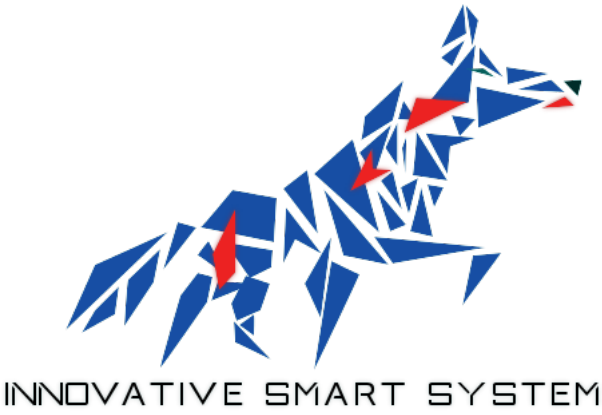

INSA Toulouse, DGEI

Toward Internet of Things

MAC Layers for Wireless Sensors Network

Authors:
Pierre Prie

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Introduction

Nowadays, to try to improve our daily life, we want to gather more and more data about everything. This is why the market of internet of things (IOT) appears and is still growing over the years. The beginning of IOT also marked the development of wireless sensor network (WSN) that connect all this connected autonomous devices togethers. WSN provide many advantages in comparison to wired network but they have strong requirement to work. The point of WSN is to connect hundreds of devices efficiently with low cost equipment and low energy needs. In this document we will speak about the medium access control (MAC) layers used in WSN. MAC Layers are responsible to manage the access to the channel, error control and quality of service (QoS) for example, therefore they are primordial for WSN and are the mains actor of energy consumption for wireless devices. We will start by seeing briefly the design challenges for MAC protocol, then we will see the 3 main based MAC protocol and finally we will see some specific MAC protocol and try to see their advantages and disadvantages.

1 MAC protocol design challenges

MAC layer is a key feature of WSN and must meets some specific points. Because of the nature of WSN, Mac protocol must have, at first, a very good energy efficiency to extend as much as possible the lifetime of the devices. The second goal of MAC layer is to manage latency. It depends on the application but in some case, data's must be sent in real time to the sink node to take the appropriate action immediately like in in-flight test for example. The third point is the throughput and bandwidth. Throughput is usually low in WSN but in some application the network will have to meet higher throughput requirement, we can again take the example of sensor on in-flight test which have to send a large amount of data to the sink-node at the same time. Other points are the scalability and the adaptability of the WSN which is conditioned by the MAC layer, that mean how the network will respond to new devices on the network or loss of devices due to lack of battery for example.

This are the main points to consider when designing a mac layer, the most important one being the energy efficiency. One way to increase energy efficiency is to minimize the energy wastage. There is four main source of energy waste in WSN that MAC layers must deals with [7]:

- Collision : There is collision when more than one packet are received at the same time by the receiver. Due to interference, the packet is corrupted and can't be used, the data have to be sent again, increasing energy consumption.
- Overhearing : There is overhearing when the node received packet that are not meant for it. That means that the node spend energy to received data that are not useful to her.
- Packet Overhead : This refer to the ratio between the useful information sent over the total data sent. Sending data require a lot of energy, so it is important that its ratio is the higher possible. To do so, control packet like RTS and CTS must be used as the minimum possible.

- Idle listening : There is Idle listening when a node is continuously listening to a channel waiting for a packet transmission. That state requires a lot of energy and must be minimized.
- Over emitting : There is over emitting when a node send data to a receiver too quickly. Then the receiver is not able to receive all the packet and information is lost, data must be sent again.

2 Main based MAC protocol : ALOHA, CSMA, TDMA, FDMA, CDMA

There is a lot of MAC protocol available for WSN who offers different functioning characteristics. Most of them can be classified in three main category : Contention-based protocols, schedule based protocols and hybrid protocols.[8]

2.1 Contention-based protocols : ALOHA & CSMA

The main point in contention-based protocols is that all the devices share the same channel and compete to communicate. That means that every time a device wants to transmit a data, it sent a packet on the channel.

The first contention-based protocol was ALOHA, it was developed in 1968. As we said, in this protocol the first device which have a data to transmit will do it immediately. When there is a collision, the device will just recent the packet latter, which consume a lot of energy and bring latency (collision increase with the number of nodes). To reduce collision, ALOHA was improved on Slotted ALOHA, which brings time slots in communication. So, when a device has to send a packet it wait for the beginning of it next time slot.

