MAC protocols dedicated to WSN – Wireless Sensor Network

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Introduction

WSNs – Wireless Sensor Networks are networks that can be formed by a large number of devices or nodes with small computing capabilities and measuring physical characteristics of the environment and communicate the information wirelessly with using radio links.

WSNs has a wide range of potential applications such as human health care, home automation and environmental.

The most important characteristic of WSN is their strong dependence on application which involves different requirement and constraints in memory and processing power. Additionally, nodes are most likely powered with batteries which makes energy consumption a major issue, and it is often very difficult, if not impossible to recharge or replace dead batteries, these limitations directly affect the network lifetime. Therefore, the design of the Medium Access Control (MAC) layer is very important because it controls the transceiver which is the most power consuming component of the node sensor, thus MAC layer has to save the maximum of power to extend the lifetime of the network, while preserving the performance of the node.

Many MAC protocols were been developed and the widely used in modern cellular communication systems like Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA) and Code Divion Multiple Access (CDMA). There principal is to avoid the interference by synchronizing the node on multiple channels that are divided by time, frequency and orthogonal codes. Other Category of MAC protocols are based on contention, like Carrier Sense Multiple Access (CSMA), the node listen to the channel before transmitting, if the channel is busy, the node delays the access and retries latter.

1. WSN general energy issues

The main issue of WSNs is to keep the lifetime of the network as long as possible, for that, The MAC layer has to focus on reducing the energy consumption of the sensor nodes. The different sources of energy waste can be classified as follows:

- Idle Listening: Idle listening happens when a node listens for possible reception, but nothing is received, this is due to the low traffic loads typically found in WSNs.
- Collisions: when multiple nodes transmit at the same time the receiver may not be able to decode the payload. Both of the sender and receiver waste energy.
- Overhearing: waste of energy occurs when the listener receive packet that is intended for another destination.
- Overheads: indirect information encapsulated in the packet if it is not treated that represent a waste of energy

2. Classification of MAC Protocols

According on the underlying access technique, MAC protocols could be classified into three general groups: Scheduled, Unscheduled and hybrid protocols.

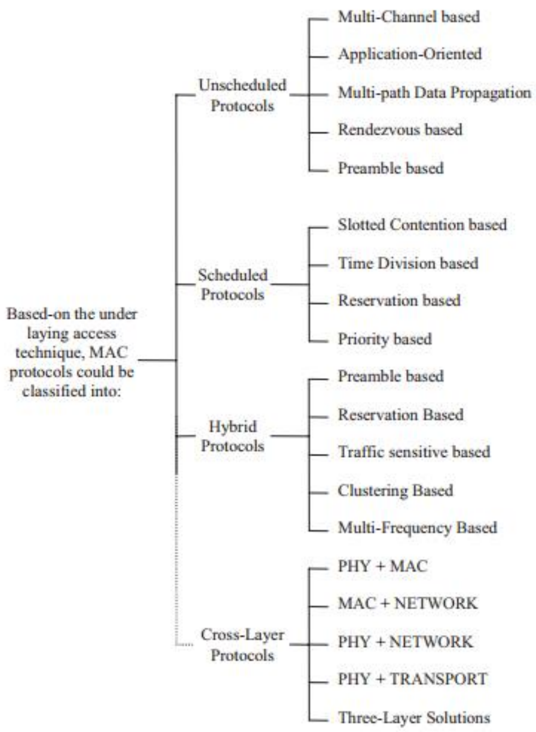


Figure 1: Classification of WSN MAC protocols [1]

2.1. Scheduled MAC protocol

Scheduled MAC protocols manage the communication between sensors in an ordered way. The most common protocol form used to organize node sensors is the TDMA, FDMA, CDMA where sensor nodes are allocated to a specific slot of frame to transmit and receive, then the node are active only in those slots and sleep in the rest. Sensor nodes provide then the capability to eliminate the collisions, idle listening and overhearing, but these advantages came with the price of increasing the messages to maintain the schedule and any mobility, redeployment or death node complicate the schedule maintenance.

