Review on Wireless Sensor Network MAC Protocols

Kilian Desportes

MAC Layer

MAC Layer goal is to set rules for **medium access**.

Responsible for the majority of the **energy consumption**, it has to manage it properly to consume less, especially in WSN networks. Goal is to :

- optimize the **loss of packets** (packet collisions)
- optimize the **hearing** and **sleep time**
- optimize the **delay to transmit**
- reduce the **overhearing** (reception of packets not destined to this device)

Channel types

2 types of channel used in WSN networks : TDMA and CSMA

TDMA	CSMA
Strict Synchronization	Synchronization is flexible
Controlled Access	Random Access
High Channel Utilization under high contentions	High Channel Utilization under low contentions
Need Central Control	Completely decentralized

TDMA : Time division multiple access

Deterministic protocol, with a schedule plan which **associates a time slot for each sensor node**.

- **Avoiding collisions** and r**educing the effect of overhearing** and **idle listening problems**.
- Require **management authority** like a dedicated access point which manages the schedule.
- Requires **strict clock synchronization**, leading to a high energy load.
- Costly for TDMA to control dynamic topology changes (Which happens often in WSN).

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.

CSMA/CA : Carrier Sense Multiple Access with Collision Avoidance

Based on **probabilistic technique** where **each node listens** (carrier sense) before it sends and if nobody transmits the node will try to transmit a packet.

- Simple, flexible and durable.
- Multiple access means **multiple sensors can access the medium** at same time = **collisions**.
- **Doesn't require clock synchronization** and global topology knowledge.
- Nodes can **join the network dynamically** without having to do extra operations.
- Nodes can receive packets from different out-of-coverage area nodes. But this leads to packet collisions.
- Packet collision leading to energy loss in sensor applications. It can be alleviated by using a RTS/CTS operation. But it’s not perfect as RTS/CTS leads to additional loss (time and frequency ressources), data packets being small.

Described Protocols

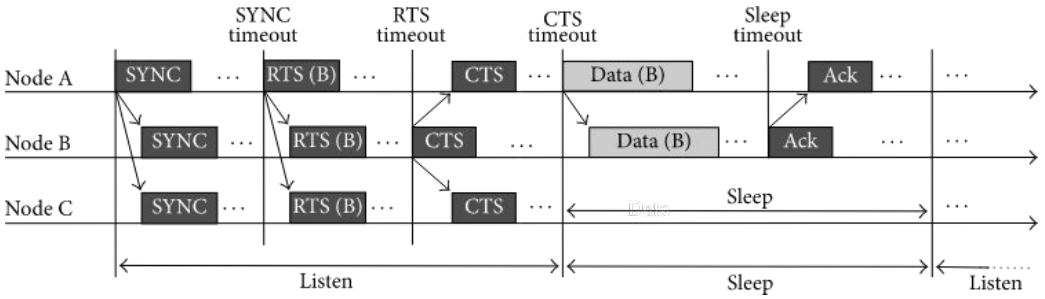
Channel Type	CSMA - Synchronous	CSMA - Asynchronous	TDMA	Hybrid
Protocol	S-MAC T-MAC P-MAC DSMAC	B-MAC X-MAC WiseMAC	TRAMA	Z-MAC

S-MAC | CSMA Synchronous

Synchronous Protocol : **based on schedule** sharing between nodes. Each node will have a schedule for its **listening** and **sleeping periods**, known by its neighbors. **Require clock synchronization** !

It will allow to communicate (sending or listening) at the right time and will optimize the sleeping time.

