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MAC Layers for Wireless Sensor Networks

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1 – Introduction

Nowadays, the technology is taking an increasing part in our everyday life. With the emergence of the *Internet Of Things (IoT)*, we have an increasing number of sensors that appears in our environment. The idea is to collect data to analyse them to act as a smart system. Thus, everything around us is becoming smart, from our watch to our home and city.

In this context, standards have to evolved in order to follow the need of the new technologies. So, to allow sensors to communicate and to send data, new protocols have been created.

This document presents different types of MAC layers and analyses some protocols develop for wireless sensor networks.

2 – The MAC Layer

The MAC layer can be defined as a sublayer of the data link layer of the OSI model, which also includes the *Logical Link Control (LLC)* layer, in charge of the control of the frame synchronization, flow control and error checking.

As we can guess thanks to its name, the *Medium Access Control* layer controls how a device on the network gains access to the data and how it can transmit them.

If we consider a network composed by wireless sensors, the medium to be considered is the air. So, every device of the network will send its messages by broadcasting them over the air. These messages will then be received be all the devices nearby them, depending of the range of the network used.

Thus, the MAC layer need to handle different functionalities to allow data to transfer from one device to another by addressing the frames, by sending them on the medium on the right moment, by receiving and transferring them to upper layers.

<u>We can resume the tasks of the MAC layer in 5 points:</u>

- Frame delimiting and recognition.
- Addressing of the frame: who is the emitter/receptor?
- Check whether the received messages are for the device or not.
- Error detection by generally using frame check sequences.
- Arbitration of access to one channel shared by all nodes.

Moreover, the MAC protocol used had to be scalable according to the network size and adjustable in case of adding or removing nodes.

Finally, as the MAC layer controls the radio transmission, which is one of the part of a device that consumes the most, it has to be energy efficient in order to allow a long battery life.

3 – Channel Access Methods

As we can see on the picture below, there are different types of medium access methods which have been developed to answer to the challenges of the wireless sensor networks. The main difference between these four categories is based on how they allow nodes to access to the medium.

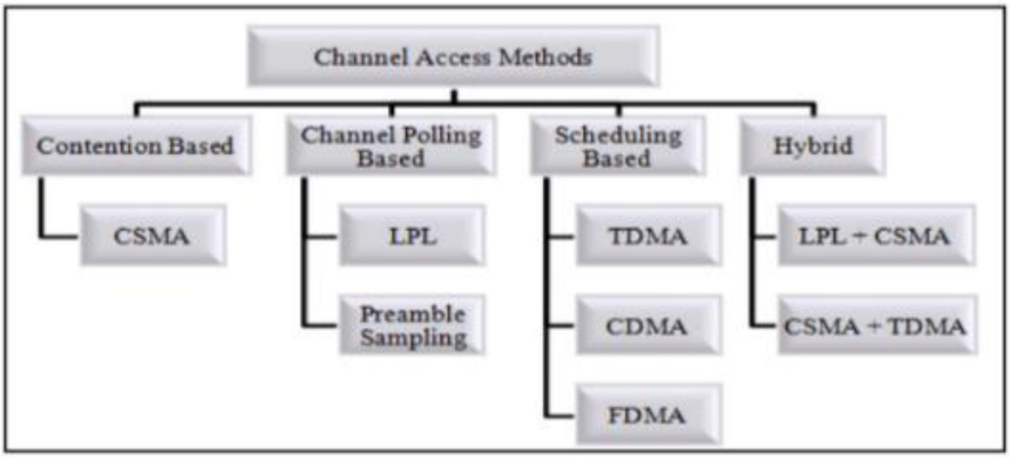

Figure 1 - Channel Access Methods for Wireless Sensor Networks

3.1 – Contention Based

In this protocol, devices compete to the channel. The nodes listened to the medium before sending messages. When this one is free, they began the transmission. We can find in this family the *Carrier Sense Multiple Access with Collision Detect / Collision Avoidance (CSMA/CA)* protocol. This protocol can be described like this:

When a device A want to send a message to another device B, it first listens to the network. If this one is busy, it delayed it transmission. Otherwise, if the medium is free, the device A send a *Ready To Send (RTS)* message to device B to tell him he wants to send him a message, and add some information like bit rate and message length. If device B is ready, he sends back a *Clear To Send (CTS)* message to A. Then, the transmission of data can begin. When all the data are transmitted, device B sends a *ACK* message to notify device A that the message has been successfully received.