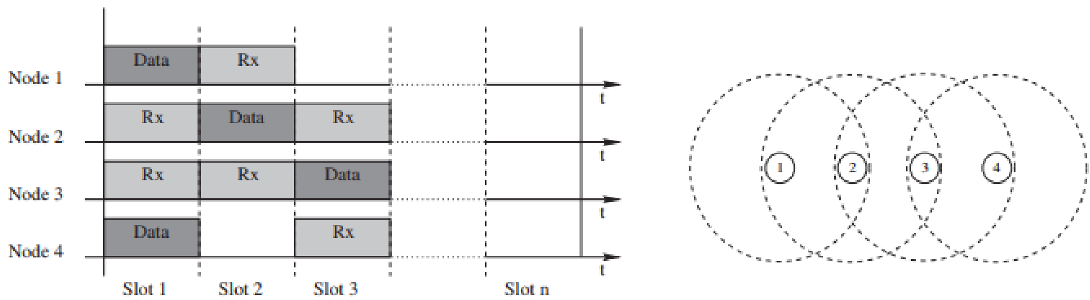


Figure 2: TDMA - MAC Protocols [5]

2.1.1. Slotted contention MAC protocol

2.1.1.1. Sensor MAC – S-MAC

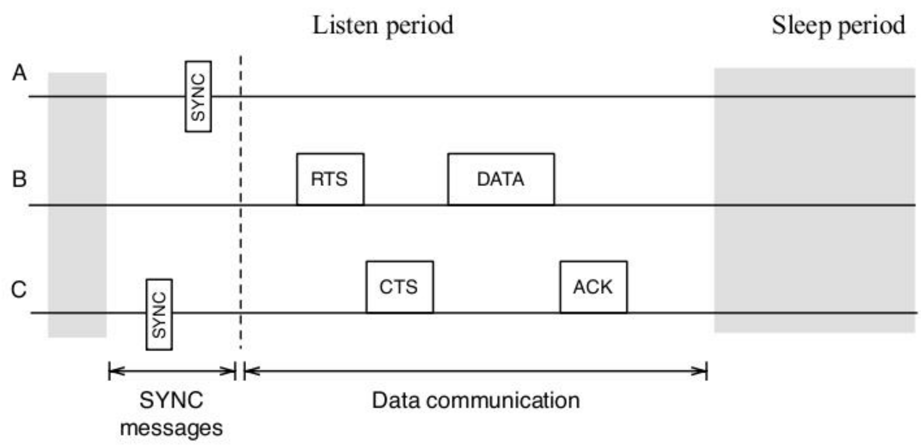


Figure 3: basic SMAC scheme [2]

The S-MAC protocol is based on local synchronisation Sleep-listen periodic scheduled. Neighbouring nodes share a common sleep schedule. If they are from different clusters, they wake up the listen period of the two clusters. The synchronization is accomplished by periodic broadcasts of SYNC packets between nodes during the listening period. The listening period is divided by two parts, the first part is for SYNC packet and the second part is for handshaking mechanism (Request To Send / Clear To Send RTS/CTS) and DATA packets. Moreover, the collision avoidance is achieved by a carrier sense.
The important advantage of the sleeping period is the reduction of idle listening time, which means more energy conservation but sleep periods are predefined and constant that may result in high latency specially for multi-hop routing and decreases the efficiency under variable traffic load.

2.1.1.2. Time out MAC – T-MAC

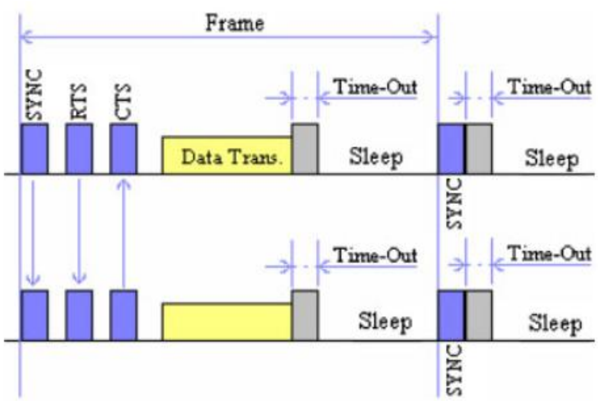


Figure 4: TMAC message transfer [1]

TMAC is based on S-MAC protocol and seek to eliminate the idle energy by setting an adaptive time out of the listening portion of the frame. Whereas sending messages throughout a predefined period, data are transmitted at the beginning of the frame, if no activation has occurred during a certain length of time (Time-Out), sensor nodes switch to their sleep mode until the next listening period.

