmitters by sending a long preamble to save the energy of the receivers. To be more precise it lets the sensor nodes to sleep (radio switched off) for relatively long periods of time and waking it up at regular intervals to check the ongoing communications. When a node wants to send a message to one of its neighbours, it starts sending short packets, also known as preambles, for the same period as the sleep period. In order to prevent collisions, the node sends a preamble that is the size of a full sleep period to make sure that the other nodes are listening to each other. For example, if the medium is being checked every 50 ms, the packet preamble must be at least 50 ms long before the receiver can detect the packet. So, if there is a preamble, the receiving node needs to stay awake until it receives the data. And if the channel is idle and the node has no data to communicate, the node returns to sleep. [6]

[4]

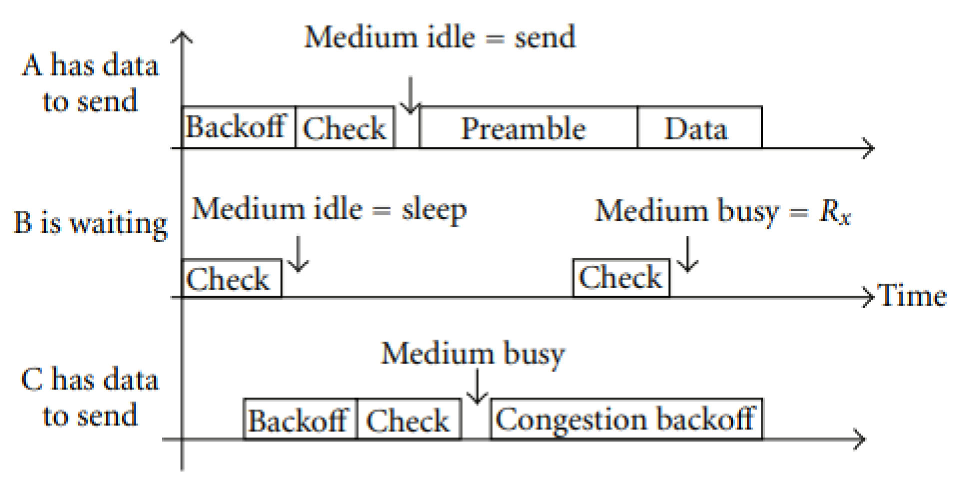


*Figure 2 B-MAC Communication*

An advantage of using B-MAC in WSNs is that it does not use RTS, CTS, ACK, or any other control frame by default, but they can be added. This means, there is no need for synchronization between nodes, and the nodes are mobile. The main disadvantage is that the preamble creates large overhearing of the nodes that are not concerned by the reception of data and a large amount of energy is wasted if you want to transmit often. [4]
Therefore, B-MAC is designed for low traffic, low power communication.

### MS-MAC Protocol

The two protocols seen previously are efficient in reducing energy consumption but have not been designed for node mobility. The objective of MS-MAC protocol is to keep the basic principle of the S-MAC protocol while improving it so that it can also manage node mobility.

Regarding mobility, the principle is that it will use any change in the received signal level as an indication of mobility if needed. Thus, this new S-MAC protocol can operate in a very energy-efficient way when the network is stationary and can also maintain a level of network performance when there are mobile nodes. [7]

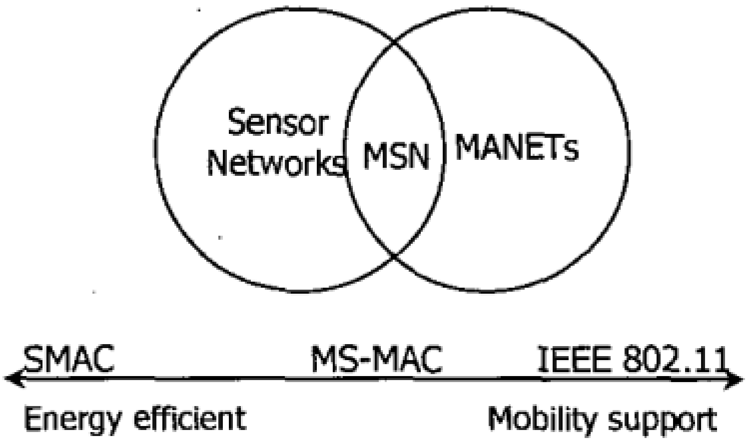


*Figure 3 MS-MAC and S-MAC comparison*
*[7]*

This protocol is therefore a good compromise between energy efficiency and mobility. The main problem with this protocol is that it is static in terms of the number of nodes. This protocol is not optimized in terms of energy when this number is dynamic, i.e. when it evolves over time. [8]

## III- Scheduled based protocol

These protocols are energy efficient because they avoid collisions and overhearing. They do not allow peer-to-peer communication and generally require nodes to form clusters. They are usually based on TDMA (Time Division Multiple Access) approaches. Scheduled based MAC protocol is divided into two categories. The first one is centralized TDMA protocols and the second is distributed TDMA protocols.[11]

The principle is simple, each node is allocated a time to speak, where the node can either speak or do nothing. Each node has its own time slot. In Scheduled based protocol, the time slot is divided between everyone, and everyone has the same clock. There is therefore a form of synchronization because not everyone speaks at the same time. But who manages this synchronization? There are two types of schedule base: Distributed and Centralized.

