MAC layers comparison

Introduction

The **Medium Access Control (MAC)** sublayer is the layer controlling the hardware used for the interaction with wired, optical or wireless **transmission medium**. It is the part of the **link layer** which provides flow control and multiplexing. In the case of **wireless sensor networks**, the MAC layer is address some particular challenges : **low power consumption**, **mobility, security** and **scalability**.

Energy wastage in wireless sensor network can be due to :

- **idle listening** : when a node is in active mode and has nothing to send or receive, it consumes the same amount of energy that if it was transmitting or receiving.
- **collision** : when neighbor nodes access to the medium at the same time it can leads to corruption of transmitted packets. If it is the case the sender will try to retransmit the message, which will consume more energy.
- **overhearing** : when a node also receive packets destined to another node.
- **control packet overhead** : exchange of control packet between nodes also wastes a lot of energy.

Another important feature for WSN is the security, in particular for medical or military applications. The security requirements are :

- data **confidentiality** : only the destinator of the data can discode it.
- data **authentication** : the receiver can verify that the data comes from the right sender.
- data **integrity** : ensure that the received data is equivalent to the sent data and has not been changed by attacker during the transmission.
- data **freshness** : ensure that the data is up-to-date.

Wireless sensor network MAC protocols are based on different techniques:

- **CSMA** : Carrier Sense Multiple Access
- **TDMA** : Time Division Multiple Access
- **Hybrid** : Using both TDMA and CSMA

The table below shows the classification of the main medium access control protocols.

CSMA (contention based)	TDMA (reservation based)	Hybrid (CSMA and TDMA)
S-MAC, T-MAC, B-MAC, WiseMAC, D-MAC, U-MAC, X-MAC, P-MAC, C-MAC etc.	ERAC, TRAMA, L-MAC, EMACS , DEMAC, BMA, SS-TDMA etc.	Z-MAC, H-MAC, PTDMA, μ MAC, SCP-MAC, R-MAC, AMAC etc.

In this report, I will present the features of the most know MAC protocols. I will start with the contention based protocols. Then I will present a reservation-based protocol. Lately, I will show how hybrids protocols take advantages of both CSMA and TDMA.

I. Contention based protocols

S-MAC

S-MAC stands for **Sensor MAC**. This protocol is based on CSMA. One of the main feature of S-MAC protocol is a static sleeping cycle. The nodes are **periodically sleeping** in order to be less energy consuming.

Fig 1 : Duty cycle for S-MAC protocol

The nodes wake up and send their data during their listening time. Sometimes, the nodes are sleeping during other nodes transmissions. This feature leads to high latency and low throughput but has the advantage to avoid frame collision and overheading.

All nodes chose their own sleep/listen times but, in order to reduce control overhead, **synchronisation** between neighbor nodes is implemented (using SYNC messages) . In order to increase QoS, S-MAC packets also contains the expected duration of the message and must be acknowledged by the receiver. For **collision avoidance**, S-MAC uses request-to-sent/clear-to-send (**RTS/CTS**) exchanges.

An **adaptive listening** can be used with S-MAC, so the next hop nodes can wake up in time to listen to possible transmissions. This option can improve the issues of latency and throughput I explained before.

However, static duty cycle remains a problem for energy consumption. In fact, sometimes when a transmission is not finished at the end of listen time, the node stay awake during the following sleeping time.

T-MAC

T-MAC stands for **Timeout MAC**. In fact, this protocol introduce a solution to the issue of static duty cycle. T-MAC works with an **dynamic timeout** mechanism. It decreases useless listening by adjusting the active period according to network traffic. T-MAC uses the same **synchronisation** and acknowledgment mechanism as S-MAC.

In this protocol, all messages are then transmitted in bursts of variable length and the node go to sleep between these active bursts.

