MAC LAYER FOR WIRELESS SENSOR NETWORKS

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1. Introduction

A Wireless Sensor Network can be defined as a network composed of multiple nodes (wireless sensors) that are able to retrieve physical/environmental conditions (like sound, pressure, temperature, etc) and exchange this data between themselves.

To provide an efficient and reliable services many factors should be considered. In this in this WSN context, one of the most relevant factors to be taken into consideration is the: Media Access Control (MAC) layer.

The MAC layer is responsible for channel access policies, scheduling, buffer management and error control. So as a part of the Communications for Connected Objects course, we're going to describe multiple MAC layer solutions used in the field of Wireless Sensor Networks.

2. A brief reminder about the MAC layer

In the OSI (Open Systems Interconnection) model, the MAC layer is a sublayer inside the data link layer, which is responsible for controlling the access to the medium of communication.

The MAC layer is situated between the Network layer (at a higher level) and the Physical layer (at a lower level). It provides an abstraction of the physical layer to the LLC and upper layers of the OSI network. And it acts on encapsulating frames received from the upper layer so they can be transmitted to the real physical medium.

3. MAC protocols strategies

One of the main problems the MAC layer has to address in this context of WSN is how to deal with multiple nodes trying to communicate at the same time in this shared medium. So these protocols propose multiple access resolutions to deal with this multiple access traffic by establishing channel access methods for transmission.

The MAC protocols for WSN can be divided into 2 categories:

- **Schedule based:** these types of protocols use synchronisation and they need a previous knowledge of the network topology to perform the schedule.
  Advantages: no collision, predictable delay
  Disadvantages: not good for large networks, not scalable

- **Contention based:** these types of protocols don't need synchronisation neither a knowledge of the network topology. The nodes compete to have access to the channel and one node is chosen at a time.

  Advantages: scalable
  Disadvantages: less performance when the traffic is too high.

Now we'll present the different MAC protocols that fit into these 2 categories.

Time Division Multiple Access (TDMA): this channel access strategy allows different nodes to access the same transmission channel by dividing the frequency band into time slots. So each node uses a time slot to transmit its data successively as it's possible to see from the picture below.

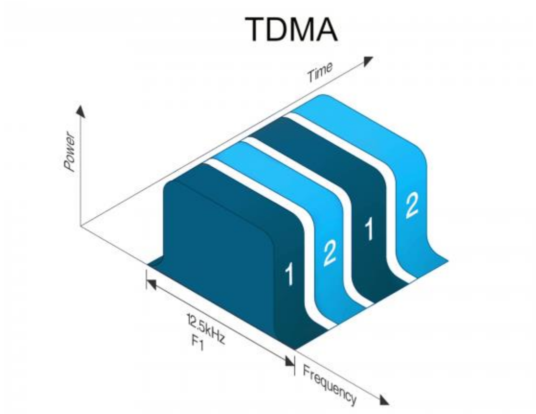

Figure 1: TDMA time division of the frequency.

Frequency Division Multiple Access (FDMA): in this strategy the bandwidth is divided in different frequencies that the nodes can access all at a same time. This way the receiver can "hear" a specific sender by selecting the corresponding frequency.

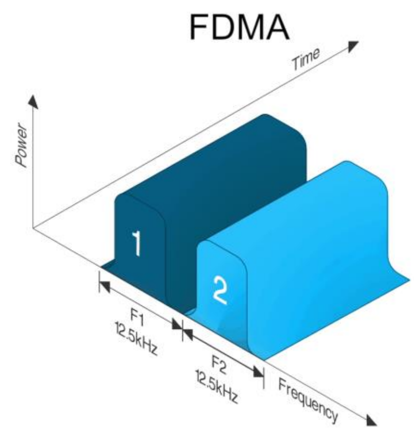

Figure 1: FDMA frequency division.

Code Division Multiple Access (CDMA): in this case numerous signals (each receives an attributed "code") occupy a single transmission channel, optimizing the use of available bandwidth. The receiver can "hear" a specific sender based on that code.

Carrier Sense Multiple Access (CSMA): in this strategy, before transmitting, the sender node "listens" to the channel to check if another transmission is taking place or not. The sender node transmits its data only if there is no transmission happening. That's why this approach is also referred as "listen before talk".
There are 2 variations of this principle:

1. **CSMA Collision Detection (CSMA/CD):** this is a refinement of the CSMA principle explained above. It uses a "listen-while-talking" approach, so when a sender is transmitting data and detects a collision it:
    - Stops transmitting
    - Sends a "jamming" signal to inform all the other nodes about the collision

- Waits a random delay before retaking the transmission

2. **CSMA Collision Avoidance (CSMA/CA):** in this case there is an orchestrator that decides when data can be transmitted. So, to send data, the sender node has to ask permission to the orchestrator and wait for an authorization response.

