MAC protocols for WSN

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1 Introduction

Wireless sensor networks (WSN) are a sector in full expansion and differ from traditional connected machines in many ways. The applications are many and the sensors and their network must be adapted to it. In most of the cases, the sensors have to be autonomous (i.e include discovery protocols, monitoring applications, etc.), to communicate in areas where the usual networks are not implemented and to have a very low power consumption.

Because the sensor networks will be more and more deployed and dense in the next decades, it is absolutely necessary to implement reliable medium-access control (MAC) protocols with an efficient management of collisions, low access delays, that will be able to face power constraints.

MAC layer is traditionally responsible for channel access policies, scheduling, buffer management, error control, and management of collisions, but the challenge is here to keep this functionalities with an high energy efficiency. Various MAC protocols exists or have been proposed for WSN, with different goals and features, depending on the application and the context. This document aims to present these different possibilities, and how each of them differ from the others.

2 Powering challenge for WSN MAC layers

Traditional MAC layer features imply an important power consumption, which is a real issue for WSN. The most consuming functionalities are[1] :

- **Idle listening** [the fact that the node is permanently in active listening even if it does not receive anything]
- **Overhearing** [listening to and receiving packets that belong to another node].
- **Packets control** [with the multiplication of packets sent for a single message (RTS, CTC and ACK)]
- **Management of collisions**

These issues must be nuanced because of the specific features of WSN.

For example, a large part of them are barely bidirectional. Their architecture implies a communication from the nodes to gateways and only a few communications need the devices to be listening, which reduce the problem of power consumption for idle listening and overhearing. However, the issue is still important for bidirectional networks.

In a same way, some of the WSN do not need an high quality of service (QoS) which makes packets control and management of collisions less necessary.

Therefore, the choice of the MAC protocol must be done with a perfect understanding of the needs and the features of the WSN we want to deploy and its application.

3 Various MAC protocols proposed for WSN

Two MAC families exist[1] :

- **Schedule based protocol** [usually implementing TDMA, this type needs a previous knowledge the topology of the WSN, which allows no collision, throughput optimisation and predictable delays, but implies a reasonable size and a stable topology for the network with precise synchronisation of all the nodes]
- **Contention based protocol** [usually implementing CSMA or ALOHA, this type is based on a concurrence between the nodes to access the channel, which does not need any previous knowledge of the network, fits for any size and allows a good scalability, but implies less performance for high load traffic, smaller data packet size and high power consumption for packets control and management of collisions]

3.1 Sensor-MAC

3.1.1 What is Sensor-MAC, pros and cons

Sensor MAC (S-MAC) is based on a local management of synchronization and periodic sleep–listen schedules[1] [2]. It uses a short and periodic synchronization packet (SYNC) broadcasted to immediate neighbors to exchange and plan sleep and wake periods. Each group of nodes will follow the same schedule to communicate.

The period for each node to send a SYNC packet is called the synchronization period, as seen in figure 3.1.1. This figure shows the alternating between wake and sleep periods.

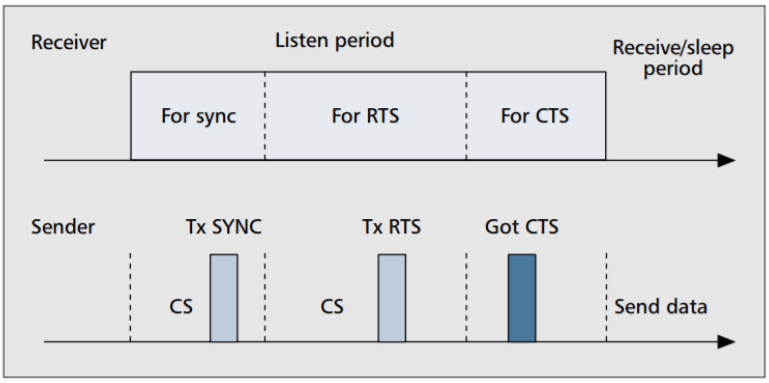

Figure 3.1.1 : schema of a sample sender-receiver communication[2]

This synchronized duty cycle and schedule periodic wake and sleep allows a reduction of wasted energy by minimizing idle listening but the weakness of the system appears when a node has to follow two different schedules (because it is a part of two different groups) with radically desynchronized periods, which leads to an high increase in power consumption and minimise the interest of this medium-access technique. The wake and sleep periods, because they are predefined and constant, may also be relevant if the traffic load gets variable.

3.1.2 QoS in S-MAC

The channel is sensed before emitting to avoid collisions (CS in the figure 3.1.1) and RTS/CTS mechanism is used for unicast (not for broadcast packets, whom risk of collision is increased). Moreover, long messages are sent in one burst of various frames to minimize communication overhead.