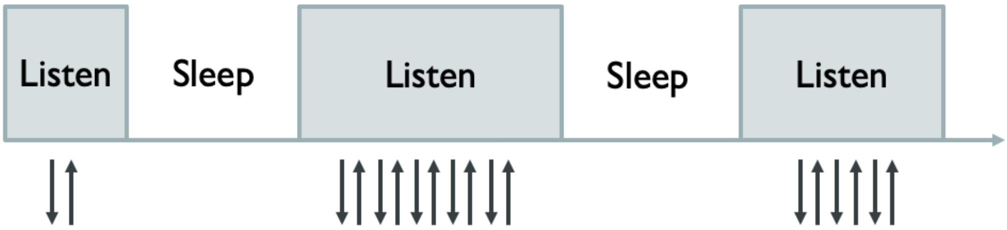


Fig 2 : Dynamic duty cycle for T-MAC protocol

If a neighbor node go to sleep when you still have to send messages, it will cause communication issues. In order to avoid this early sleeping problem T-MAC uses **FRTS** (Future Request To Send) mechanism and full buffer priority. This mechanism also provides **flow control.**

P-MAC

P-MAC stands for Pattern MAC. A node gets information about the activity in its neighborhood through **patterns**. Depending on these patterns, a sensor node chose either to put itself into a long sleep for several time frames (when there is no traffic) or to wake up at the reception time (known through the pattern information). Thus PMAC tries to save more power than SMAC and TMAC, without compromising on the throughput.

B-MAC (CSMA based)

B-MAC stands for **Berkley MAC**. This protocol provides a flexible interface to obtain low power operation, high channel utilisation and avoid collisions.

B-MAC feature to reduce power consumption is an **adaptive preamble sampling scheme**. This technique consists of listening for activity of the medium at fixed time intervals. It optimizes duty cycle and minimizes idle listening. In fact, when a node wants to send a message, it first sends a long wake-up preamble with destination information and then the message. When receiver wakes up, it listens to the channel if it senses a preamble it turns on its radio. If the message is destined to this node it waits for it, otherwise it goes back to sleep. This technique is part of a feature called **"Lower Power Listening"** (LPL).

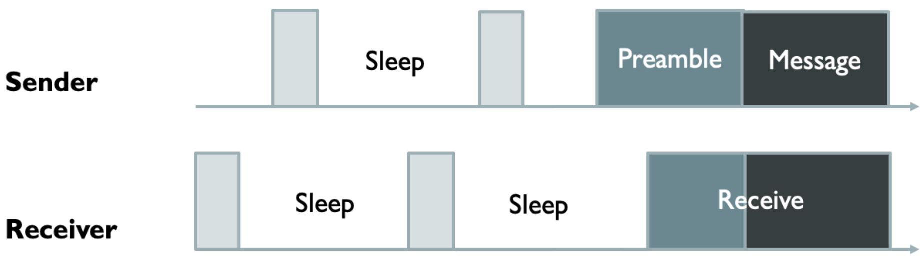


Fig 3 : Preamble mechanism of B-MAC protocol

It is one of the most used protocols because it has a very **simple implementation** and can be **reconfigurable** by lower layers. It is part of TinyOS for example.

This protocol is effective for high and low data rate. It uses **clear channel assessment** (CCA), back offs for channel arbitration and acknowledgments for reliability. It is tolerant to changes to the network and **synchronization** and **routing** are built above its implementation. It is scalable to large networks.

B-MAC+

B-MAC+ is a **new implementation of Berkley MAC** protocol. It tries to **limits waste** in energy consumption due to large preambles, using series of little preambles.

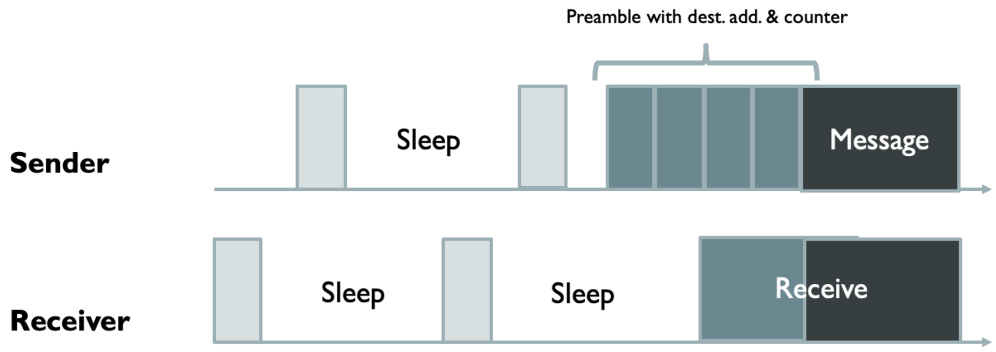


Fig 4 : Preamble mechanism of B-MAC+ protocol

X-MAC

X-MAC is a **low-power improvement** of B-MAC and B-MAC+ protocols. It uses a shortened preamble approach, which is a **serie of short preamble packets**, each packet containing the destination address and remaining number of preambles.
When the sender wants to transmit a message it first sends this serie of preambles at fixed interval, long enough to receive an answer from the targeted receiver. When the receiver get the preamble with its address it sends an **acknowledgment** to the sender. When this acknowledgment is received by the sender, it stops sending preamble and send directly the message.