- **Periodical Listening**
- **Reducing collision**
- **Preventing unintentional receiving** (overhearing)

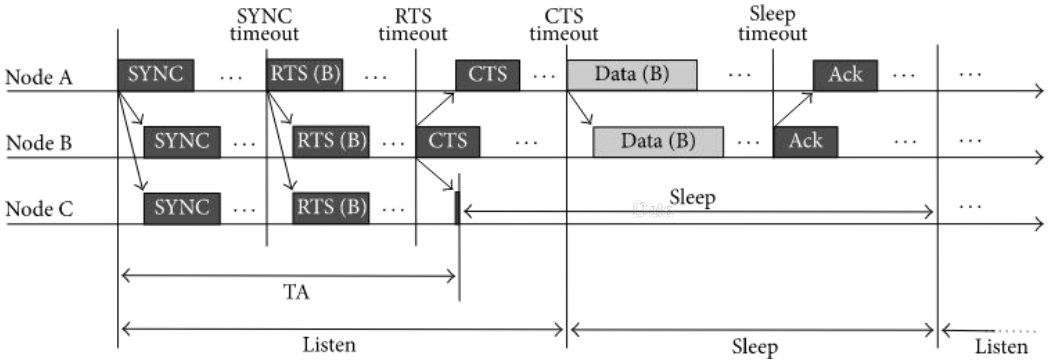


T-MAC | CSMA Synchronous

T-MAC is based on S-MAC. It will work with scheduling too.

The improvement compared to S-MAC is a **timeout that occurs** (switching in sleeping mode) when a node receives nothing for a long time.

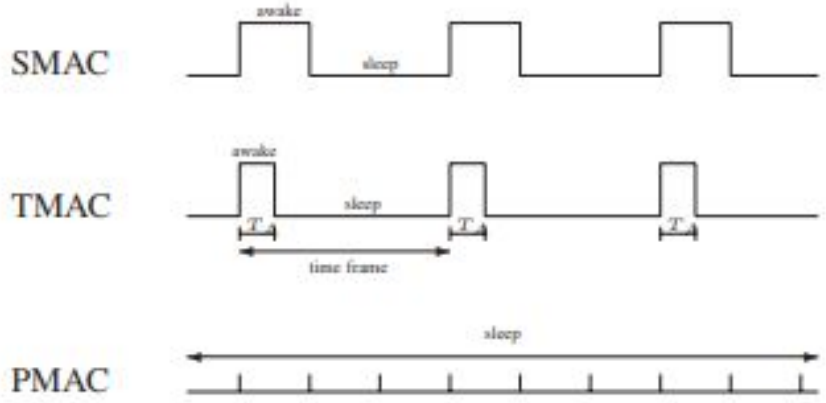
This will be very useful for variable traffic densities (if the traffic was important, then decrease, node will switch in sleep modes instead of staying in listening, and consume energy for nothing).



P-MAC | CSMA Synchronous

P-MAC is based on S-MAC.

Improvement is the **determination of sleeping period** that is **not stable but adapted to the traffic** and the neighbors of the nodes.

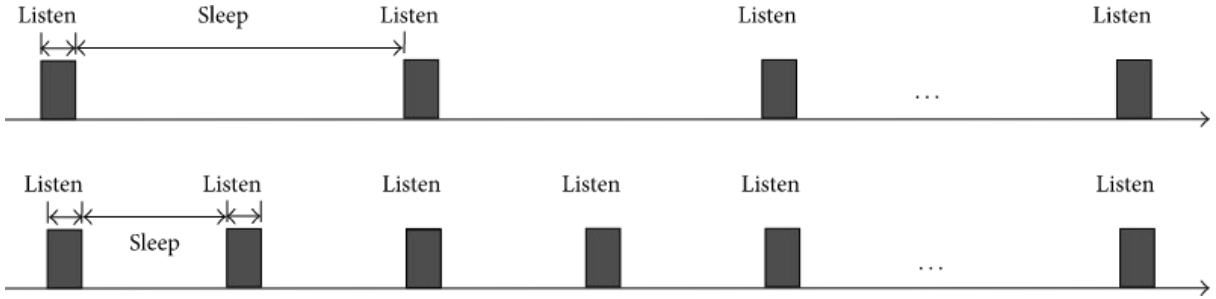


Comparison in case of ‘no traffic’

DSMAC | CSMA Synchronous

Based on S-MAC;

Adding a **dynamic time zone feature** to S-MAC Protocol. **Reduce the latency** for delay-sensitive applications. All nodes share one hop latency in SYNC period are in the same time zone, **improve latency over energy consumption**.