In wire networks like Ethernet, another CSMA protocol exists: the CSMA/CD (Collision Detection). This one is impossible to apply in wireless network because is this protocol each device listens to the medium and is able to know if another device is "speaking" or not. In a wireless network, this is impossible because if we take for example two devices A & B, talking to another device B, so A and B can be too far from each other to know that there are both talking to C at the same time.

3.2 – Scheduling Based

Devices using this protocol are schedule on partitioned channels in time, frequency or code, in order to avoid collision. We have three different techniques:

- **Time Division Multiple Access (TDMA):** TDMA used a temporal multiplexing to control the access to the medium. Each node uses the communication channel at the same frequency but only during a definite time called *slot*. Thus, as each node

is the only one to talk on the medium during its slot, it can use all the bandwidth allows by the network characteristics, to transmit its message.
Regarding the power consumption, this method is very efficient because each device knows already when it will be able to send message so it avoids *overhearing* and *idle-listening* to know when the medium is free. The rest of the time, the device can be in *sleep mode* to save energy. However, one of the node has to periodically send synchronization frame to be sure that all nodes are well synchronize.
Finally, TDMA is not appropriate to networks with a lot of nodes because the more you add device, the smaller will be the slots.

- **Code Division Multiple Access (CDMA):** CDMA used a multiplexing based on a random allocation of code. It uses a spread spectrum technique. Each node can access the medium at the same time but every transmission own a single code as an identifier.
This method imply that each device knows the code of the devices that they want to communicate with.

- **Frequency Division Multiple Access (FDMA):** FDMA used a frequency multiplexing. This means that we allocate to each device of the network, a part of the total bandwidth of the network. Thus, all nodes can send data at the same time.
Regarding the power consumption, this method avoids the synchronization of all devices, like in TDMA. The collisions are avoided because each device uses its own frequency band. However, because the bandwidth of each device is reduced, the transmission time will be bigger than in TDMA and CDMA, which increase the power consumption.

So, these three protocols are energy efficient thanks to their capacity to avoid collisions, overhearing and idle-listening. The problem is that the division in time or frequency doesn't allow us to deploy a network with a big quantity of devices without affecting the performances of the network.

3.3 – Channel Polling Based

In this category, we have the *Low Power Listening (LPL)* and the *Preamble Sampling*. Both of these methods are based on the same technique. When a device want to send a message to another device, it first sends a preamble on the network. When the receiver detects energy on the channel, made by the preamble message, it wakes up from its sleep-mode and wait to receive data (or until some timeout).

This method increase the energy consumption of the sender because it need to send extra bytes as preamble, but it is more efficient for the receiver which can stay in sleep-mode until it receives data.

3.4 – Hybrid

These protocols are called "hybrid" because they combined two different protocols that we saw previously in order to compensate the weak points of each protocols take individually.

For instance, we can take the example of CSMA/CA + TDMA which aims to access both contention period (CSMA/CA) and contention free period (TDMA). In order to check whether a channel is free for transmission CSMA/CA required a carrier sensing. For transmitting the packets during contention period the node competes with other nodes and sends the packets to other device using the CSMA/CA mechanism. But during the contention-free period, the node can transmit packets in a collision free manner using TDMA slots without any carrier sensing.

4 - Protocols developed for wireless sensor networks

This section describes some protocols developed for wireless sensor networks and based on the channel access methods describes before.

4.1 – S-MAC

S-MAC, for *Sensor MAC*, is based on *CSMA/CA* channel access method. So, it guarantees avoidance on collision and reduces power consumption.

To work, this protocol place a node in a listening state. If the medium is clear, this node is going to send a SYNC packet with a schedule defining listen and sleep periods. All the nodes that received this SYNC packet will adopt this schedule. During a listening period, if a node has a packet to send, it will send a RTS packet and wait to receive a CTS packet from the receiver, as it is described in the *CSMA/CA* protocol. All the other nodes, which are not involved in this exchange enter in the sleep mode, while the two nodes which communicate exchange data and ACK packets.

