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Report MAC protocols dedicated to WSN /IoT

As technology becomes a bigger part of our lives, the number of connected objects surrounding us gets higher. This represents a challenge since more data needs to be sent continuously from multiple sensors communicating in a network. In order to control the dataflow in a network the communications are ruled by a protocol : a MAC (Media Access Control) protocol. It attempts to efficiently and equitably allocate use of a shared communications channel to users that share a media network. In this report we will present the different kind of MAC protocols for Wireless Sensor Networks (WSN)

I. Main protocol types

MAC protocols can be divided in two main types : Contention Based protocols and Schedule based protocols. Moreover, there are currently a few hybrid protocols which combine the advantages of the two previous protocols cited above.

- Contention based protocols:

Contention based protocols are mainly based on Carrier Sense Multiple Access (CSMA). It basically means that all the nodes share a common channel and compete for it. Before sending a message, the sender will listen, if it detects someone using the channel, the transmission of the message is aborted and postponed. These protocols are quite popular because of their simplicity, their flexibility in terms of synchronization, their scalability and durability. Moreover, it does not need much infrastructure support nor global topology knowledge. Nonetheless, one of the main drawbacks of this type of protocol is the high energy consumption due to unnecessarily listening to the medium. Other issues would be the high cost of packet collisions (known as hidden terminal problems), unintentional receiving, lower performance for high load traffic, and the data packet size which is usually small. The packet collisions can be avoided by using a RTS/CTS operation: when a node wants to transmit data to another node, it sends out a RTS 'Request to Send' packet. The receiver node replies with a packet called CTS 'Cleared to Send' packet. After the transmitter node receives the CTS packet, it transmits the data packets. Nonetheless, this generates additional load to the network.

- Scheduled based protocols:

Scheduled based protocols are mainly based on Time Division Multiple Access (TDMA). It basically means that all the nodes have sending and listening periods. This avoids unnecessary listening to the medium, packet collision and unintentional receiving. It provides predictable delay, increases the overall throughput and fairness (channel capacity is fairly shared among the nodes without reducing the efficiency of the network). This functioning requires a strict synchronization. Nonetheless, these protocols require high energy loads from sensor applications for the strict clock synchronization. It also requires knowledge of the topology and does not answer well to dynamic topology changes that can occur for instance due to conditions of the physical environment, battery cuts, or corruption of the node. There are not good for large network and are not scalable. Moreover, TDMA allows low channel use during low latency and leads to a higher latency when compared to CSMA because a node in TDMA can only transmit in its own time zone.

II. Some protocols and their characteristics

1. Synchronous protocols

This is a non-exhaustive list of synchronous protocols, some which are detailed below :

- Sensor-MAC (S-MAC):

This protocol uses a CSMA – CA (Collision Avoidance) RTS/CTS channel access method. Basic concept of SMAC is periodic sleep listen schedules which are handled locally by the sensor network. This result on a reduced power consumption of the network equipment. From there, the main challenge is agreeing on a synchronised transmission schedule between the nodes. Nodes which are adjacent form clusters virtually and they share common sleeping and listening schedule in order to avoid hidden terminal problems. If two nodes are close to each other but are not in the same cluster, they will both wake up at the listening schedule of the two clusters, resulting on more energy consumption. There are two possible states :

- Listening schedule: the nodes wake up in order to send in order the synchronisation packets called SYNC then transmit the data frames.
- Sleeping schedule: the nodes shut off the radio in order to save the battery

At first, the nodes start listening to the channel for a specified period waiting for synchronisation packets SYNC. If no packet is received, the node chooses a scheduling et transmits it (in a SYNC packet) in order to inform the nodes close by. This packet contains the wake-up time of the node, along with the time until the next wake up. If on the contrary during the listening period, the node receives a SYNC packet from another node, it will follow the other node’s scheduling and retransmits it in a SYNC packet. If a node has already adopted a scheduling and it receives a different one from another node, then it adopts both scheduling arrangements then transmits a SYNC packet with both wake up periods to the other nodes. A feature of S-MAC is message passing through which a long message is sent in burst by dividing it into small messages. This helps in energy saving by using common overhead. However, this concept of sleeping schedule may also result in high delay termed as latency which will be significant in case of multi-hop routing algorithms, as each node in between will have their own sleep schedules. This is known as sleep delay. This protocol is interesting because of the low power consumption resulting of the sleep schedules. Moreover, its easy implementing and its efficiency transmitting long messages makes it a good protocol for Wireless Sensor Networks.