Therefore, QoS for S-MAC protocol is quite important, but because of the wake-and-sleep scheduling, packets may be delayed during the transmission. This is called sleep delay, and will get worse for multihop routing. A technique is proposed to face this issue, by waking up the nodes that overhears a neighbor's transmission at the end in this transmission, by it implies an increase in power consumption.

3.1.3 Improvements: T-MAC, DSMAC and S-MACL

Because the static sleep–listen periods of S-MAC result in high latency and lower throughput, some improvements have been proposed in new generations of Sensor-MAC called Timeout-MAC, Dynamic Sensor-MAC[2] and S-MACL[1].

Three protocols based on Sensor-MAC have been proposed. The first one, T-MAC, aims to enhance the poor results under variable traffic loads, while the second one aims to decrease the latency of S-MAC and the third one aims to solve the border node problem.

1. Timeout-MAC (T-MAC) aims to improve the weakness of S-MAC under variable traffic loads. The listen period is not constant anymore and ends there is no activity for a time threshold called TA.
2. Dynamic Sensor-MAC (DSMAC) aims to decrease the latency and may be particularly interesting for delay-sensitive applications by adding a dynamic duty-cycle feature to S-MAC. All nodes begin with the same duty cycle and they communicate their one-hop latency value (time between the queuing of a packet and its transmission) within the SYNC period, which allow the emitter node to adapt its sleep time to the average one-hop latency. If this value leads the nodes to short their sleep time, the duty cycle is doubled so that they wake up earlier and communicate faster but still fit with the duty cycle of nodes that keep the initial duty cycle. This additional duty cycle improve the latency observed with DSMAC compared to S-MAC and decrease the power consumption per packet.

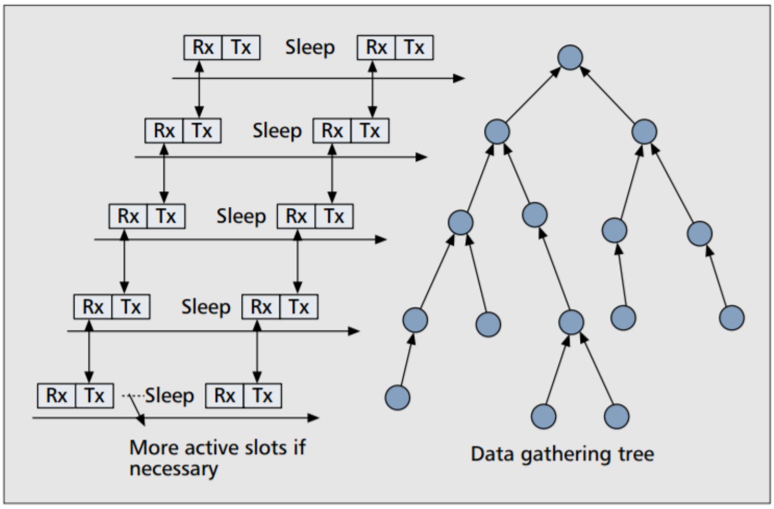

Figure 3.1.3.1: schema of DSMAC duty cycle doubling[2]

3. S-MACL (global sleeping schedule) aims to solve the S-MAC border node problem (the fact that some nodes have to follow multiple sleep schedules causing them to wake up more often than the other nodes[7]) by giving each of them an unique ID in the entire network. The nodes are divided in two parts : synchronizers and followers[1].
Three situations may happen:

   - **If a node do not receive an SYNC packet** after the first listening period, the network impose another node's schedule to it. This reference is the synchronizer, whereas the following node is the follower.
   - **If the node receives one with the same schedule** as the current one (the one of the neighbors it knows), nothing changes from S-MAC.
   - **If a node receives one with a schedule different than the neighbours**, it compares the ID of the node it is currently following with the new one it just received and follows the higher ID. In the contrary, if the new one has a lower ID, the node will announce its own schedule in the next listening time.

   S-MACL is proposed to eliminate the need for some nodes to stay awake longer than the other nodes and this study[7] shows that it reduces the energy consumption and increases the life time of wireless sensor networks significantly.

3.2 WiseMAC

3.2.1 What is WiseMAC, pros and cons

WiseMAC has been proposed by Amre El-Hoiydi and Jean-Dominique Decotignie as a medium access control protocol designed for wireless sensor networks. It is based on non-persistent CSMA (Carrier Sense Multiple Access) and all sensor nodes are defined to have one single-channel[2] with preamble sampling (see part 3.3.1) to decrease idle listening and medium overloading. In fact, it exploits the knowledge of the sampling schedule of one's direct neighbors to use a wake-up preamble of minimized size[3], which allows a drastic reduction of the energy wasted due to overhearing.