B-MAC | CSMA Asynchronous

Asynchronous protocol : **Periodic sleep/wakeup cycles** (but these periods are not stable and can differ for each nodes).

When there is a data to send :

- Node switched the radio mode and start to send a **preamble** (announcement), this one has to be **long enough to be received by every other nodes** (> sleep period)
- Afterward, the nodes start to transmit

No need to synchronization.

Using of LPL (**Low Power Listening**) to check if another node is sending a preamble.

X-MAC | CSMA Asynchronous

Based on B-MAC.

The improvement is the **sending of better preamble**, using **target address** of the node that needs to receive the frame.

Nodes that are not the target can directly go on sleep mode after receiving the preamble only.

WiseMAC | CSMA Asynchronous

Similar to B-MAC.

The improvement is the **preamble length** that is **adapted** to the **wake-up period** of neighbors listeners.

TRAMA | TDMA

Based on **TDMA**. **Switching nodes OFF** when not transmitting or receiving. **Packet collision will not occur**.

3 mains components :

- Neighbor Protocol (NP), **gathers information** from neighbor nodes.
- Schedule exchange protocol (SEP), **nodes exchanges** 2-hop neighbors information and programs.
- Adaptive Election Algorithm (AEA), **decides** on the nodes that will transmit and receive by using the neighbors program.

Z-MAC | Hybrid

Implemented on the top of B-MAC.

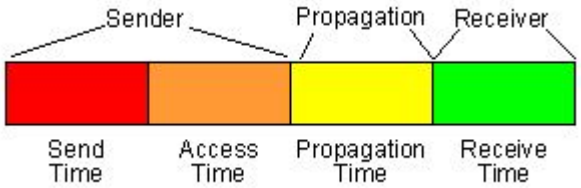
3 phases of **initialization** (that does not occur again except if there is a big topology change) :

- **Neighbors discovery** (1-hop neighbors + its list of neighbors = 2-hop)
- **Slot assignments** (Flexible to allow new nodes to join later)
- **Local frame exchange**
- **Global time synchronization**

Better idle listening than B-MAC because of both high contention TDMA and CSMA low contention.

CSMA as the baseline MAC scheme, TDMA schedule to enhance channel utilization during high contention.

Clock Synchronization



Time Synchronization in wireless networks is **extremely important** for **basic communication,** but it also provides the **ability to detect movement**, **location**, and **proximity**.

CSMA protocols does not require clock synchronization to work properly as their can listen the medium and retry if needed, however, to **improve efficacy** and **packet collision**, synchronization can be implemented.

Synchronized Protocols

Synchronized protocols are based on **scheduling** between every neighbors. The synchronization is required to maintain the ‘same’ schedule between nodes.

Synchronization is done with a **SYNC packet**.

Synchronizer node (the ones that create the original schedule) send **SYNC packets** to its **followers** (ones that receive the schedule).

Listening intervals with synchronized protocols are divided in two intervals : SYNC listening and RTS listening.

Synchronized Protocols

Protocols are : S-MAC, T-MAC, P-MAC, DSMAC, Z-MAC

P-MAC : Synchronization **adapted to the current traffic** and **neighbors**.

DSMAC : **SYNC packet** contains **nodes duty cycle** to allow **global adaptation** between nodes.

Z-MAC : Synchronization during the **setup phase**.

TRAMA : **Clock synchronization** required for TDMA.

Non-Synchronized Protocols

B-MAC, X-MAX, WiseMAC are working with **preamble mechanic**.

Synchronization is not required, each node has its **own schedule independently**, depending on different received preambles.

Localization

Localization is to **assign geographic coordinates to each nodes** with an unknown position in the deployment area.

Based on **co-operative localization** : Small number of **anchor nodes**, with known localization, other nodes forming the network around them. **Distance is approximated using propagation time between nodes** (Radio Signal Strength Indicator, **RSSI**, can be used).

This require to have a clock synchronization between nodes to **estimate the offset** of each one.

