Wireless Sensor Networks Report
MAC layers for WSN

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Introduction

This report was realized in the context of the 5^{th} year *Innovative Smart Systems* at INSA Toulouse, for the *Wireless Sensor Networks* module, which is a part of the *Communications for Connected Objects* course. It aims at describing various MAC layer solutions used in the field of Wireless Sensor Networks. First, we will remind what is the MAC layer. Then, we will study examples of MAC layers, going through their characteristics, strengths, weaknesses and differences.

1 Reminders and generalities about the MAC layer

1.1 The place of the MAC layer within the OSI model

Let's start this report by reminding what is the MAC layer. It is a part of a bigger standard called the OSI (Open Systems Interconnection) model. This model aims at representing the way systems communicate. It is general and can be useful to understand various communication standards, such as cellular or computer networks. It is structured in different layers, which correspond to different abstraction levels, from the application layer (which is the entry of an application to the network) to the physical layer (which studies the physical phenomenons used to convey the information, such as electromagnetic waves or bits on a wire).

A typical communication between two systems relies on a stack of protocols corresponding to the different layers. When studying a protocol, it is key to know at which layer it operates in order to understand its context and usage. You may find in fig. 1 a simple representation of the OSI model, in which I explained the main functions and principal protocols of the different layers.

As you may see, the Medium Access Contol (MAC) layer is a part of the the second layer in the OSI model, the Data Link layer. The Link layer is the slice of the OSI model in charge of the communications between two directly connected machines, such as two computers in the same LAN, or a radio emitter and its receiver.

The MAC layer is, at its name indicates, the the part of the Link Layer in charge of controlling the access to the communication medium. It encapsulates the higher-level frames to be transmitted, and handles the way messages behave regarding to collision in the communication medium (which can be a cable, or a free space in the case of a wireless transmission).

N°	OSI Model (7 layers)		Data unit	Description		Protocol examples
7	Application		Data	Access point of the applications to network services		Web, BitTorrent, DHCP, DNS, FTP, IRC, SSH, Telnet, Websocket, POP/IMAP...
6	Presentation		Data	Conversion and encryption (optionnal)		HTML, XML, TLS, ASCII, Unicode...
5	Session		Data	Exchange synchronisation and session handling (optionnal)		HTTP/HTTPS...
4	Transport		Segment	End-to-end connexion between processes and rate control		TCP, UDP...
3	Network		Packet	Routing and addressing		IP, ICMP, ARP, RIP, RARP...
2	Link	LLC	Trame	Communication between directly connected machines, Collision avoidance (TDMA, CDMA, CSMA CD/CA/CR...)	Error and rate control	Ethernet, CAN, Token Ring, WLAN, 3G, 802.1...
		MAC			Medium Access Control	
1	Physical		Bit	Numeric/Analog binary transmission, Sending/Receiving, Modulation/Demodulation		RJ45, Bluetooth, Wi-Fi, Coaxial cable, Manchester Code, ADSL, USB, Wireless USB...

Figure 1: Simple representation of the OSI model

1.2 The principal MAC strategies

The main problematic of a MAC layer protocol is to grant access to multiple actors to a same shared communication medium. You may find below a non-exhaustive list of the most widespread strategies used in order to achieve this multiple access :

- **TDMA (Time Division Multiple Access)** This strategy uses a temporal division of the bandwidth. If we take an analogy of people talking in a room, this solution would be for each person to talk when it is its turn.

- **FDMA (Frequency Division Multiple Access)** Here, the bandwidth is divided in distinct frequencies, and each user is assigned a unique frequency. The receiver chooses the sender it wants to hear by demodulating the signal with its assigned frequency. In our analogy, several persons would talk at the same time but you would be able to differentiate them because their voice is different, and focus on a single one.

- **CDMA (Code Division Multiple Access)** A code is assigned to each communication. The receiver is able to reconstruct the message because the different codes used are said to be "orthogonal". It allows to cut the message into segments and to send them over several frequency channels within the bandwidth. Many variants exist (synchronized or not). The message is divided in time and frequency. This allows a message to be transmitted within a wide range of frequencies, which can sometimes be useful (it is called "spectrum-spreading"). In our analogy, one person can use different voices, and people can talk at the same time, but never two at the same time with the same voice ! You are able to differentiate them because each person talks in a different language.

- **CSMA (CD/CA) (Carrier sense Multiple Access)** Contrary to the previous ones, the sender listens to the medium to determine wether it is possible to start an emission. It comes in different variants :

  - **CSMA/CD (Collision Detection)** The sender listens to the medium all the time. If it wants to send a message, it checks that no message is being transmitted. It it is the case, it starts transmitting, else it waits for the end of the ongoing transmission. If a collision is detected, the transmission is stopped and will be retried after a random time. In our analogy, everyone would wait for the person speaking to be finished before starting to talk in order not to interrupt him. Everyone is at the same level of rights, just like during a conversation between friends.

  – **CSMA/CA (Collision Avoidance)** Here, a master is designed. If a sender wants to emit, it has to ask for permission to him, specifying information about the message (datarate, length...), and wait for his authorization. In our analogy, this would be close to a classroom context where a student has to ask for permission to the teacher before talking.

- **SDMA (Space Division Multiple Access)** This last one is still in research. Here, the medium is separated into several physical spatial pipes where the sender can address the receiver as in a one-to-one privileged channel. Devices such as Smart Antennas are capable of detecting the direction of arrival are able to identify such spatial channels. In our analogy, you could identify the person talking to you and extract their sentence thanks to their relative position within the room !

2 Comparison of different MAC layers dedicated to WSN

In this section we will present the main MAC layers used in Wireless Sensor Networks and compare them.

