**University of Toulouse**
**Institut National des Sciences Appliquées de Toulouse**
135 Avenue de Rangueil, 31400 Toulouse, France

**DEPARTMENT OF**
**COMPUTER AND ELECTRICAL ENGINEERING**

A REPORT

ON

# MAC Protocols for Wireless Sensor Network

*SUBMITTED BY*

**Thomas ZENNARO**

*UNDER THE GUIDANCE OF*

**Prof. Daniela DRAGOMIRESCU**

**(Academic Year: 2020-2021)**

December 19, 2020

# Contents

# 1 Introduction

Wireless sensor networks require different performance criteria than those found in conventional networks. Indeed, it is necessary that these networks can self-manage, be self-sufficient in energy and must be easy to configure. In order for the sensor life to be as long as possible, protocols at the MAC layer level are needed to meet this requirement. In addition, other parameters are to be taken into account: type of channel used, security... The most important features that MAC protocols have to achieve are the following: collision avoidance, energy efficiency, scalability and adaptability. Through this report I present some families and examples of MAC protocols as well as their characteristics.

# 2 Synchronous contention based MAC protocols

For these protocols, synchronization mechanisms are provided between each WSN node. In addition, nodes may strategically decide to be active or sleep mode depending on the state of network occupancy [?]. Nodes have common active/sleep periods. When they are active, they send data, and where they are sleeping they can reduce the consumption by saving energy [?]. They use CSMA as channel method and also IEEE 802.11 DCF.

## 2.1 Some protocols

### 2.1.1 SMAC

The Sensor MAC (S-MAC) protocol is one of the first protocols proposed for wireless sensor networks.

This protocol use the **CSMA/CA channel** method in order to avoid collisions and the problem of hidden stations. We can solve this problem with the RTS/CTS mechanism. So it is a real advantage in order to locate some near stations.

It is based on the **synchronization** of the wake-up and sleep periods of the sensors, with the implementation of a duty cycle to identify the modes of activity and sleep [1]. Indeed, nodes listen to the channel for a set time. They expect a SYNC package. If no packet is received, the node selects a sequence and transmits it in a SYNC packet to inform neighbouring nodes. This package contains the waking/waking times of the node. However, if the node receives a SYNC packet from another node during its activity period, it must follow its neighbor's schedule and re-transmit it in turn into a SYNC packet. We can therefore have a node with 2 sequences, which means that it must be active at the time of the two associated sending frames [2]. A drawback that we can notice is that the awake period generates a delay. We can have latency particularly for multi-hop networks

### 2.1.2 TMAC

For the Timeout-MAC (T-MAC) protocol, a periodic alarm clock is dedicated for each node of the network so that they can communicate with its neighbors.

The **CSMA channel** method is also used. Communication between nodes is always done through the RTS/CTS mechanism (to avoid possible problems of hidden frame and station collisions).

Regarding the **synchronization** process, this is based on the same principle discussed in Part S-MAC above. The nodes transmit their SYNC from time to time. Nodes must not transmit data only at the beginning of their period of activity. All nodes that have received the given schedule must wake up, which requires an activity duration that must take into account the waiting (or delay) of the SYNC packet or the reception of an RTS (Request To Send) signal [2][3]. This time must consider:

1. the length of the contention period ($T_c$)
2. the length of a RTS packet ($T_{RTS}$)
3. the waiting time ($T_W$)

Finally, $T = T_c + T_{RTS} + T_W$. The figure 1 shows data transmission comparison between S-MAC and T-MAC (In the next figure, $T$ has the same meaning that $TA$).

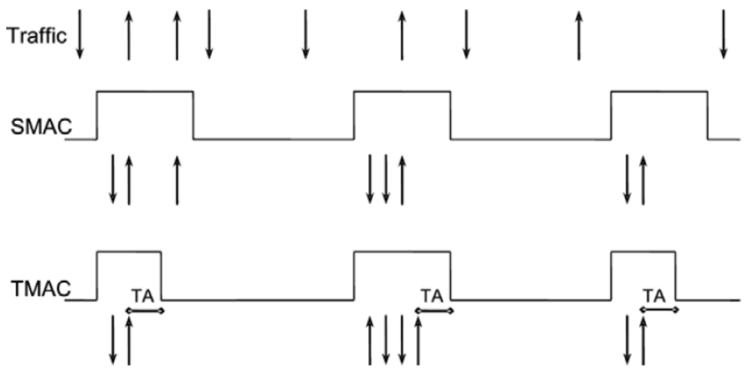


Figure 1: Data transmission with S-MAC and T-MAC protocols [4]

TMAC can save more energy than SMAC, having some flexibility for active time (so may reduce it).