ALOHA: in this strategy the sender nodes are given access randomly to a central computer via common frequency band f1 and they computer centre broadcasts the received signal via f2.
There are 2 variations of ALOHA:

1. **Pure ALOHA:** in this case, whenever a node sends data, it waits from an acknowledgement from the receiver. If it doesn't receive an acknowledgement, it assumes that a collision occurred and the frame was destroyed. So the sender waits a random delay until resending the data.

2. **Slotted ALOHA:** in this case, the time is divided in slots. So the nodes are only allowed to send one frame at a time and at the beginning of the slot. So if a node, isn't able to place the frame onto the channel at the beginning of the slot it misses the time slot then it has to wait until the beginning of the next time slot.

4. MAC layers for Wireless Sensor Networks

In this part we'll present some of the MAC layers used in WSN:

Sensor MAC (S-MAC): in this strategy nodes adopt a sleep cycle accordingly to a schedule. So nodes are put into sleep mode and listening mode periodically.
This is a solution that provides a **higher latency** and a **lower throughput** but it can be **more efficient in terms of energy**.
This protocol works in a synchronised way using a time division-like (**TDMA**) strategy. So when a timer expires, the node is woken up and go into listening mode to decide where they transmit data or go back to sleep. To transmit data, S-MAC uses a **CSMA/CA** strategy asking for permission to send data and waiting for an authorisation response.
One advantageous characteristic of this protocol is the division of long messages making the network more adaptable to a variation in topology. Whatsoever, network latency increases as nodes alternate between active and sleep mode.

- *Advantages:* More efficient in terms of energy, protocol is simple to implement, long messages can be efficiently transferred using message passing technique.
- *Disadvantages:* RTS/CTS are not used due to broadcasting which may result in collision, since sleep and listen periods are fixed variable traffic load makes the algorithm efficient, it can happen overhearing or idle listening because of the scheduled time.

Time out MAC (T-MAC): this strategy uses sleep/active duty cycles such as S-MAC but in a more **dynamic** way, they don't have a fixed schedule. During an active period of a node (sending/receiving data), if no action is detected during a certain period of time, a timeout is activated and the node goes to sleep mode. So this is also an example of a mix between **TDMA** and **CSMA/CA**.

This type of transmission is based on Request-To-Send (RTS), Clear-To-Send (CTS) and acknowledgment (ACK) packets, making this protocol more reliable and reducing collision rates of paquets.
An advantage is that, differently from S-MAC (where listen periods are fixed, and sometimes nodes with less data will waste energy by idle listening), energy consumption and idle listening are reduced due to the dynamism. Whatsoever, it cannot support high data rate applications and has a lower sensitivity to latency.

- *Avantages:* TMAC can easily handle variable load due to dynamic sleeping schedule.
- *Disadvantages:* TMAC's major disadvantage is early sleeping problem in which nodes may sleep as per their activation time and data may get lost especially for long messages.

Berkeley MAC (B-MAC): it is a versatile low power MAC that uses CSMA protocol and a preamble technique. The node is woken up every check interval. If there's an activity during this period, it stays on for receiving data but if there is no data the time out forces the node to sleep. It is mostly used for low power and low traffic WSNs. Uses **CSMA/CA**.
This protocol B-MAC has a very low power consumption, a very high throughput and it supports reconfiguration to improve latency and network performance. However, B-MAC has a few drawbacks, such as it has no ability to handle multi-packet environments.

Traffic adapted MAC (TRAMA): this strategy uses random access periods to get and signalize information from two hop neighbors through a Neighbour Protocol (NP), a schedule exchange protocol (SEP) which allows to exchange two-hop neighbour information and schedules and adaptive election algorithm (AEA). This makes it a more complex algorithm but really efficient and adaptive. According to its current traffic and propagated to the neighbours, it decides whether to transmit or not. So it adopts a time-division strategy, **TDMA**.

5. A brief comparison

Here we make a brief comparison of the protocols seen above, we'll compare them considering some essential characteristics that one should take into consideration when designing MAC protocols:

- *Throughput:* measures efficiency. In the case of a wireless link, it may be related to capacity.
- *Scalability:* Scalability refers to the protocol's adaptation to an increase in network size, traffic, overhead and load.
- *Latency:* Latency can be referred as the time delay between message transmission and message arrival. Latency is an important constraint for time-critical applications.

Protocol	Throughput	Energy consumption	Latency	Scalability
S-MAC	Low	Low	High	High
T-MAC	Low	High	High	Low
B-MAC	High	Moderate	Moderate	Low
TRAMA	High	Low	High	High

6. Conclusion

During this research we could see there are many MAC layer protocols proposed for sensor networks, some of them I chose not to get into details because they were similar to the other ones already cited. There is not one protocol which is accepted as a standard and one of the reasons behind this is because the MAC protocol is really application-specific. Depending on the specifications required by the network we should choose the MAC layer protocol that fits the best.

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