2.1 Aloha

Aloha[2] is an historical simple random access technique, implementing the CSMA-CD strategy. The sensors can listen to the media in order to avoid transmitting when another is already in communication. If a collision is detected, both stop and will try again after a random amount of time.

2.2 S-MAC

S-MAC, or "Sensor MAC"[1] is a strategy where nodes switch between a listening mode and a sleep mode periodically. You get a lower throughput and a higher latency, but you gain in terms of energy efficiency. If nothing happens, nodes go into a periodic sleep mode during which they stop listening and awake later thanks to a timer. At the expiration of the timer, they listen to eventual communications and decide wether they should go back to sleep or not. If a node is transmitting, it does not go into the periodic sleep before the end of the transmission. S-MAC uses an ACK scheme where the sender asks for permission to send to the receiver. The sender asks with a RTS (Request To Send) packet, and gets a CTS (Clear To Send) response. Then, it knows the way is free and sends the message. In this way, it is a **CSMA-CA** strategy.

This protocol is synchronized and works with a schedule policy. Each node stores a schedule locally which contains scheduling information of all its neighbors. To initialize the schedule, a node will listen for a certain amount of time and wait for an incoming schedule. If it does not happen, it computes a schedule itself and broadcast it to its neighbors. This will be the **synchronizer** node. If a node receives a schedule from a neighbor, it simply follows it and is called a **follower** node. If a node receives a schedule but has already one, it computes a new schedules with both and broadcasts it before going to sleep. This protocol also implements synchronization mechanisms between the nodes. In this way, this protocol also uses **TDMA** principles.

To sum up, S-MAC is a MAC strategy made for Wireless Sensor Networks that uses a combination of TDMA and CSMA-CA.

2.3 T-MAC

T-MAC, or "Timeout MAC"[1] is derived from S-MAC, but here the sleep and active periods are not fixed. Indeed, a node goes idle if no event has occurred for a time (timeout). As S-MAC, it is a mix between TDMA and CSMA-CD. It also uses RTS/CTS.

2.4 B-MAC

B-MAC, or "Berkeley MAC"[3] is another protocol that uses a CSMA-CA technique. Its strengths are a low power consumption and a highly reprogrammable interface. B-MAC adapts itself to the network at initialization, which gants optimal cycles and minimizes the idle listenning times. It is perfect and widely used for low traffic, low power Wireless Snsor Networks.

2.5 Z-MAC

Z-MAC, or "Zebra MAC"[1] runs on top of B-MAC and combines features of TDMA and CSMA-CA, with time-slot assignment. It is a good alternative to B-MAC for high load applications, but its higher complexity can be a problem.

2.6 RL-MAC

RL-MAC, or "Reinforcement Learning MAC"[2] is a MAC layer strategy that adaptively adjusts the sleeping schedule based on local and neighboring observations. Each node can deduce the state of other nodes thanks to a reinforcement learning decision process.

2.7 TRAMA

TR-MAC, or TRaffic-Adaptive Medium Access protocol[2] is a TDMA based protocol where the nodes exchange neighbouring information with their direct neighbours. It allows the network, and therefore its schedule, to adapt to throughput changes. However, the elaboration of a global scheduling by only transmitting neighbouring information provokes a high overhead and a lot of processing for each node.

2.8 LEACH

LEACH, or "Low-Energy Adaptive Clustering Hierarchy"[2] is a self-adaptive protocol that works by dividing nodes in local clusters. Each cluster has a "head" in charge of collecting all data and sending it to the gateway. The head changes regularly amongst the available nodes in order to balance energy consumption. The cluster uses a TDMA where the schedule is decided by the head. Between the different clusters, a CDMA is used in order to avoid interferences with neighbour clusters when communicating to the gateway.

2.9 L-MAC

L-MAC, or "Lightweight MAC"[4] uses TDMA to provide the nodes in the network a collision-free communication. The network organizes itself its time slot assignment and synchronization.

2.10 Summary table

We will now compare the main MAC technologies used in Wireless Sensor Networks in the table below :

Name of the technology	Kind of access	Particularity
Aloha	CSMA-CD	Historical protocol, where nodes start emitting again after a random amount of time if a collision is detected.
S-MAC (or Sensor MAC)	TDMA and CSMA-CA combination	Widespread WSN protocol with periodic sleep cycles.
T-MAC (or Timeout MAC)	TDMA and CSMA-CA combination	Protocol derived from S-MAC with variable sleeping schedule.
B-MAC (or Berkeley MAC)	CSMA-CA	Widespread highly re-programmable protocol suitable for low power, low throughput WSN applications.
Z-MAC (or Zebra MAC)	TDMA and CSMA-CA combination	Alternative to B-MAC with better high-load handling but higher complexity.
RL-MAC (or Reinforcement Learing MAC)	TDMA	Adaptative protocol based on Reinforcement Learning.
TRAMA (or TRaffic-Adaptive Medium Access protocol)	TDMA	Adaptative protocol where nodes communciate with their direct neighbours.
LEACH (or Low-Energy Adaptive Clustering Hierarchy)	TDMA within the cluster, and CDMA between different clusters	A protocol with a cluster based management.
L-MAC (or Lightweight MAC)	TDMA	Lightweight WSN protocol with timeslot assignment.

Table 1: Characteristics of different MAC layer technologies for Wireless Sensor Networks

Conclusion

In this report we explained what was the MAC layer and what was its purpose. Then, we focused on the field of Wireless Sensor Networks and went through a variety of solutions allowing nodes to access the communication medium safely. We saw that all solutions mainly relied on TDMA, CSMA, or a combination of the two.

References

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