If a communication needs to go through neighboring intermediate nodes before arriving at the packet's receiving node, RTS/CTS problems may occur. Indeed, if an RTS is lost, the recipient may go to sleep before receiving the packet. To do this, there is the FRTS mechanism: we specify that the node must not sleep before receiving the packet.

## 2.2 Power consumption

There is no doubt that Wireless Sensors Networks have haevy energy constrains. The figure 2 shows the energy consumption depending on the arrival of data packets over inter-arrival time intervals (throughput). We can notice that, the CSMA contention-based protocol is the furthest from the ideal curve (in blue on the figure) that one would like to obtain. The T-MAC 1% protocol seems to be the one that comes close to the desired curve but the difference in energy consumed is still important for example for a 1,000 second packet inter-arrival time (over $10^2$ µW) [4].

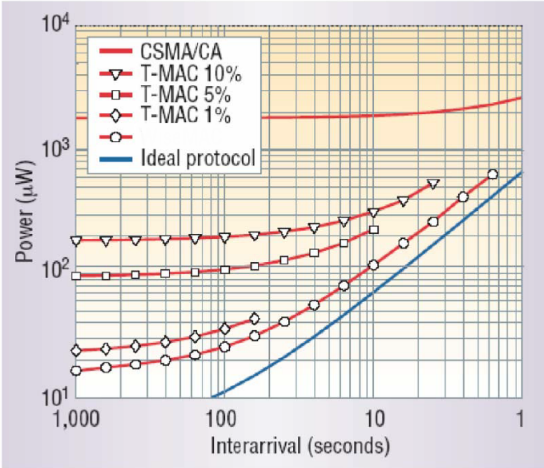


Figure 2: Energy consumption of some contention based protocols depending on inter-arrival packets [4]

Then, to reduce energy losses due to collision, CSMA is suitable for this purpose through the exchange of RTS/CTS signals to verify that data can actually be sent. Therefore we avoid sending data for nothing and save energy.

### 2.3 Role for the main protocols of this category

There are many MAC protocols which are interesting features and can be adapted for different use cases. The figure 3 sums up these protocols.

| Function | Protocols |
|---|---|
| Canonical Solution | SMAC [52] |
| Increasing Flexibility | TMAC [54], E2MAC [55], SWMAC [56] |
| Minimizing Sleep Delay | Adaptive Listening [57], nanoMAC [58], DSMAC [59], FPA [60], DMAC [61], Q-MAC [62] |
| Handling Mobility | MSMAC [63] |
| Minimizing Schedules | GSA [60] |
| Statistical Approaches | RL-MAC [66], U-MAC [67] |
| Using Wake-Up Radio | RMAC [68], E2RMAC [69] |

Figure 3: Some different MAC protocols and their main feature [4]

## 3 Preamble MAC protocols

For these protocols, there is no synchronization process. Therefore, nodes define their waking time independently of neighbouring nodes, but with similar waking periods. Nodes have moments when they are active to see the state of the communication channel, else they are sleeping. One of the advantages is that the transmitter and the receiver are not synchronized with each other when the preamble is sent. We're reducing active listening effects a little bit. An example of preamble sampling is given in Figure 5. These protocols use also LPL (Low Power Listening) method. However, there is a downside to energy consumption because if a receiver has to wait to listen to a whole preamble but it does not concern it in the end, the energy of a node is consumed unnecessarily [1]. One idea would be to be able, for example, to encapsulate the address of the receiver in the preamble.

## 3.1 Some protocols

All protocols in this category will use **TDMA** methods for channel access.

### 3.1.1 B-MAC

The Berkeley-MAC (B-MAC) uses **LPL** and preamble sampling methods in order to have communication with low power [5]. At some moment, a node can wake up in order to perform a check of the current status of the transmission channel by using the CCA (Clear Channel Assessment), used to have an overview of the channel status [1]. With that, we have a controlled use of the channel and consequently the probability of collision is reduced.
On the other side, when a receiver detect a preamble, it has to stay active during the preamble acquisition because the data generally follows this preamble.

