MAC protocols dedicated to WSN/IoT

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I. Introduction

Wireless Sensor Networks (WSN) is a hot topic among academicians, industrials, chip manufacturers and service providers as they allow large-scale deployments in many applications (e.g. environmental monitoring, military, medical surveillance...). Moreover, Internet of Things (IoT) brings WSN to a whole new dimension by bringing things (e.g. sensors) or objects in general to the internet. This allows for the emergence of new business models and deployments leveraging a smart synergy between Cloud Services, Smart Devices and Distributed Sensors.

However advanced these discussions may seem, low level improvements are still happening and are allowing for further cost and service quality optimization of WSN / IoT backed architectures. For example, optimizing the Medium Access Control (MAC) layer protocols allows, among other things, to reduce the energy consumption of the sensors and to extend their lifetime.

Throughout this report, we aim to provide an overview of the most used MAC protocol within IoT and WSN industries such as (S-MAC, T-MAC, ...)

II. Sensor-MAC

Sensor Media Access Control (S-MAC) protocol was primarily designed for WSN. As a reminder WSNs are basically a network of battery-operated interdependent computing and sensing devices. The latter would collaborate for a common application (e.g. environmental monitoring).

	S-MAC	Traditional MACs (e.g. IEEE 802.11)
Energy Conservation	Important	less important
Self-configuration	Important	less important
Per-node fairness	less important	Important
Latency	less important	Important

Table 1 - S-MAC vs Traditional wireless MACs comparison

Individual nodes would remain largely inactive for long periods of time, but then become suddenly active when something is detected. Table 1 summarises the key differences between traditional wireless MAC protocols priorities and S-MAC and WSN requirements in general.

S-MAC uses three novel techniques to reduce energy consumption and support self-configuration.

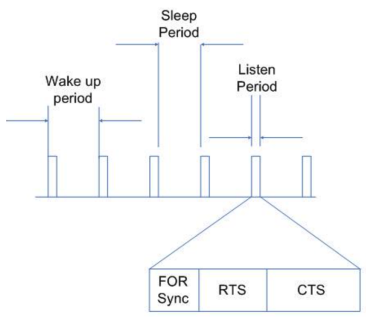

Figure 1 - Example of S-MAC duty-cycles

- Nodes would sleep periodically when listening to an idle channel. Neighboring nodes. Neighboring nodes from virtual clusters auto-synchronize on sleep schedules.
- S-MAC sets the radio to sleep during transmissions of other nodes. Only in-channel signaling is used
- S-MAC applies message passing to reduce contention latency for sensor-network applications that require store-and-forward processing as data moves through the network.

To do so, S-MAC is based on a synchronous duty-cycles protocol, i.e. nodes switch between active and sleeping states. S-MAC leverages clock synchronization to reduce clock drift among neighboring nodes by sharing a SYNC-packet (including its address and next sleep time)

As a result, S-MAC consumes 2 to 6 times less energy than 802.11 MAC for traffic load with messages sent every 1 to 10 seconds.

Advantages

- Increased energy efficiency
- good scalability and collision avoidance

Disadvantages

- increased end-to-end latency due to the periodic inactive states.

III. Timeout-MAC

Timeout-MAC or (T-MAC) is a MAC protocol that is derived from S-MAC protocol. While the sleep and active periods are fixed in S-MAC. T-MAC defines a timeout constant *Tact* after which sensor nodes would deviate to sleep period if no event has occurred.