<u>Advantage:</u>

- Decrease the energy consumption thanks to the sleeping mode.

<u>Disadvantages:</u>

- Increase latency as the sender has to wait that the receiver wakes up before sending packets.
- Sleep and listen periods are predefined and constant, which decrease the efficiency of the algorithm under variable traffic load.

The following picture shows a S-MAC exchange example. Nodes A, B, and C are within range of each other. D is within range of C and A transmits to B:

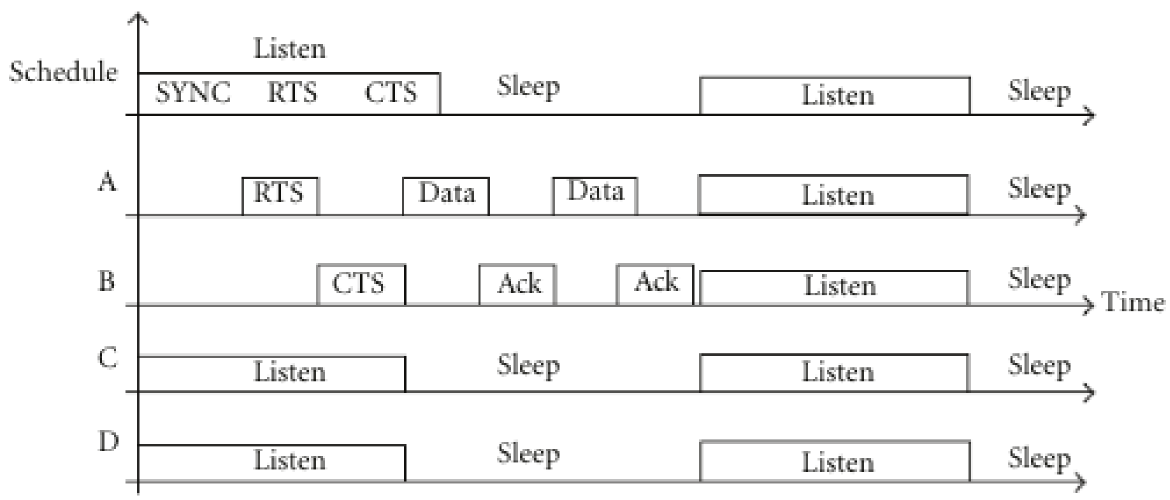

Figure 2 - S-MAC example

4.2 – T-MAC

T-MAC, for *Time-out MAC*, is a more evolved version of *S-MAC*. It is based on the same algorithm but it reduces the *idle listening* timeout, during which the nodes listen to the medium for a message. While *S-MAC* synchronizes each node on the listening period of its neighborhood, *T-MAC* obliges its nodes to enter in a sleep mode after a certain time without receiving anything.

<u>Advantage:</u>

- Decrease even more the power consumption.

<u>Disadvantage:</u>

- Increase even more the latency.

4.3 – B-MAC

B-MAC, for *Berkeley MAC*, is based on the *LPL* channel access method. In this protocol, when a node wants to send a packet, it waits during a backoff time before checking the channel. If the channel is clear, the node transmits its packets, otherwise it begins a second backoff time. If the channel is idle and the node has no data to transmit, the node returns to sleep. Each node must check the channel periodically according to *LPL* algorithm.

<u>Advantages:</u>

- Idle Listening is reduced to a minimum.
- No synchronization.
- Simple to implement.

<u>Disadvantage:</u>

- Preambles create large overhead.

