MAC protocols dedicated to Wireless Sensor Networks (WSN) / Internet of Things (IoT)

Zacharie Hellouin
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Introduction

A growing number of technologies are based on Wireless Sensor Networks (WSN). While WSNs became common, a new paradigm emerged: Internet of Things. Most of the time, WSNs are constituted of a lot of small communicating sensor devices that are resources constrained.

In order to communicate in such networks, end-nodes generally use the same wireless transmission medium. This creates the need for a protocol capable of responding to multiple requirements in terms of reliability, responsiveness, power-consumption, security, data throughput and scalability.

Because the Medium Access Control (MAC) sublayer coordinates and controls how the hardware interacts with the transmission medium, it plays a key role in the performances of the network architectures cited above. Together, the MAC and the Logical Link Control (LLC) sublayers form the Data Link Layer which is the second layer of the Open Systems Interconnection (OSI) model standard.

Numerous MAC protocols exist, and several are still in development. In this work, we chose to focus on some of the most widely used ones in the context of WSN. In this work, we will detail and compare the characteristics of S-MAC, T-MAC, B-MAC, X-MAC, ER-MAC and MMSN.

Sensor-MAC (S-MAC)

S-MAC is one of the first MAC protocols specifically designed for WSNs. It is a contention-based protocol, and more precisely a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)-based protocol.

This means that nodes are aware of the state of the channel they want to use; each node has a fixed duty-cycle (that depends on the use of the WSN) and will alternate between sleep and listen states. During listening, a node will emit if there is no activity on the channel. Associated with the "Request to Send / Clear to Send" (RTS/CTS) packets exchange, nodes can negotiate the use of the channel and make a reservation for a communication. Unlike traditional CSMA, in S-MAC, long data is divided into fragments and ACK responses follow each fragment reception.

The use of RTS/CTS packets allow to avoid the problem of unreachable nodes, and the duty-cycles allows nodes to save power by avoiding over-emission and idle listening (listening during sleep times). However, these duty-cycle create latency, and listening while nothing is transmitted can be useless (over-listening). When compared to asynchronous protocols presented later in this work, the overhead (RTS/CTS and ACK) is heavy.

Moreover, S-MAC is synchronous: nodes will periodically exchange synchronization messages with neighbours to communicate their duty-cycle, thus forming a cluster of synchronized nodes.

In order to allow nodes mobility, synchronization frequency must be increased, but this creates a risk of network overload and augments power consumption.

Timeout MAC (T-MAC)

T-MAC is an evolution of S-MAC that aims to reduce the problem of over-listening. In order to achieve this, the duty-cycle is dynamically adjusted using a timeout-period: the listening phase ends if no activation events (radio activity, knowledge of near exchanges…) are detected. Thus, it consumes less power than S-MAC. However, a node can lose synchronization with other nodes within a cluster.

Berkeley MAC (B-MAC)

While B-MAC is also contention-based (the nodes know the current usage of the medium), it is an asynchronous protocol. This means that it doesn't require synchronization. Receivers sleep most of the time and listen shortly to sense if any data is incoming (Low Power Listening). If data needs to be received (i.e. a preamble is detected), it will continue to listen until complete reception of the preamble. Then, the data header indicates the destination of the packet and the node can decide whether it continues to listen or not.

This process is a simple, lightweight link protocol that is adaptable to topology changes, so it can be used with upper layers.

However, it encounters a lot of problems that are avoided by S-MAC and T-MAC:

- over-emitting: a long preamble will be emitted until the receiver wakes up
- over-listening: if a preamble is detected, the node will listen until its end even if it's not the receiver
- collisions
- latency
- unreachable nodes aren't managed
- High power consumption comparatively to other protocols

X-MAC

Like B-MAC, X-MAC is an asynchronous protocol which uses preambles. It aims to solve some of the problems encountered by B-MAC. Unlike B-MAC, the ID of the intended receiver is contained inside periodically emitted short preambles, so that other nodes can return to their sleep. When the receiver senses a preamble with his ID, he sends an ACK to the sender who can begin to send the data while the receiver stays awake to listen.

These techniques reduce the latency of the B-MAC and make it more power-efficient but is not well suited for broadcast communication. X-MAC remains adaptable to topology changes.

Energy-and-Rate based MAC (ER-MAC)

Like S-MAC, ER-MAC relies on duty-cycles and uses Time Division Multiple-Access (TDMA). This protocol is more complex since it takes into account the power level of each nodes to optimize power consumption of the whole WSN. With ER-MAC, low energy nodes and transmitting nodes are allocated more time slots than others, they can transmit if they need to or sleep if they have nothing to transmit while other need to say awake. Since ER-MAC is TDMA-based (scheduled), it has no collisions but needs tight clock synchronization. Thus, it is not adapted to mobile nodes communication and changing topologies.

Multi-Frequency MAC (MMSN)

Unlike other MAC protocols previously presented, MMSN uses frequency assignment at the beginning of the deployment: nodes are assigned a physical frequency following an assignment scheme. This allows simultaneous communication between nodes without collision. Since the frequency assignment happens during deployment, it can be difficult to adapt the network to topology changes. However, mobile nodes shouldn't be a problem.

Conclusion

During this work, we were able to discover the extreme diversity of available MAC protocols for WSN. Even if we tried to present some of the most classical protocols, it is still difficult to have a clear overview of existing technologies. We explored some of the advantages and drawbacks of the presented protocols, but these considerations are much more relevant in the context of a precise application. Indeed, power consumption and reliability can vary greatly depending on the context of the network deployment: nodes mobility, changing topology, QoS needed… During WSN architecture conception, MAC protocols must be compared extensively in context in order to choose an adapted technology. Despite the effort, this comparison is primordial considering the key influence of the MAC layer on the WSN's effectiveness.

References

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