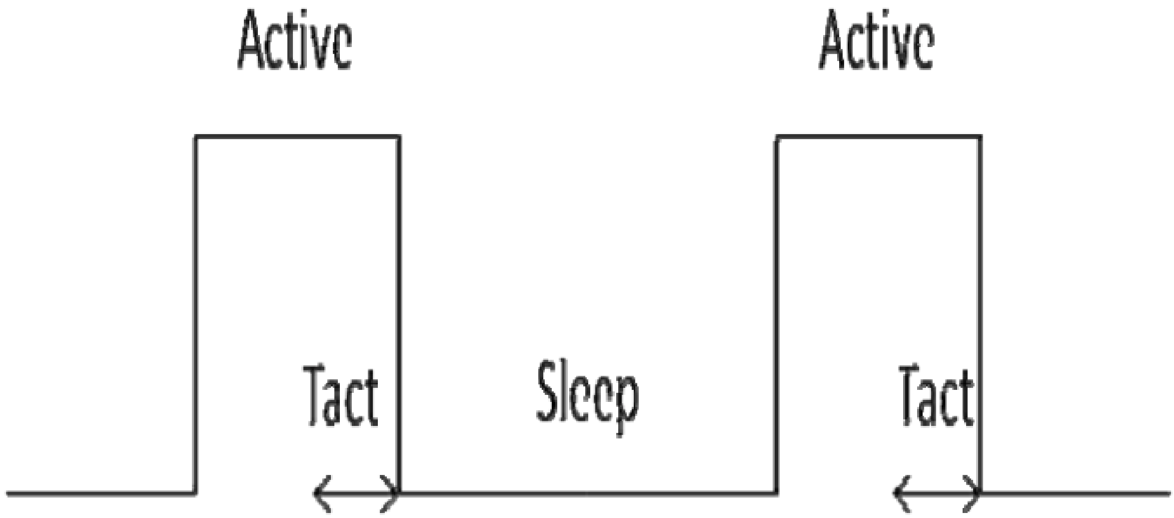

Figure 2 - T-MAC protocol dynamic adjustment of sleep / active periods

The interval *Tact* needs to be greater than the sum of contention time, length of an RTS packet, turn-around time and the length of CTS packet.

Reducing the idle listening time allows for further reduction of energy consumption and network overload. On the other hand, we undergo an increase of end-to-end latency compared to S-MAC. In addition, nodes in the interference range of a sender or a receiver can unnecessarily activate themselves and waste energy.

IV. Berkeley-MAC

B-MAC (Berkeley MAC) is a carrier-sensing media access (CSMA) protocol for wireless sensor networks that provides a flexible interface to achieve ultra-low power operation, efficient collision avoidance, and high usage. canals. To achieve low power operation, B-MAC uses an adaptive preamble sampling scheme to reduce duty cycle and minimize idle listening. B-MAC is designed for low traffic, low power communications, and is one of the most widely used protocols.

The B-MAC is an answer to problems that S-MAC and T-MAC are unable to solve such as:

- **Flexibility**: The need for accounting for network condition change.
- **Simplicity:** The need for simple implementations with small code for devices with limited RAM sizes
- **Scalability:** When high-scalability is your top priority

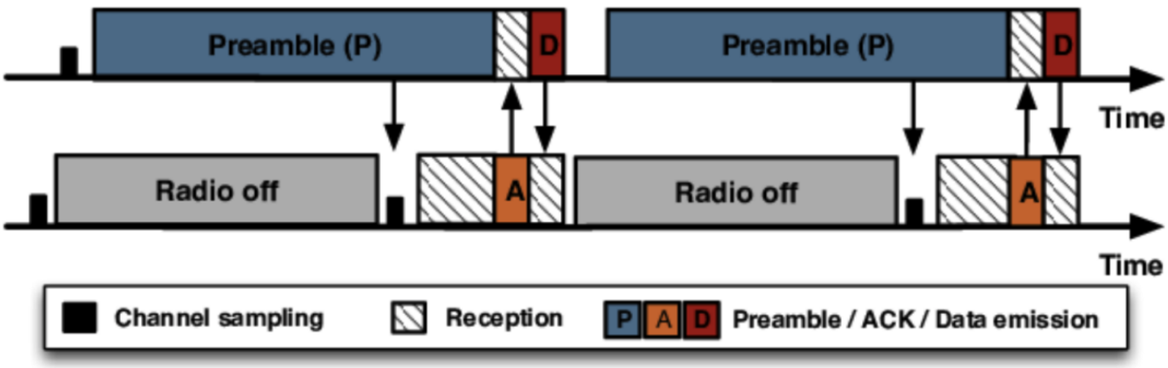

Figure 3 - Example of preamble-sampling MAC protocol

The main use-case for B-MAC is to monitor applications, but it is flexible enough to be used for other applications and services. The CCA (Clear Channel Assessment) is used in the B-MAC protocol packet backoffs for channel arbitration, link layer acknowledgements for reliability, and low power listening (LPL) for low power communication.

V. Zebra-MAC

Zebra-MAC or Z-MAC has a hybrid model. It combines the strength of TDMA in high contention with the adaptability of CSMA-based protocols in low contention. Nodes in Z-MAC have two modes

- low contention level LCL
- high contention level HCL

A node can transmit data, when the channel is clear if one of the following conditions is met:

- general case: the node is the owner of the time slot
- LCL case: the node wins the channel by contention
- HCL case: the current slot is not owned by any of its two-hop neighbors