Carrier Sense Multiple Access (CSMA) is the second contention-based protocol. The main difference with ALOHA is that before sending a packet, the device will "sense" the channel to see if there is already a communication or not on the channel. If a collision occur the device reschedules the transmitting to a random time. There is three improvement of the CSMA protocol : CSMA/Collision Avoidance (CA), CSMA/Collision Detection (CD), CSMA/Collision Resolution (CR). CSMA/CD and CSMA/CR are meant to be used in wired network, so we will only present CSMA/CA. This protocol proposes to manage the case where two device who don't see each other try to communicate with the same node. To do so the transmitter sent a small Ready to Send (RTS) packet to the receiver. This one returns a Clear to Send (CTS) packet to the transmitter who can then transmit its data. If the transmitter do not received a CTS packet, the channel is already used, it waits before retry to access the channel. With this protocol the channel is allocated on demand. Even if the RTS and CTS packet are small they represent a huge consumption of energy on WSN because the useful data transmitted are also small packet.

With this two main protocol, ALOHA and CSMA/CA, we saw that contention-based protocol don't need to have a precise synchronization and that communication between node is possible immediately. Contention-based protocol scale more easily across changes in node density or traffic load. The network is flexible and allows node mobility.

Sigfox network use LPWan Mac layer which is bases on Random Frequency and Time Division Multiple Access (RFTDMA) who can be compared to Aloha slotted protocol.[3] The packet are transmitted immediately by the transmitter. To avoid collision, packet are send tree times with Random frequency on the bandwidth (100Hz used over 200kHz of bandwidth). Each packet contains 12 octet of data and 12 octet of control packet. Lora network use its own Mac layer LoraWan which is bases on Aloha slotted protocol[3]. On the contrary of Sigfox network, for Lora communication there is a need for synchronization/identification before being allowed to uses the channel.

2.2 Schedule based protocols

Schedule based protocols are focused on energy efficiency, they allow devices to share the same frequency channel by pre-allocated them different time-slot. Then schedule based protocols are collision free protocols. They require a good synchronization between devices and organization of duty-cycles that allows low consumption for devices, they are most of the times in sleeping-mode. Because of their structure schedule-based protocols do not respond well to modification of node density or movement of nodes in the networks. Nodes cannot communicate immediately on the networks, pre-communication and time allocation are necessary.

The main schedule-based protocol is Time Division Multiple Access (TDMA). Other protocols like Frequency Division Multiple Access (FDMA) or Code Division Multiple Access (CDMA) can be associated to schedule based protocols because they are collision free.

In TDMA protocols the nodes are scheduled centrally by different time slots. The nodes only wake up during their time slots to listen and communicate, they go back in sleep mode in other time slot. In dynamic TDMA, a separate signaling slot is used to broadcast request for timeslot, which brings more flexibility. As we said before TDMA is very efficient in energy consumption but require a very good global time synchronization between all the nodes. It does not respond well to topology change in the network (due to new or loss of devices) because it required a new schedule organization on each topology change.

Frequency Division Multiple Accesses (FDMA) allocates users with different carrier frequencies of the radio spectrum. It is also a collision free medium, but it requires additional hardware to dynamically communicate with different radio channels. This increases the cost of the sensor nodes, which is the opposite of what we want in WSN.

Code Division Multiple Access (CDMA) employs spread spectrum technology and a special coding scheme (where each transmitter is assigned a Code) to allow multiple users to be multiplexed over the same physical channel. It also offers a collision free medium, but it requires high computational operation that increase the energy consumption of devices which is on opposite of what we want on WSN.

Bluetooth Low Energy used TDMA protocol with Frequency Hopping Spread Spectrum (FHSS) and Gaussian Frequency Shift Keying (GFSK). The master is always awake and manage the synchronization of the slaves. The master communicates with the slave during a time slot.

NB-IOT technology used single-carrier frequency division multiple-access (SC-FDMA) [1]

2.3 Hybrid protocols

Hybrid protocol basically used CSMA + TDMA to combine the advantages of each protocol. Then depending on the network and on the action of the device, it's protocol will change between CSMA and TDMA.