The main issue of T-MAC is the early sleeping problem, which happens when neighbour still have messages to send and nodes goes into sleep mode. To overcome with this problem the protocol use Future Request To Send (FRTS) to be sent before the Time-Out expire and force the node to stay in active mode.

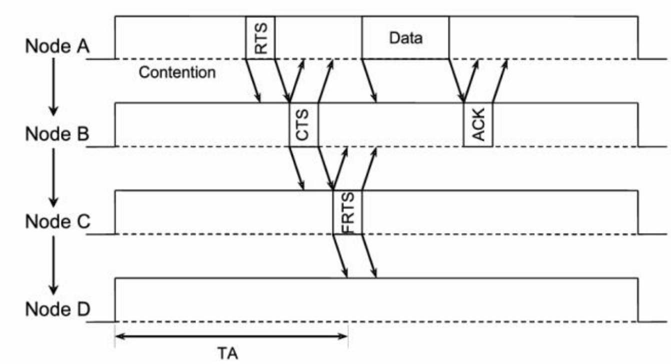


Figure 5: Future Request To Send scenario [2]

2.1.1.3. Dynamic S-MAC (DS-MAC)

The S-MAC has latency issue due to sleeping period, DS-MAC aim to reduce the sleep delay by dynamically changing the duty-cycle of the sleeping period depending on the application demand and battery level. When the traffic load is increasing, nodes increase their duty-cycle if and only if the battery level is above a specific threshold by sending SYNC packet to the concerned nodes informing about the additional schedule.

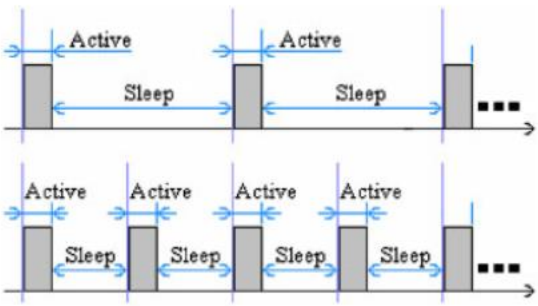


Figure 6: Doubling of duty cycle in DSMAC [1]

2.1.1.4. Mobile Sensor MAC – MS-MAC

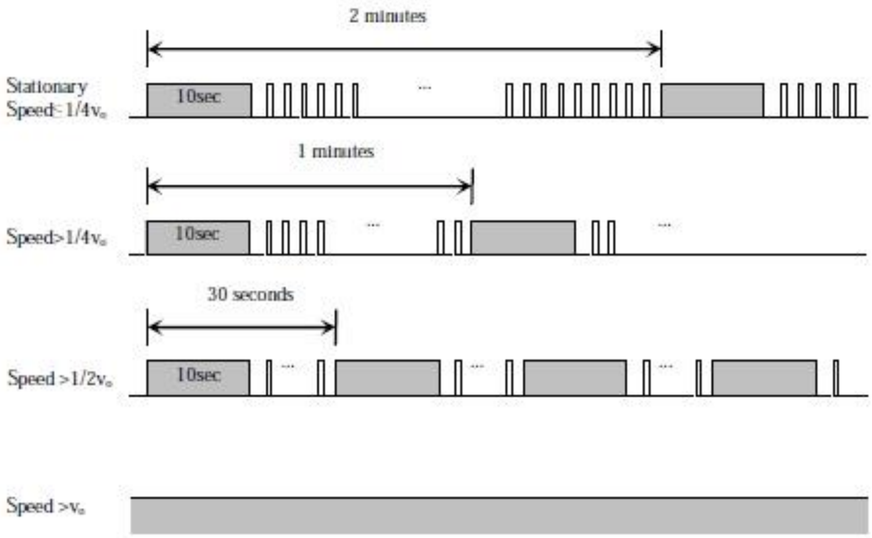


Figure 7: Frequency of synchronization period in MS-MAC depends on mobile speed [2]

The MS-MAC is based on the S-MAC protocol but it varies the sleeping time dynamically depending on the velocity of the mobile nodes by sending SYNC packet at every schedule like in S-MAC.