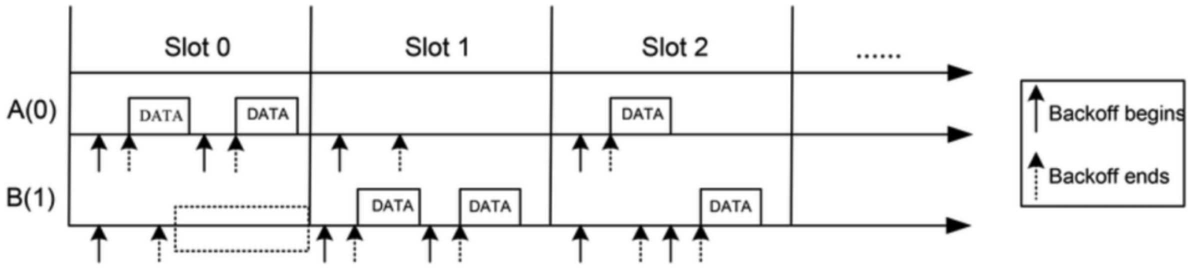

Figure 4 - Channel access mechanism of EETA-ZMAC protocol

Advantages

- Simple, Robust and flexible.
- CSMA: clock synchronization and network topology have no reqs. Nodes are allowed to join and exit without extra operational overhead.

Disadvantages

- Risk of access collision in multi-hop topologies

VI. Dynamic-MAC

Power Efficient Dynamic Mac or D-MAC features a tree-like organization of the nodes. The data delivery path is directed (unidirectional) tree-graph. There is a unique path between a given sensor node and a sink node. This model allows for continuous packet forwarding due to wake-up / sleep schedule of sensor nodes.

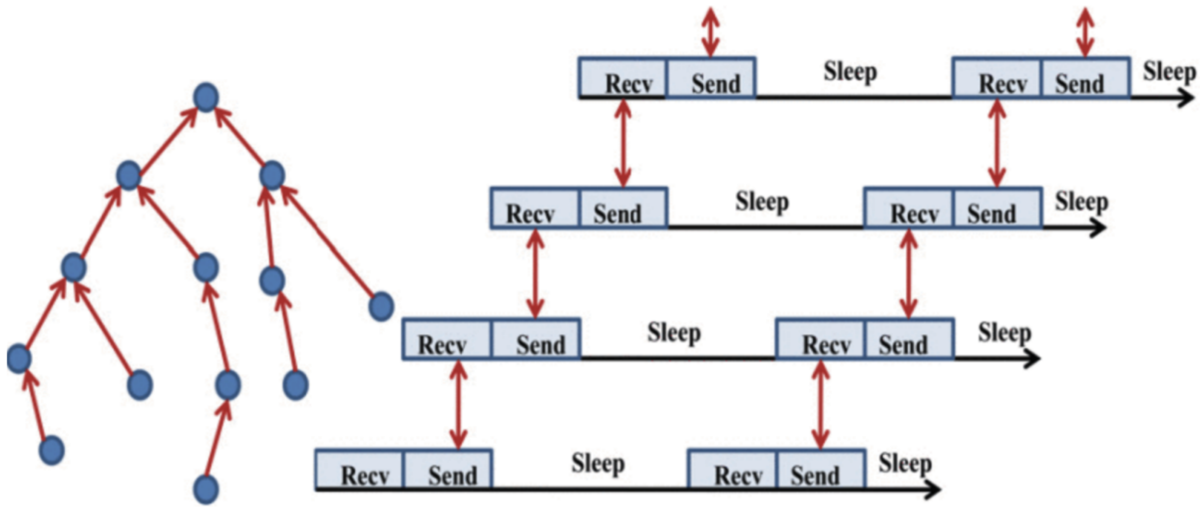

Figure 5 - D-MAC and its Data Gathering Tree

Here are the cycle steps of D-MAC protocol

- RX(Receive): A node waits to receive a package and sends ACK to the sender upon the reception of the latter.
- TX(Transmit): A node transmits a package to the next node in the graph. If there are many packets to send in TX period, a node increases its duty cycle and requests nodes along its multipath to do the same.
- SLEEP: Energy saving mode

Advantages

- End-to-end latency is reduced from sensor nodes to sink, compared with T-MAC and S-MAC
- Increased energy efficiency
- The use of ACK avoids the overhead caused by RTS and CTS in the context of sensor networks with small data packets.

Disadvantages

- Risk of collisions at the same level
- Tree graph raises a concern for energy consumption
- Limited to applications with low nodes mobility. Not suitable for all-around use-cases.
- Traffic is unidirectional and this can be a limitation when comparing to D-MAC and S-MAC

VII. TEEM (Traffic Aware Energy Efficient MAC)

We finish our overview with TEEM protocol, which consists of an improved version of S-MAC. The main modifications include reduced idle listening when no data is being transmitted by turning off node's radio much earlier.