Because it does not require any set-up signalling or network-wide synchronization, the power consumption is decreased for both emission and reception and it fits for any size, topology and traffic conditions.

3.2.2 What is the preamble sampling technique ?

In this technique, a preamble packet is sent to the receiver node to alert it before sending a data packet and all nodes sample the medium regularly with different periods for each[2]. This system allows the node to stay listening after waking up if the medium is busy not to overload the network. In the other hand, this mechanism leads to over-emitting that increases with the length of the preamble. Moreover, the receiver node may not be ready to listen, even after receiving the preamble, because of interferences for example, and the emitter node has no way to know it.

3.2.3 QoS in WiseMAC

Each node is aware of the sleep schedules of its neighbors and keeps a table of them, which will be updated during every data exchange. Based on the knowledge of the sleep schedules of the neighbors, the transmission will begin so that the destination node's sampling time corresponds to the middle of the sender's preamble, which allow the receiver to be ready to receive the data packet. The disadvantage of this technique appears when we want to broadcast a message, because we need to buffer the data packets for neighbors in sleep mode and deliver them at different moment depending on the wake up period of each neighbor, which implies a increase of power consumption.

Because it uses non-persistent CSMA, WiseMAC is also sensitive to the problem of the hidden terminal, which may leads to collisions if a node starts to transmit the preamble to second node that is already receiving a third node's transmission whom sender is invisible for the first node.

3.3 DMAC

3.3.1 What is DMAC, pros and cons

DMAC aims to achieve very low latency for convergecast communications[1], but still be energy efficient. It implements a slotted Aloha algorithm where each node may have to receive a packet from a node "below" it and transmit it to a node "above", such as shown in the figure 3.3.1.

[1]Type of communication in which at the beginning, each agent has some initial piece of information, and information of all agents has to be collected by some agent that will be collected by another agent and so on[ref4], which makes it the opposite of broadcast and the most frequent communication pattern observed within sensor networks[4]

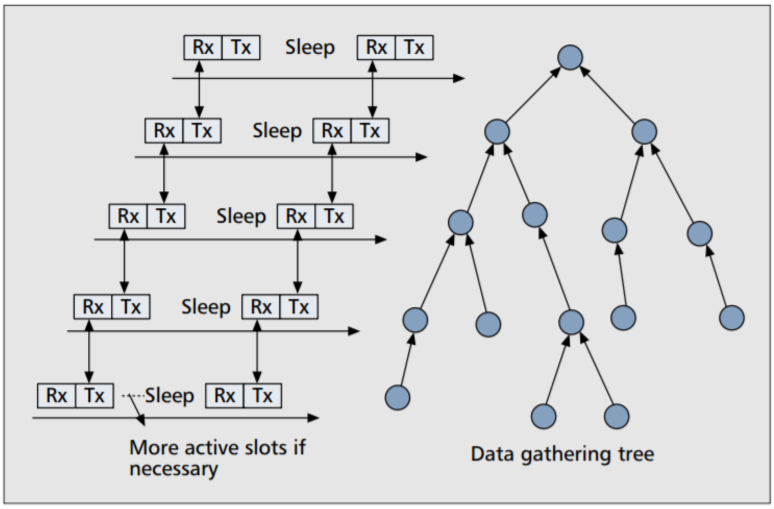

Figure 3.1.1 : Schema of a data gathering tree and its implementation in time slots for DMAC[2]

3.3.2 QoS

Because it assigns slots that are timely successive in order, DMAC limits collisions and achieve low latency for the transmission within the entire data transmission path compared to usual wake-and-sleep-periods techniques. However, since it does not implement any collision avoidance method, collisions may occur between two nodes sending at the same time to the same node, which means that these two nodes have the same level in the gathering tree.

Therefore, DMAC may be a good solution for WSN that need a very low latency but tolerates loss of data due to collisions.

3.4 Pattern MAC

3.4.1 What is Pattern MAC ?

Pattern MAC (P-MAC) uses a dynamic sleep and wake up schedule according to the node traffic and its neighbours[1]. It proposes to solve the problem of the fixed duty cycles that are implemented in most of MAC protocols for WSN such as S-MAC. Indeed, a fixed duty cycle causes a degradation of the throughput under heavy traffic whereas energy may be consumed "for nothing" under light loads. P-MAC adapts the duration of these duty cycles to the node's own traffic and its neighbors' one.

3.4.2 QoS in P-MAC

This study [8] shows that P-MAC achieve more power savings under light loads, and higher throughput under heavier traffic loads than S-MAC.