Localization

To be able to localize nodes, we need :

- **Rapid adaptation to topology changes** (mobile nodes)
- **Clock synchronization**
- **Transmission of period ranging probes**
- These probes should be send during reserved time slots.

Security Mechanisms

Broadcast wireless communication = **vulnerability**

CSMA/CA protocols are easy to attack, for example :

- **Keeping nodes awake** by broadcasting are right time (schedule or preamble)
- **Replaying SYNC packet** to **modify schedule** of nodes and prevent them to sleep.
- **Using CTS/RTS packets to create collisions**.

In addition, **easy to "listen"** due to wireless channel + broadcast

TDMA and **Hybrid Protocols** are **hard** to attack : **Predefined time slot** and **long sleep periods**.

Security Mechanisms

Security implemented through different mechanisms :

- CTR, counter mode, **counter based encryption**.
- CBC-MAC, **integrity and authenticity field added to frame**.
- CCM, **combination of both** CTR and CBC-MAC.

Wireless channel can be used as a means to authenticate :

- Channel that changes in time = **natural refresh**
- Slow time variation = **channel response can be accurately estimated** within the **coherent channel time**.
- **Comparison of wavelength** to detection who is speaking.

Nodes Mobility - Synchronous Protocols

In **synchronized** protocols, **mobile nodes keep radio receiver until reception of a SYNC frame** (to know schedule). Amelioration can be implemented, like in MS-MAC, with **synchronisation period adapted in function of the node speed**, detection with **RSSI signal**.

In MAC synchronized 802.15.4, **nodes are linked to a coordinator**, and they can **detect** and **re-link** themselves to a **new coordinator** as they move.

Into synchronized environment, **the need to resynchronize everything to integrate the mobile node cause high energy consumption**.

Nodes Mobility - Asynchronous Protocols

Preamble functioning is **hard** to **adapt to mobility**.

If the nodes are from another network, **preamble length will differ** = impossible communication.

X-MACHIAVEL, based on X-MAC, implement synchronization with a preamble protocols :

- Mobile node try to access the medium but a fixed node is sending its preamble, **the mobile nodes send a special ACK to announce it will transmit its own frame** to the fixed node that were sending the preamble. In addition, every nodes that received the ACK can become the destination node for the mobile node frame (in case these one is moving out of range of the old node).

Power Consumption

Main goal of MAC Protocols in WSN.

Very variable for a given protocol :

- Packet size
- Traffic
- Network size

Synchronous = P-MAC < S-MAC < T-MAC < DSMAC
Asynchronous = WiseMAC < B-MAC < X-MAC
Hybrid = Z-MAC
TDMA = TRAMA

+- order of release, each n+1 protocol being almost all the time based on the n protocol.

Each protocol has its **own advantages** and **disadvantages**. Most of time, **the protocol can be less energy consuming in exchange of latency**.

Power Consumption

Protocol	S-MAC	T-MAC	X-MAC	P-MAC	B-MAC	WiseMAC	TRAMA	Z-MAC
Energy Saving	Power savings over standard CSMA/CA	20% less than S-MAC	Better than SMAC,BMAC,WMAC	Low	Better power saving, latency and throughput than SMAC	Better than smac and classic LPL	High	Low
Advantages	Low traffic -> low energy consumption	Adaptive active time	Savings with LPL. Gains continues as network density increases	Adaptable to traffic and neighbors	Low overhead when the network is idle. Consume less power, easy to implement.	Energy consumption both at sender and receiver, and at non target receiver, increase latency at each hop.	TDMA : no collisions Unicast	Adaptive to traffic
Disadvantages	Sleep latency	Early sleeping problems	Unable to schedule small listening periods.	Renogiciation of schedule useless if the network is not changing	Overhearing bad performance when heavy traffic. Long latency.	Low power for low traffic, Do not incur overhead due to synchronization	Latency	Poor handling of high frequency of topology change (setup phease)

Conclusion

Every protocols have **advantages** and **disadvantages**, and are **optimised** for a **given usage**.

In function of the WSN you want to use and, for example, if you need mobility, low power consumption or short latency, you have to deploy different protocols.

Thank you for your attention !