Centralized MAC protocols require a centralized controller to coordinate channel access among the various nodes and ensure collision-free operation. In this way, the wasted energy due to collisions can be eliminated. This type of protocol is preferred in WSNs because it is collision-free, and it can also turn off nodes which are in unallocated slots, saving the energy expenditure due to idle detection and listening. However, this type of protocol also has shortcomings. When using TDMA, the central controller consumes more energy than the other nodes, and the scheduling tends to be dynamic, making the mechanism more complex. In addition, this system requires clock synchronization between all nodes, which also dissipates additional energy. [5]

Distributed MAC protocols usually provide random multiple access to a wireless medium. With distributed MAC protocols, nodes operate in a decentralized manner. As a result, it is easy to implement and is more scalable. However, these protocols are not collision-free, and the "listen before talk" scheme requires that all nodes continue to detect the channel. This can cause significant energy waste due to collisions, idle listening, and overhearing. [5]

### *L-MAC - Distributed MAC Protocol*

L-MAC (Lightweight MAC) is a MAC protocol based on TDMA. The L-MAC protocol contains data transfer periods, which are divided into time slots. In contrast to traditional TDMA-based systems, the LMAC protocol's time slots are not distributed among the network nodes by a central manager. Indeed, this protocol works in a distributed way, it is an algorithm that will distribute the time among the nodes. Moreover, each node has its own time slot to transmit. This feature saves energy, because there is no risk of collisions and therefore retransmissions. [13]
The principle of this protocol is as follows: Firstly, it will start by setting up its network, i.e. during the first 5 periods, the nodes cannot send data, they each choose their own time slot (if two nodes have the same one, they randomly choose another time slot that is not taken).In addition, it is important to know that the L-MAC protocol frame is divided into two sections: a control section and the data section. The control message contains the destination of the data, the length of the data unit and information about the occupied time slots. [13]
If there is no transmission, the nodes automatically return to sleep mode and free up their time slots. And if there is a transmission, after receiving the control message, the nodes that are not the intended receiver go back to sleep. Both the receiving and sending nodes go back to sleep after receiving/sending the transmission. It is important to note that only one message can be sent in each time slot. [13]

**TDMA based protocols like L-MAC can provide good energy efficiency, but they are not scalable in node mobility.**

## IV- Hybrid protocol

Hybrid protocols are using both synchronized and preamble protocols at the same time. For example, the SCP protocol mix the different characteristics, it uses the B-MAC preamble and the synchronization of S-MAC.

### *Z-MAC*

Z-MAC (Zebra Mac) is an example of a hybrid protocol and combines CSMA and TDMA. The main feature of Z-MAC is its adaptability to the level of contention in the network, so that in the case of low contention it behaves like CSMA, and in the case of high contention it behaves like TDMA.

The Z-MAC protocol consists of a series of steps. First, there is neighbour discovery, talk time slot assignment, and global time synchronization. In the case of neighbour discovery and time slot assignment, the Z-MAC protocol first performs a neighbour discovery process to establish its one-hop neighbour list. A node periodically pings its one-hop neighbour nodes to build its one-hop neighbour list. As the process continues, each node can assemble its two-hop neighbour list using information obtained from pings of its one-hop neighbour nodes.[11]

Then Z-MAC implements a distributed random slot assignment algorithm to each node, using the DRAND function which is a distributed implementation of RAND. DRAND ensures that no multiple nodes in a two-hop neighbour list are scheduled for the same slot to avoid interference. The advantage of using DRAND is its scalability because it does not depend on the network size, but on the local neighbourhood size of each node.[9] Once the DRAND phase ends, each node transmits its frame size and slot number to its two-hop neighbourhood. As a result, a node knows the frame and slot information of its one-hop and two-hop neighbours. Upon completion, all nodes synchronize to slot 0 and are then ready to proceed to the data transmission phase

Once the slot allocation is done, each node must decide how long it can use its slot to communicate. When a node has data to transmit, it checks to see if it owns the current time slot. If it is, it can send, otherwise it waits for the priority node to send and waits for the channel to become available. [11]

Z-MAC is very robust to slot assignment failures, synchronization errors, and dynamic channel conditions. However, it needs global time synchronization during the installation phase, which causes energy consumption in the sensor nodes.

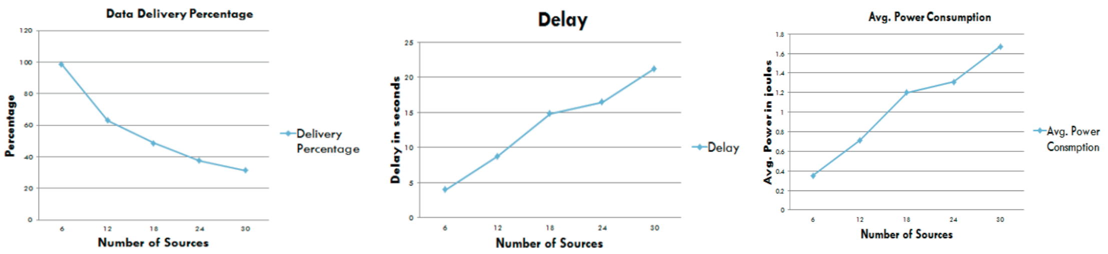


*Figure 4 (a) Data delivery percentage ;(b) Packet average delay of scenario; (c) total energy consumed*

[11]

A study was done to test the limitations of the Z-MAC protocol depending on the data load. Three parameters were considered: Power consumption, time to receive a packet, and data delivery rate. These results clearly show the huge performance degradation of the Z-MAC protocol under high data load. We can see in the graph (a) that the delivery rate has decreased by 30%, which means that a lot of data has been lost. The consumption and the delay follow the same trend, there is a strong increase when the number of nodes grows. Both factors, the low delivery percentage, and the high-power consumption, make the current Z-MAC protocol very unfavourable for high data throughput in a WSN.[11]

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