Regarding the **energy consumption**, One can have a significant energy consumption due to the emission of the preamble (of more or less length) friends also because of the fact of remaining active during the duration of reception of the data (coming therefore after the preamble).
To best define the channel monitoring intervals, it is necessary to know the traffic flow generated by the issuing entity/application. B-MAC use LPL in order to dynamically configure the check interval for a node. For instance, there exists the EA-ALPL (Energy-Aware Adaptive Low Power Listening), which is interesting to the configuration of the listening mode [4].

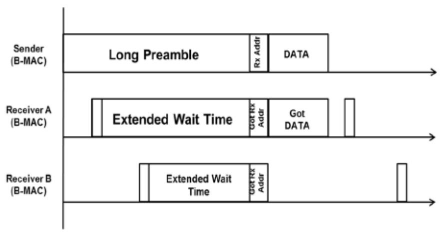


Figure 4: Example of B-MAC temporal communication [1]

### 3.1.2 Wise-MAC

The Wise-MAC protocol is used to reduce the **energy consumption** of B-MAC due to the variable diffusion of preambles (before the transmission of useful data). For this, it allows the use of much shorter preambles. the idea is that a node has access to the awaking time of the neighboring nodes, so the length of the preamble can be adjusted accordingly. We therefore save emission energy.
It is possible to create a table in which we store the awaking times of each neighbouring node. We can recover this time thanks to an acknowledgement frame during a data reception for example.
The example of implementation of the Wise-MAC protocol is shown in figure 5.

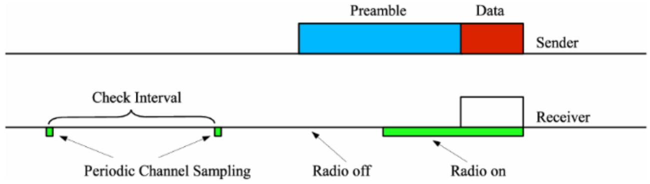


Figure 5: Example of a data transmission/reception with a preamble sampling [4]

There is no doubt that with this technique, the overhearing issue is reduced when the data traffic is heavy.
Nonetheless, this protocol is not suitable when the topology of the network is going to frequently change. It can cause latency and can increase the length of preamble. Indeed, nodes can have difficulties when communicating because they may have to update the awake time of the neighbour nodes.

# 4 Scheduled based MAC protocols

For this category of protocols, methods using can combine both **TDMA** and **FDMA**. Indeed, it is possible to have several nodes that use different time intervals and channels at a different frequency. In addition, TDMA will bring interesting benefits regarding the reduction of frame collisions in the network, the minimization of active listening [4]. As a result, communications traffic is relatively well managed.

## 4.1 Some protocols

### 4.1.1 TSMP

The Time Synchronized Mesh Protocol (TSMP) is based on **TDMA** methods. As its name suggests, this protocol requires a synchronization mechanism.
Communication is defined by time interval. Therefore, nodes will tend to consume less energy because they are only active during the moments of communication.
In addition, with the use of FDMA methods, different frequency intervals are used, and therefore interference can be avoided and thus the reliability of the frame exchanges on the channel can be ensured.
In order to facilitate the **synchronization** of frame exchanges, a marking mechanism must be put in place, thus monitoring. Nodes based on TMSP will have to exchange the minimum amount of information possible in order to better synchronize the activity periods. To do this, a node must know the activity period of the neighbouring nodes. This is important in order to improve **power consumption** [4]. Therefore, it is then possible to set up a planning table in which the majority of the network nodes are filled in as well as the time and frequency intervals. This will make it possible to solve possible synchronization problems since we will ensure that a node does not receive two transmissions at the same time for example.

### 4.1.2 EMACS

The Energy Efficient-MAC (EMACS) is a MAC protocol based on **TDMA** [3]. For this protocol, three kind of nodes are defined [4]:

1. active node
2. passive node
3. dormant node

They have different roles. Indeed, dormant nodes are useful in order to save energy. On the contrary, both active and passive nodes are useful for network communication. But passive nodes can only communicate with active nodes.
The particularity is that the time is divided into frames and each frame is divided into slots [3]. We find three parts in a such slot:

1. Communication Request (CR): in this part, an active node wait a possible communication exchange from a passive node;
2. Traffic Control (TC): in this part, an active node transmits useful information (synchronization, scheduled times...) to passive nodes
3. data

So **localization** mechanisms are put in place. Indeed with this process describe above, we can draw a network topology.
Furthermore, a passive node has to be active only during exchanges with an active node (transmission for the CR part and reception for the TC part). So the rest of the time they can be in sleep mode.
It is difficult for actives nodes to save energy, they almost don't have sleep periods.