The problem is when node moves, it takes two minutes to get connected to a new cluster as the figure 7. To overcome this problem. The border nodes must follow the synchronous periods of the two virtual clusters, and set a v_0, if the velocity of the mobile node v_{mn} is higher than $\frac{1}{4}v_0$, we divide the schedule cycle by 2, (1 minute), if $v_{mn} > \frac{1}{2}v_0$ we divide the schedule cycle by 4, etc.

2.1.2. Time Division MAC Protocol

2.1.2.1. Lightweight MAC – L-MAC

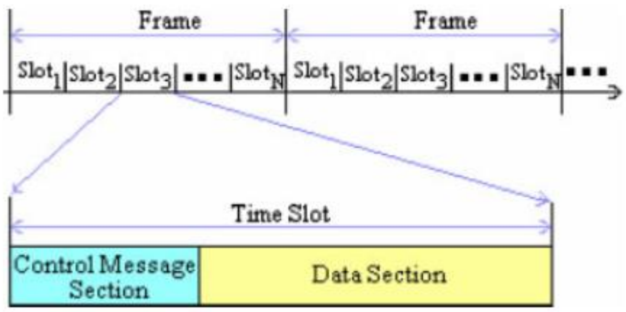


Figure 8: LMAC frame format [1]

L-MAC protocol is based on Time Division Multiple Access (TDMA). Time is divided into multiple repeated frames; each frame is subdivided into multiple slots and each sensor node is allocated to a specific slot giving this node the control of transmitting over this time interval.

Unlike TDMA based system, L-MAC time slots are divided using a distributing algorithm. During a time, slot, node always transmit a message that is composed of two parts: control message and data unit

The control message has a fixed size and it carries ID of the time slot, the distance between the node and the gateway, the address of the receiver and the length of the data

The control data is also used to keep the transmission sequence of the data section for each node synchronized.

2.2. Unscheduled Protocols

2.2.1. Preamble MAC protocols

2.2.1.1. Berkeley MAC – B-MAC

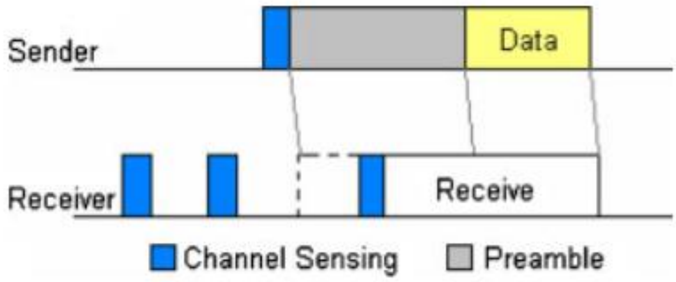


Figure 9: B-MAC transfer [1]

B-MAC is based on preamble sampling which sensor node are independently follow a sleep schedule based on the target duty cycle for the sensor network.

B-MAC consist of four parts: Channel Assessment (CCA), packet backoffs for channel mediation, link layer acknowledgements for reliability, and low power listening (LPL) for low power communication.

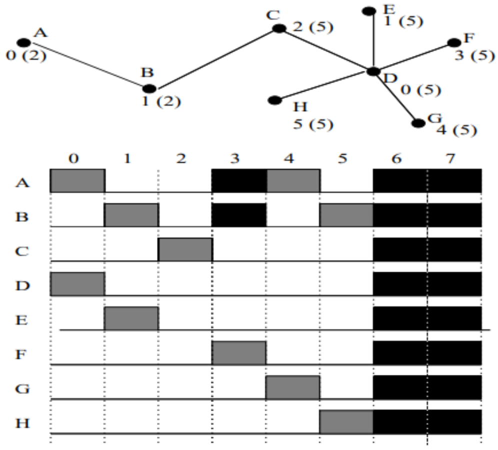
When there is no traffic nodes are in sleep mode, they wake up only if the sender transmit a preamble packet long enough to be captured by the receiver, the receiver node get the backoff packet first then the DATA

B-MAC protocol is efficient only in low traffic condition, otherwise, B-MAC remain awake for longer time waiting for the packet transmission.

2.3. Hybrid Protocols

2.3.1. Preamble MAC Protocols

2.3.1.1. Zebra MAC – Z-AMC



Z-MAC combine of CSMA as the basic MAC scheme, and TDMA as an indication to improve contention resolution. CSMA is used in low traffic and switches to TDMA for high traffic loads.