- Timeout MAC (T-MAC):

In this protocol, each node wakes up periodically to communicate with adjacent nodes. There are active and inactive periods and the use of RTS/CTS (Request-To-Send, Clear-To-Send) method (avoiding collisions and hidden terminal issues) as in the S-MAC protocol. The main difference is that T-MAC protocol adapts to traffic. It allows the nodes to increase it active period if needed. It also aims to avoid keeping the radio ON when there is no traffic on the channel. An active period ends no activation event has occurred for a given time TA. An activation event is :

- Trigger of a frame timer
- Receiving data
- Detection of a communication on the radio channel
- Receiving ACK packets

Even though the dynamic sleeping schedule makes this protocol more efficient, one of the main disadvantages is that nodes can switch to sleep mode while on active period and data might get lost, even more with long messages. Nonetheless, the delay is improved compared to S-MAC.

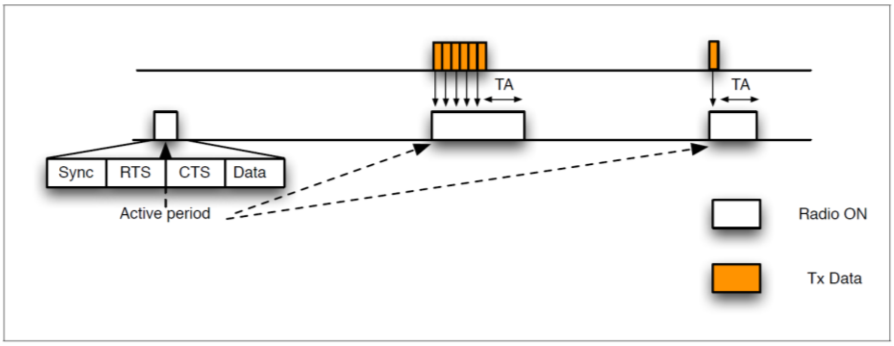

Figure : T-MAC protocol

- Dynamic MAC (D-MAC):

This protocol represents a solution to the delay found in the S-MAC and T-MAC protocols, while keeping in mind the necessity to lower the power consumption. This protocol is mostly adapted to converge cast traffic since the main concept is that the wake-up periods match the transit of the data frame. This way, the data will be transmitted as fast as possible to the well. Each node has an active period divided in two parts, the first one (RX) to receive data and the second one (TX) to transmit packets to the parent. While this protocol is fast, nothing is implemented to avoid collisions if nodes from two different branches end up communication to one of the parent nodes at the same time. Another drawback is that any change in the topology of the network requires for the slots associated to each node to be calculated again.

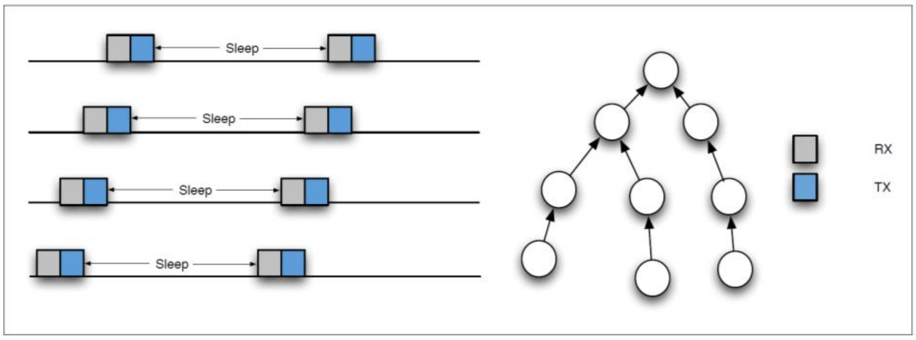

Figure : D-MAC protocol

2. Asynchronous protocols

This is a non-exhaustive list of asynchronous protocols, some which are detailed below :

- Berkeley MAC (B-MAC):

This protocol answer to the high delay that the synchronous protocols can't avoid while saving the battery. One of the first and main solutions proposed is the Berkeley MAC protocol which is characterised by the existence of a preamble. When transmitting a package, the node will first send a long preamble (longer than the sleeping periods of all the nodes in order to be sure to be detected) which does not carry any kind of information. This preamble allows simply to be detected by surrounding nodes. This protocol uses Low Power Listening which basically means that the nodes go from active to inactive periodically, only the active state is usually for a really short period where it just analyses the channel (Clear Channel Assessment). This corresponds to the part where the preamble might be detected. If activity is detected on the channel, the nodes stays awake until it knows the destination of the packets depending on which it will go back to sleeping mode. This protocol benefits from the fact that it does not require synchronisation between the nodes. Moreover, B-MAC offers a high-level interface allowing to configure the wake-up interval in order to find the best compromise between energy and network throughput. One of the main drawbacks of this protocol is the preamble that requires to be long enough to be detected, which increases the latency mainly for multihopping applications and for applications with dense traffic or topology. There is also an overhearing issue since when a preamble is detected each node will have to keep listening until the end, in order to know to which node, the data is destined to.