## 4.2 Some drawbacks

These kinds of mechanisms can generate some complexity in the network. In addition, it may be difficult to effectively maintain the network and synchronization operations and thus avoid frame collisions. There may be a scalability problem [4].
If we want to broadcast, it is not optimal in terms of the energy consumption of the network since the transmitter must send the same frame to all the receptor nodes concerned, so it carries out the transmission operation several times in a row [4].

# 5 Hybrid MAC protocols

The protocols are going to combine characteristics on the other categories. Indeed, we can merge or alternate network techniques, depending of the topology and the state of the network. For example, we can have TDMA-FMDA combination. It will depend on MAC performances that we want for a network. If we need to minimize energy consumption at node level, it will be interesting to choose collision-free MAC protocols [3], if we want real time process, contention-based MAC protocols are not suitable...

## 5.1 Some protocols

### 5.1.1 HyMAC

This hybrid protocol combines **TDMA** and **FDMA** representations [1]. The particularity is that a frame will be divided into two specific periods:

1. scheduled slots
2. contention slots

These two periods will depend on the transmission time of the frame in question. Furthermore contention slots will be interesting for broadcast communication.
For HyMAC, synchronization is not a necessarily a requirement. To build network knowledge, each node will resort to the sending of a simple packet ("HELLO" packet [1]) in order to inform the neighboring nodes and especially the central station of the network. Indeed, the latter will be able to build a schedule table and then assign to each node a schedule period (by sending a "SCHEDULE" packet [1]).
So the HyMAC protocol will be suitable for real time WSN, it can limit frames collisions.

## 5.2 Other hybrid MAC protocols

To go further, there are other protocols with have specific features that can be interesting for differents WSN.

| Function | Protocols |
|---|---|
| Flexible MAC Structure | IEEE 802.15.4 [5] |
| CSMA inside TDMA Slot | ZMAC [91] |
| Minimizing Convergecast Effect | Funneling MAC [93], MH-MAC [79] |
| Slotted and Sampling | SCP [74] |
| Receiver Based Scheduling | Crankshaft [95] |

Figure 6: Overview of other hybrid MAC protocols [4]

# 6 MAC protocols comparison

The following table sum up the different characteristics of each MAC protocols family that we compared between them. We emphasis their channel access type, their synchronization, their potential localization capability, if they do something for saving energy and minimize power consumption.

| MAC protocols categories | | | | |
|---|---|---|---|---|
| **feature** | **Synchronous** MAC protocols | **Preamble sampling** MAC protocols | **Scheduled based** MAC protocols | **Hybrid** MAC protocols |
| Channel access | CSMA/CA | TDMA | TDMA, FDMA | TDMA, FMDA, and/or CSMA |
| Synchronization | Yes | No | Yes | It depends |
| Localization capability | Not optimal | optimal | yes | it depends |
| Energy/power consumption | variable (decreasing collisions.. | it depends (length of the preamble...) | variable (defining active/sleep periods...) | variable (depending of the hybridization) |

# 7 Conclusion

To conclude, works on MAC protocols for WSN needs has been numerous. There are a multitude of MAC protocols for each family. Each category of protocols will have advantages over the others (prioritize the synchronization of communications, focus on energy saving...). In addition, other factors will be important, namely the topology, the network and its maintainability, or the sector of activity in which the WSN will be implemented.
This state of the art allowed me to have a global overview of MAC protocols for sensor networks, directly related to the IoT.

# List of Figures

# References

[1] A. Kumar, M. Zhao, K. Wong, Y. L. Guan, and P. H. J. Chong, "A comprehensive study of iot and wsn mac protocols: Research issues, challenges and opportunities," *IEEE Access*, vol. 6, p. 76228–76262, 2018.

[2] J. Vaudour and V. Gauthier, "Comparaison de différentes couches mac pour les réseaux de capteurs," p. 8.

[3] R. Lin, Z. Wang, and Y. Sun, "Energy efficient medium access control protocols for wireless sensor networks and its state-of-art," in *2004 IEEE International Symposium on Industrial Electronics*, vol. 1, May 2004, p. 669–674 vol. 1.

[4] A. Bachir, M. Dohler, T. Watteyne, and K. Leung, "Mac essentials for wireless sensor networks," vol. 12, p. 222–248, Jun 2010.

[5] A. S. Althobaiti and M. Abdullah, "Medium access control protocols for wireless sensor networks classifications and cross-layering," *Procedia Computer Science*, vol. 65, p. 4–16, Jan 2015. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1877050915029002