The figure below shows an example of the *B-MAC* protocol:

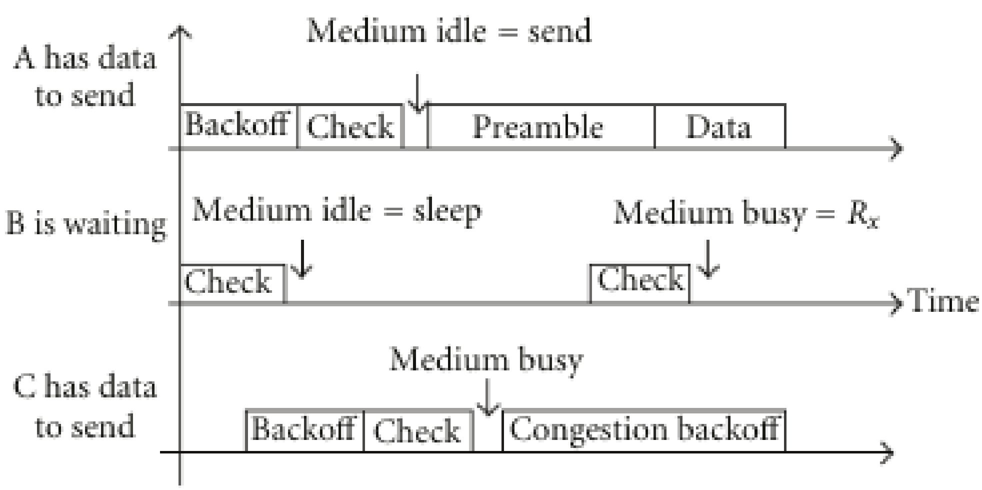

Figure 3 - B-MAC protocol example

5 – Energy Consumption

As we saw on the previous part, power consumption, at the MAC level, depends on the protocol used. Depending on the time passed in sleep-mode, listening-mode, transmission, if it's needed to send preamble or not, the consumption may vary a lot. As power consumption represents a big deal in sensor networks, some protocols try to reduce drastically the power consumption but it affects the performances such as latency.

Instead of calculating the energy consumption for each protocol existing for the MAC layer, we are going to study what are the sources of energy waste in these protocols.

- **Idle listening:** most of the time, the devices keep their radio in a ready to receive mode, because they don't know when they will receive a message. Because this mode keep the radio on, it consumes a lot.

- **Collisions:** when collision occurred between packets, this means that they have to be sent again. It results in a waste of energy to retransmit and receive other packets.

- **Overhearing:** it happens when a device has to process messages that are not addressed to it. This occurs under heavy traffic situations and when messages are broadcasting.

- **Over-emitting:** it occurs when a device try to send a message to a receiver which is not ready to receive packets (if it is still in sleep mode for example).

- **Complexity:** more the algorithm is complex, more the device will have to work to apply it and less it will remain in sleep-mode. But of course, a simple algorithm won't be able to provide complex functions. So, a compromise has to be found between performance and energy consumption.

7 – Conclusion

We saw in this document that there is a lot of MAC protocols develop to allow sensors to communicate in a wireless networks. Depending on the context, we have to choose the one that match the most our need in terms of performance and energy consumption.

The chart is a comparison between the 3 protocols presented in part 4.

Protocol	Type	Technique used	Scheme used	Energy saving	Latency	Energy efficiency	Throughput	Advantage	Disadvantage
SMAC	Contention based	Adaptive listening	Fixed duty cycle, virtual cluster, CSMA	Power savings over standard CSMA/CAMAC	Low	Medium	Low	Low energy consumption when traffic is low	Sleep latency, problem with Broadcast
TMAC	Contention based	Future request to send	Adaptive duty cycle, overhearing, FRTS	Uses 20% of energy used in S-MAC	High	High under variable traffic	Low	Adaptive active time	Early sleeping Problem
BMAC	Contention based	Low power listening	LPL, channel assessment software interface	Better power savings, latency, and throughput than S-MAC	High	Low	Medium	Low overhead when network is idle, simple to implement, Consumes less Power	Overhearing, bad Performance at heavy traffic. Long transmission latency

Figure 4 - Comparison between S-MAC, T-MAC and B-MAC protocols

Sources

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[3] : Ilker Demirkol, Cem Ersoy, and Fatih Alagöz – *"MAC protocols for wireless sensor networks: A survey"* - IEEE Communications Magazine (2006).

[4] : Ahlam Saud and Manal Abdullah – *"Medium Access Control Protocols for Wireless Sensor Networks Classifications and Cross-Layering"* - International Conference on Communication, Management and Information Technology (2015).