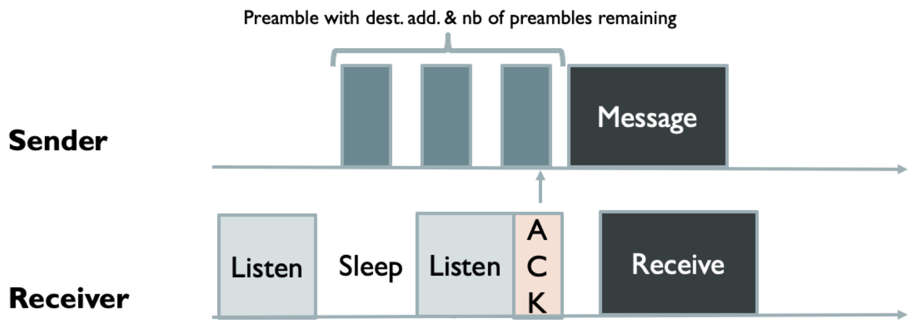
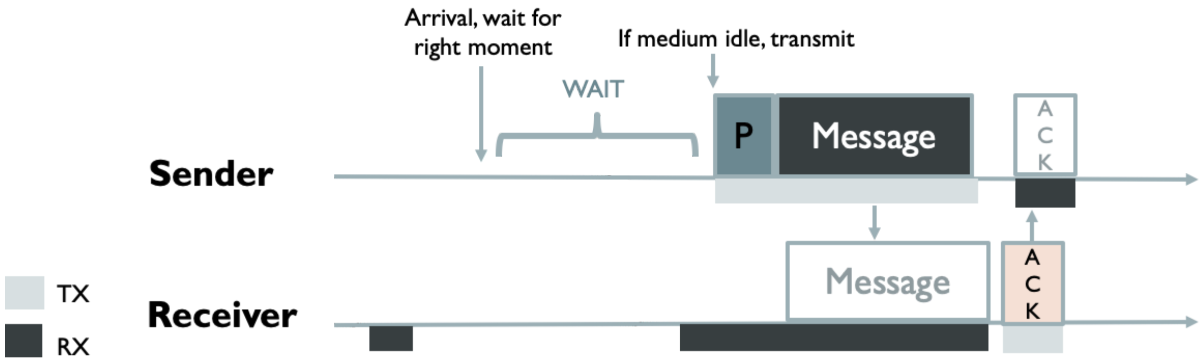


Fig 5 : Preamble mechanism of X-MAC protocol

This way, some useless preamble are avoided. This **reduces energy** at both receiver and sender sides and also **reduces latency** per hop.

Wise-MAC

Wise-MAC protocol is based on non-persistent CSMA and uses preamble sampling technique to reduce power consumption. WiseMAC requires **no network-wide synchronization** and is **adaptive to traffic load**. WiseMAC relies on **learning the sampling schedules of direct neighbors** of a node. These schedules are used to minimize size of preambles. To recover packet losses, a link level acknowledgement is used in WiseMAC. The WiseMAC ACK packets are also used to inform other nodes the remaining time of next listening sampling. These nodes store this time in their **sampling tables**, and then know precisely when their neighbors are listening and can send their data at this **exact time**.



Scheduled/Reservation based:

TRAMA

TRAMA Protocol, **Traffic Adaptive Medium Access Control**, is a method based on traffic in the network. TRAMA uses 3 main mechanisms :

- **Neighbor Protocol** (NP) : nodes discover their 2-hops neighbors by exchanging lists.
- **Schedule Exchange Protocol** (SEP) : nodes exchange their expected sleeping/active schedules.
- **Adaptive Election Algorithm** (AEA) : a protocol which chose the senders and receivers for each time slot regarding the results of NP and SEP. The nodes which are not chosen for this time slot switch to low power mode.

TRAMA reaches better percentage of sleep schedules and collision-free transmissions than CSMA-based protocols. This protocol seems to have a drawback which is **high latency**. It is a great protocol for use cases needing a high energy efficiency and throughput but are not delay sensitive. For example, **periodic data collection** and **monitoring applications**.