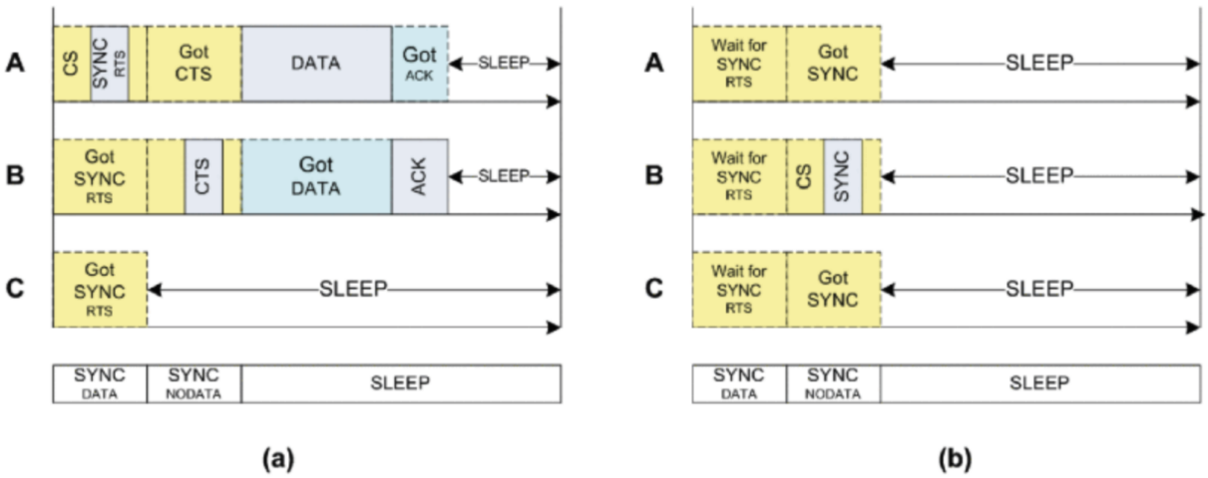

Figure 6 - Overview of TEEM protocol

The most important optimization behind TEEM protocol is that a node with data to transmit can schedule its transmission together with an RTS packet, thus, it only needs to contend the channel once.

Advantages

- Greater energy efficiency than S-MAC

Disadvantages

- Higher end-to-end latency compared to S-MAC

VIII. Conclusion

In this report we made an overview of a wide range of MAC layer protocols used for IoT / WSN systems. Researchers have worked over decades towards the optimization of energy consumption and the reduction of end-to-end latency at the MAC level.

Common patterns are:

- Alternation of active, sleep periods
- Some approaches feature smarter ways that adapt to the network activity
- Most of the protocols that we studied have foundations within S-MAC protocol.

With the high cloud adoption rate due to Covid-19 crisis and the massive investments governments and companies alike are spending on Cloud Technologies, the IoT and WSN technologies are here to stay and the Golden Age of Smart, connected, digital devices is coming.

References

[1] Wei Ye, John Heidemann and Deborah Estrin, In Proceedings of the 21st International Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2002), New York, NY, USA, June, 2002.

[2] T. V. Dam and K. Langendoen, "An adaptive energy-efficient MAC protocol for wireless sensor networks," in ACM Sensys'03, Nov. 2003

[3] Joseph Polastre, Jason Hill, and David Culler. 2004. Versatile low power media access for wireless sensor networks. In Proceedings of the 2nd international conference on Embedded networked sensor systems (SenSys '04). Association for Computing Machinery, New York, NY, USA, 95–107. DOI:https://doi.org/10.1145/1031495.1031508

[4] Injong Rhee; Warrier, A.; Aia, M.; Jeongki Min; Sichitiu, M.L. (June 2008). "Z-MAC: A Hybrid MAC for Wireless Sensor Networks". IEEE/ACM Transactions on Networking. 16 (3): 511–524. CiteSeerX 10.1.1.534.5720. doi:10.1109/TNET.2007.900704

[5] Tong F, Peng Y. A Data-Gathering, Dynamic Duty-Cycling MAC Protocol for Large-Scale Wireless Sensor Networks. Sensors (Basel). 2020;20(15):4071. Published 2020 Jul 22. doi:10.3390/s20154071

[6] Changsu Suh and Young-Bae Ko, "A traffic aware, energy efficient MAC protocol for wireless sensor networks," 2005 IEEE International Symposium on Circuits and Systems, 2005, pp. 2975-2978 Vol. 3, doi: 10.1109/ISCAS.2005.1465252.