Zigbee technology used CSMA/CA + TDMA protocol. In nonbeacon mode, the protocol is CSMA/CA. The node checks the medium before transmit, if busy it waits for a random period of time. In beacon mode, devices can be on active or inactive mode. At the beginning of the active period, a master sends beacon frames about period duration to make duty cycle vary. Then a contention frame start allowing devices to send frames using CSMA/CA. The first waiting time (before checking the medium) can be very small to minimize idle listening in low traffic. The node can sleep immediately after receiving an acknowledgement[3].

We resume on the following table the main characteristics of CSMA and TDMA protocols

	CSMA	TDMA
Synchronization	Almost no synchronization	Need for a strong synchronization
Access to the channel	Random Access, or on demand	Strict controlled access
Network structure	No master / slave	Need for a central control to allow communication
Scalability, Adaptability and mobility	Good	Weak
Energy consumption	Not optimized	Optimized

3 Discussion about some MAC protocols

In this part we will see some MAC protocols that are often quoted in academic papers about MAC protocols for WSN. More details and explanations about this protocols are available on this references[2][5][6][4][3].

S-Mac : S-MAC is a CSMA based protocol which used fixed duty-cycle. Nodes creates virtual clusters by periodically exchanging sleep schedules with their neighboring. Then S-MAC allows a good energy saving but introduce latency when a node try to communicate with a sleeping node.

T-MAC : T-MAC is a CSMA based protocol that improve S-MAC by suppressing the fixed duty-cycle. Now the listen period of a node ends only if no activation event has occurred for a time TA, then the duty-cycle is flexible. because of early sleeping nodes, the T-MAC protocol brings more latency and reduce the throughput but increase the energy efficiency.

DS-MAC : DS-MAC is a CSMA based protocol that aim to improve S-MAC by reducing its latency. In DS-MAC, nodes shared their sleep schedules but also a one-hop latency value. When this value became too high, nodes divides their sleep times by two, reducing the latency.

Wise-MAC : Wise-MAC is a protocol with one communication channel that used non-persistent CSMA with preamble sampling that precedes each data packet for alerting the receiving node. In this MAC protocol, all nodes have their own sleep schedule that they exchange with their neighbors. Nodes wait for the medium to be idle before communicating after they wakes-up. To reduce power consumption, Wise-MAC protocol allows to dynamically determine the length of the preamble based on the knowledge of the sleep schedule of neighbor's nodes. The power consumption of Wise-MAC protocol is supposed to be lower than S-MAC

B-MAC : B-MAC is a CSMA based protocol based on duty-cycle with small wake times. To be sure that the receiver node will be wake up to receive the data, the transmitter sends a preamble which is larger than the period between two wake-time of the receiver. With this protocol, the power consumption is very low, but the preamble is very long regarding of the useful data sent.

D-MAC : D-MAC is an improved Slotted ALOHA protocol based on TDMA where slots are assigned to nodes based on a data gathering tree. The aim of the protocol is to achieve very low latency, but still be energy efficient. To do so during the receive period of a node, all its child nodes has transmitted periods and subsequent slots are assigned to them if they are successive in the data transmission path. D-MAC is very efficient on low latency, but collision may be a problem if nodes that have the same schedule try to communicate with the same node. To work, D-MAC require to know the transmission path, so it do not allow scalability or mobility.

TRAMA : TRAMA integrate TDMA and CSMA. The aim is to provide energy-efficient conflict free channel access by creating transmission schedules that are adaptive to changes. The protocol consists of three components: the Neighbor Protocol (NP), the Schedule Exchange Protocol (SEP) and the Adaptive Election Algorithm (AEA). The NP gathers information from neighbor nodes. SEP allows nodes to exchange two-hop neighbor information. AEA is used to select one sender/receiver within two-hop neighborhood. It seems that TRAMA provides higher energy efficiency than S-MAC but brings more latency than classic CSMA-based protocols

Z-MAC : This protocol integrate TDMA and CSMA. Z-MAC is based on the concept of owner slot. Owner slot is accessed in TDMA when the others are access in CSMA. Z-MAC has two basic components. First is called neighbor detection and slot assignment, and the other one local framing and synchronization. By this, collisions are increasingly reduced and decrease the energy conservation.

Conclusion

As we see, there is a lot of MAC protocols for WSN. It seems that most of them are based on CSMA maybe because this kind of protocols brings more adaptability to topology changes and mobility on the networks. However, none of these protocols have been selected as a standard because there is no MAC protocols better than the others, each of them have advantages and drawbacks and finally the choice of one of them will depend on the application.

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