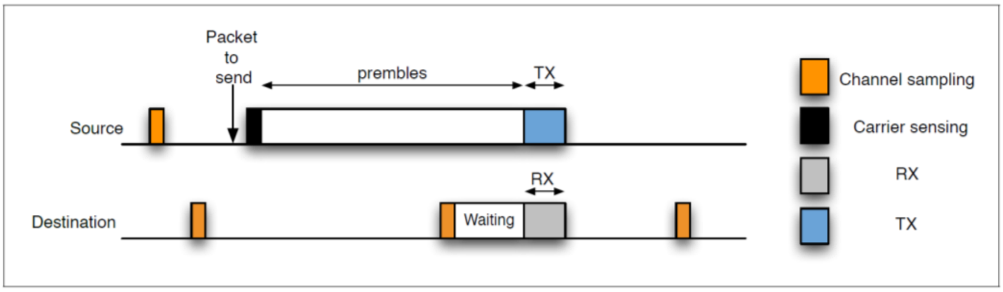

Figure: B-MAC protocol

- Wise-MAC protocol:

This protocol uses the same preamble concept as B-MAC. Wise-MAC aims to lower the energy consumption due to the long preamble. To do that the protocol has Access Points kind of nodes that learn the sampling schedule of the adjacent nodes to use a wake-up preamble of minimised size. This way, when a node will want to transmit data it will know when to transmit the shorter preamble. Therefore, the access point nodes have a learning phase of the network. At first the preamble's size is similar as the one in the B-MAC protocol. However, after the data frame is received successfully, the receiver will send an ACK packet containing its scheduling allowing the nodes to adapt the size of their preamble for the future communication. Because of low power consumption it provides a very long life to the battery. Moreover, the external need of synchronization can be eliminated because it can handle the clock drift in good way. Nonetheless, sleep, wake up and listing modes are not properly schedule in WiseMAC protocol results in power consumption to update the table again and again. Sometimes the broadcast packets are buffered for neighbouring nodes and delivered many times when they come in wake up mode, so this will consume power. It also suffers the hidden terminal problem, due to which it is facing problem of packet collision.

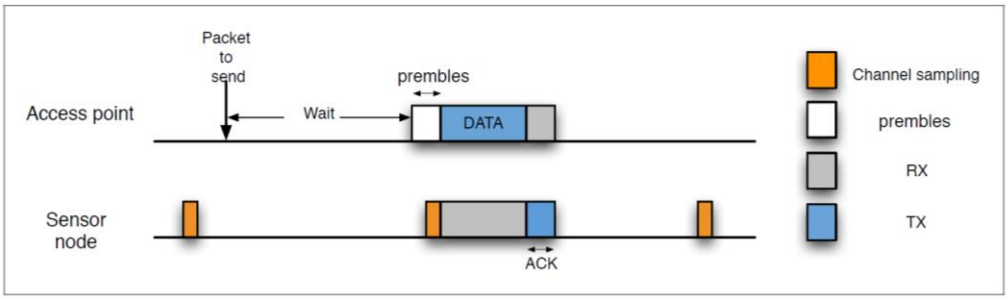

Figure : Wise MAC protocol

- X-MAC protocol :

The X-MAC protocol is another solution proposed to lower the energy consumption provoked by the transmission of a long preamble. The idea here, is to cut the preamble in several micro preambles. Each micro preamble is separated by pauses, that are long enough to allow a node to send an ACK packet. In each preamble this time, there is the address of the receiving node. This technique allows to reduce the energy consumption since the nodes that are not in the receiving end will rapidly go back to sleeping mode without waiting for the end of the preamble. The latency will also be reduced since once a node detects a preamble that is addressed to it, it will be able to stop the transmission of the preamble by sending an ACK packet to inform the node that it can send the data.

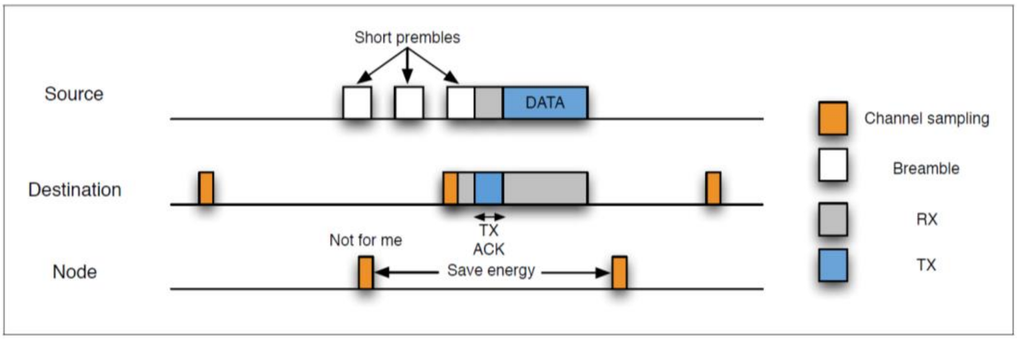

Figure : X-MAC protocol

3. Hybrid protocols

This is a non-exhaustive list of hybrid protocols, some which are detailed below :