L-MAC

L-MAC stands for **Lightweight MAC**. It uses **TDMA** to allow nodes to share channel without collision. L-MAC is a **receiver-initiated** MAC protocol. The network is organized in time slots and **self-synchronized**. In fact, child nodes coordinates their wakeup time with their parent node without any synchronization or schedule exchanges through messages. This leads to a **high energy efficiency** and **low delivery delay** because each node knows when to send their data.

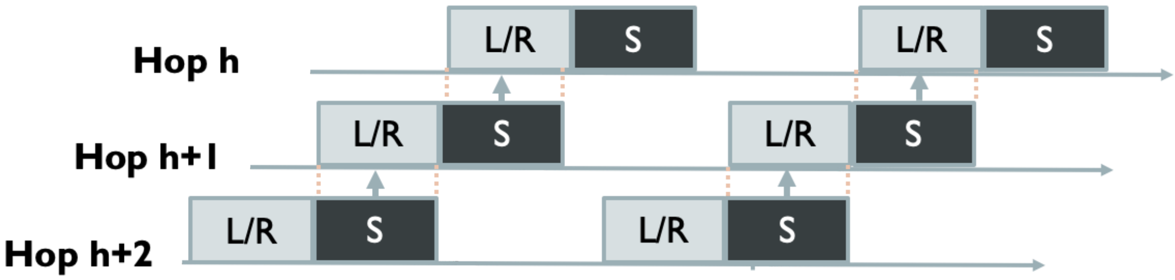


Fig 5 : Child/parent nodes coordination in L-MAC protocol

Hybrid and event based :

Hybrid protocols take advantage of CSMA and TDMA techniques. CSMA has the advantage to be simple and scalable while TDMA avoids collisions naturally. Both technique have drawbacks. For example, we have seen that CSMA-based protocols uses RTS/CTS but it means overhead. We have seen that in most of TDMA-based protocols synchronization is needed. Hybrid protocols therefore try to make the best combination of these technique to address WSN challenges.

Z-MAC

Z-MAC stands for Zebra MAC. The network behaves at **low data load** as in CSMA and **high network traffic** as in TDMA.

Z-MAC protocol starts with a set-up phase composed of four main steps :

- **construction of the network topology**

  Each node transmits ping. These pings are not only used for connectivity checking but also to transmit information about the sender and all know information about its neighborhood. Through these pings every nodes discover the network from direct neighbors to indirect ones.

- **distribution of time slots**

  Z-MAC uses **DRAND algorithm** to allocate time slots depending on the neighborhood list. This algorithm ensures that no two indirect neighbors receive the same time slot. It reduces latency and avoid collisions. A time slot can have multiple owners but they must be neighbors. A sender can transmit data at any time but has priority only on its time slot.

- **exchange of local time frame**
- **network-wide synchronization**

Z-MAC implements HCL mode, which stands for **High Contention Level.** A node is in HCL mode when it receives a **Explicit Contention Notification** (ECN) from its two-hops neighbor. A node in HCL mode is not allowed to contend for the channel on the two-hops neighbor time slot. ECN are sent when a node realises that it loses too many packets (based on ACK and CCA mechanisms). This feature increase QoS of the protocol.

Experiences have shown that for high contention Z-MAC is better than B-MAC protocol. However, for low contention B-MAC has better results.

Conclusion

Class	Protocol	Collision	Overhearing	Idle listening	Latency	Scalability	Throughput
Contention based protocol (CSMA)	**S-MAC**	High	Low	Low	Low	Very low	Low
	T-MAC	Good	Low	Low	Low	Very low	Low
	P-MAC	x	Low	Low	Moderat e	x	Low
	B-MAC	Good	Very low	Low	Low	Scalable for WSN with low traffic	Good
	B-MAC+	Good	Low	Very low < B-MAC	Low	Scalable for WSN with low traffic	Good
	X-MAC	Good	Low	Very low < B-MAC+	Very low	Scalable for WSN with low traffic	Good
	Wise MAC	Very low	Very low	Less	Low	High	Good

Scheduled based protocol (TDMA)	**TRAMA**	Very low	Very less	Very less	High	High scalability for low traffic WSN	High
	L-MAC	Very low	Very low	Low	High	x	High
Hybrid protocol (TDMA & CSMA)	**Z-MAC**	Very low	Low	Low	Moderate	Good	Moderate

Sources

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