3.5 B-MAC

3.5.1 What is B-MAC ?

B-MAC (versatile low power MAC) is the default MAC protocol for TinyOS[1]. It uses the CSMA protocol and provides a flexible interface to obtain ultra low power operation, effective collision avoidance, and high channel utilization[6]. To achieve this goal, B-MAC uses preamble sampling such as WiseMAC and sends a preamble packet that is slightly longer than the sleep period of the receiver node to make sure it will be ready to receive the data packets.

3.5.2 QoS in B-MAC

This protocol improve considerably the probability to receive the data packets, but imposes overhearing (all the neighbors will listen to the preamble) and excess latency (due to the duration of this preamble). This study[6] shows that using B-MAC brings better packet delivery rates, throughput, latency, and energy consumption than S-MAC. Another protocol is based on this technique and aims to decrease the latency due to preamble packets, as explain is the next part.

3.6 X-MAC

3.6.1 What is X-MAC ?

Various MAC protocols for WSN uses preamble packets and preamble sampling to improve the probability of receiving. Therefore, these long preamble introduce latency and make the non-targeted listening, which increase power consumption for nothing[5].

X-MAC (short preamble MAC) aims to solve the B-MAC problems sending the ID of the receiver node within the preamble so that the other nodes can go back to sleep because they are not concerned[2]. Moreover, X-MAC proposes to put short pauses between preamble packets so that the receiver node can acknowledge this preamble when it wakes up and allow the emitter node to stop sending preamble and start sending data packets.

3.6.2 QoS in X-MAC

Tests show that using X-MAC reduces power consumption at both the emitter and receiver and reduces per-hop latency[5]. It consist in a improvement of MAC protocols based on preamble such as B-MAC and WiseMAC.

3.7 TSMP

3.7.1 What is TSMP ?

TSMP (Time Synchronized Mesh Protocol) uses TDMA and frequency division multiplexing FDMA over 16 frequency channels[9] divided into time slots so more than one node can access the medium at the same slot but with different frequency. It was first designed for industrial automation. Usually time slots have a duration of 10 ms, which is long enough for any single transaction[9]. It uses a graph as a routing structure that forms directed end-to-end connections among devices[9].

3.7.2 QoS in TSMP

This MAC protocol enables secure communications in a managed wireless mesh network with low energy consumption[9]. But since it uses a complex routing structure, TSMP shows an high complexity and a low scalability and requires a precise synchronization, as well as a huge need of memory compared to other methods[1].

3.8 Traffic-Adaptive MAC

3.8.1 What is Traffic-Adaptive MAC ?

Traffic adaptive MAC (TRAMA) aims to increase the utilization of classical TDMA in an energy-efficient manner[2] by using single time slotted channel access divided into random and scheduled access period[1]. Random access periods are used for signalling, synchronizing and updating two hops neighbour information while scheduled access periods (using the receiver node's schedule) are dedicated to data transmission. A system of election of the node whom schedule will be followed is deployed to avoid any collision and eliminate the hidden-terminal issue.

The emitter node' s MAC layer has to calculate the transmission duration needed (noted Schedule Interval) and the number of slots for which it will have the highest priority among two-hop neighbors within the period [t, t+ Schedule Interval][2]. Then, it can announce this number of needed slots and the targeted nodes (using a bitmap) within a schedule packet, as well as the slots that it will not use but for which it would get the highest priority, so that these slots can be reused by its neighbors. These priorities are calculated with an hash function depending on the node and the slot we are considering.

3.8.2 QoS in TRAMA

Thanks to the announcement of the slots that will be used for a transmission and the targeted receivers, TRAMA enables an optimization of the use of each slot as well as power savings for nodes that are not concerned by the transmission. Tests showed[2] that TRAMA allows a higher percentage of sleep time and less collision compared to CSMA-based protocols such as WiseMAC or B-MAC. Therefore, it implies that all nodes that are not transmitting during the random-access period must be listening for schedule exchanges.

3.9 Comparison Table

	Time sync. needed	**Com. pattern support**	**Type**	**Scalability**
S-MAC[2]	No	All	CSMA	Good
WiseMAC	No	All	np-CSMA	Good
P-MAC	Yes	All	CSMA	Medium
B-MAC	No	All	CSMA	Good
X-MAC	No	All	CSMA	Good
TSMP	Yes	All	TDMA/FDMA	Low
TRAMA	Yes	All	TDMA/CSMA	Good
DMAC	Yes	Convergecast	TDMA/Slotted Aloha	Weak

Figure 3.5.1: Comparison table between MAC protocols for WSN[2]

[2]S-MAC in the table stands for S-MAC, T-MAC, and DSMAC

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