- Zebra-MAC (Z-MAC) protocol:

Z-MAC protocol is one of the first hybrid protocols. It combines CSMA and TDMA explained in the first part of this report. This protocol is based on B-MAC protocol and uses CSMA as a baseline in case of low contention. However, it relies on TDMA schedule to enhance contention resolution. For this protocol, a node can transmit in any slot. Like in CSMA/CA, before a node transmits in a slot, it listens to see if the channel is free. Nonetheless the owner of the slot has priority to access the channel. This priority is implemented by giving a smaller back off period for those nodes. The goal is that when a node which has priority wants to transmit, Z-MAC reduces collisions since those nodes can transmit beforehand. However, if the slot is not used by that node, other nodes can use it. In Low Contention Level the non-priority nodes can transmit during any slot. This can create collision issues. When a node has a higher contention (which is detected by the loss of multiple ACK packets), it goes on High Contention Level mode. In this mode each slot is assign to its own node. The main benefits of this protocol is that it adapts easily and efficiently to the different traffic conditions. Using both CSMA and TDMA lowers the energy consumption. The avoidance of collisions is better handled than in protocols only based on CSMA. And the latency is smaller than in TDMA protocols. Nonetheless, the nodes synchronisation is more difficult, particularly with a high density of nodes.

- H-MAC protocol:

H-MAC protocol is based on slotted ALOHA (ALOHA is a medium access control (MAC) protocol for transmission of data via a shared network channel. Using this protocol, several data streams originating from multiple nodes are transferred through a multi-point transmission channel). The nodes that have packets to transmit negotiate slots with the destination nodes during active time and transmit/receive the data packets in pre-negotiated slots during sleep time. If the nodes do not have to transmit or receive any data packets go to sleep during the sleep-time slots.

4. Summary

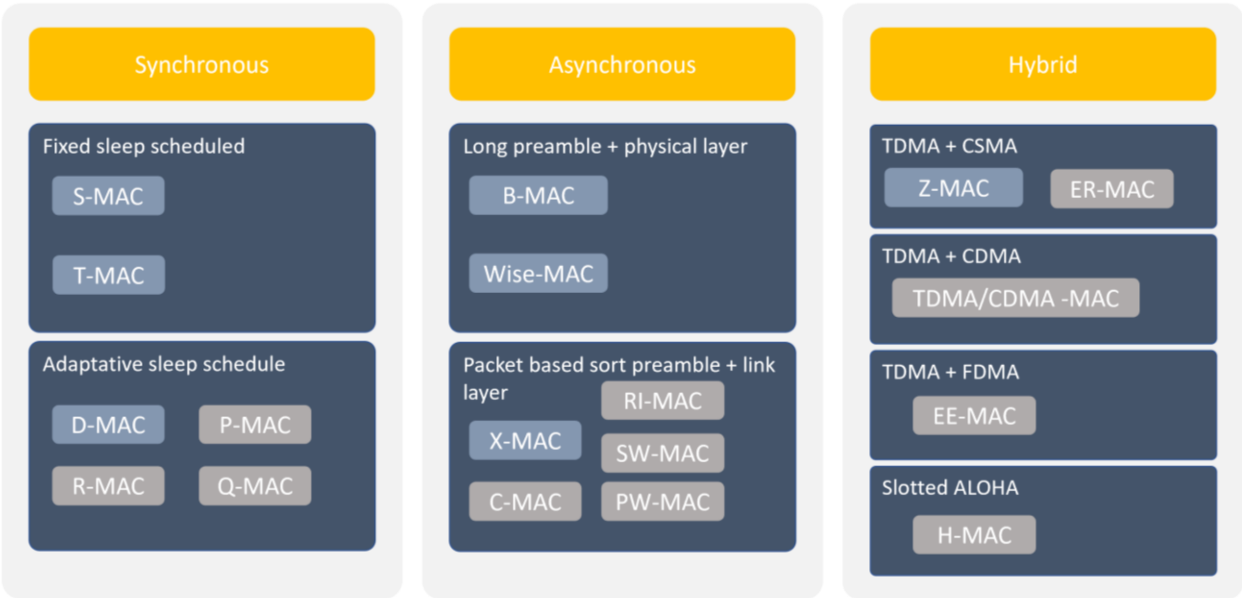

Figure : Single layer some MAC protocols

Conclusion :
Currently, there are plenty of options available when it comes to MAC protocols for Wireless Sensor Networks. While the power consumption and the latency are some of the main necessities of those network, they all have different benefits and drawbacks. It is important to choose the protocol that fits the best the needs of each specific application.

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