Z-MAC uses DRAND (Distributed Randomized TDMA scheduling for Wireless Adhoc networks), an efficient scalable channel-scheduling algorithm, used to guarantee that a time slot is not assigned to two nodes located within three hops from each other, Any node assigned to a time slot is called an owner, other non-owner. Unlike TDMA, a node may transmit at any slot, before transmitting, it always performs a carrier-sensing to check if channel is clear then transmits the packet. However, transmitting priority is for owner of the slot first then the non-owner

3. Energy Consumption

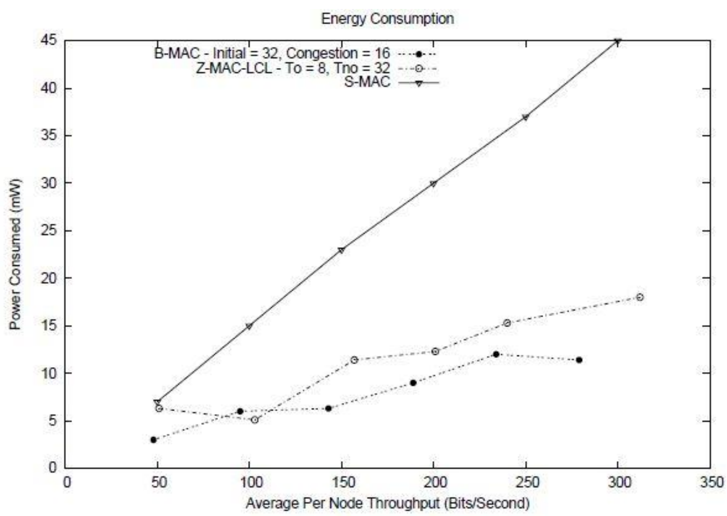


Figure 10: Power efficiency in low-data rate applications with low duty cycle [2]

The graph represents the power efficiency according to the nodes average bit rate of three different protocols B-MAC, Z-MAC and S-MAC

the evolution of each graph tends to be linear, thus the ratio Energy bit is the slope of the graph

$$\frac{mW}{\frac{Bit}{s}} = \frac{mW \cdot s}{bit} = \frac{joules}{10^3 \cdot bit}$$

$S - MAC$: $\frac{35}{10^3 \cdot 250} = 140 \frac{\mu j}{bit}$

$Z - MAC$: $\frac{11}{10^3 \cdot 200} = 55 \frac{\mu j}{bit}$

$B - MAC$: $\frac{6}{10^3 \cdot 140} = 42 \frac{\mu j}{bit}$

4. Summery

General classification	Specific classification	Advantages	Disadvantages	Energy Consumption and Energy saving	Mobility	Localization
Unscheduled protocols	B-MAC	Better performance in term of latency	Low efficiency when traffic is high	Sleep mode when no traffic $42 \frac{\mu j}{bit}$	NO	NO
Scheduled protocols	S-MAC	Low energy consumption when traffic is low	Latency	Power saving over CSMA/CA $140 \frac{\mu j}{bit}$	NO	NO
	T-MAC	Adaptive active tile	Early sleeping mode	Less energy the S-MAC	NO	NO
	DS-MAC	Reduce sleep delay	-	-	NO	NO
	MS-MAC	Adaptive sleep period and resolve the problem of mobility	cannot ensure reliable communication between stationary nodes and mobile nodes	Less energy the S-MAC	YES	NO
	L-MAC	Scalable Collision free Reduce idle listening Energy Conservative protocols	Control overhead is high Limited scalability and adaptability to node changes		NO	YES
Hybrid Protocols	Z-MAC	mixing CSMA and TDMA, Z-MAC becomes more robust	Protocol complexity is high	$55 \frac{\mu j}{bit}$	NO	YES

5. Conclusion

Throughout this report, we have discussed the specific requirements of MAC protocols in wireless sensor networks, classified the research on MAC in wireless sensor networks and the many proposed protocols. we have summarized the general classes of MAC protocols, each MAC protocol could be adapted for different applications

I didn't focus too much on the security side of each protocol, indeed for the power consumption, I couldn't cover all the protocols to find the ratio energy over bits.

Finally, over this research, I was able to build an idea about MAC layer protocols in WSNs, which are very useful in the IoT domain

6. References

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