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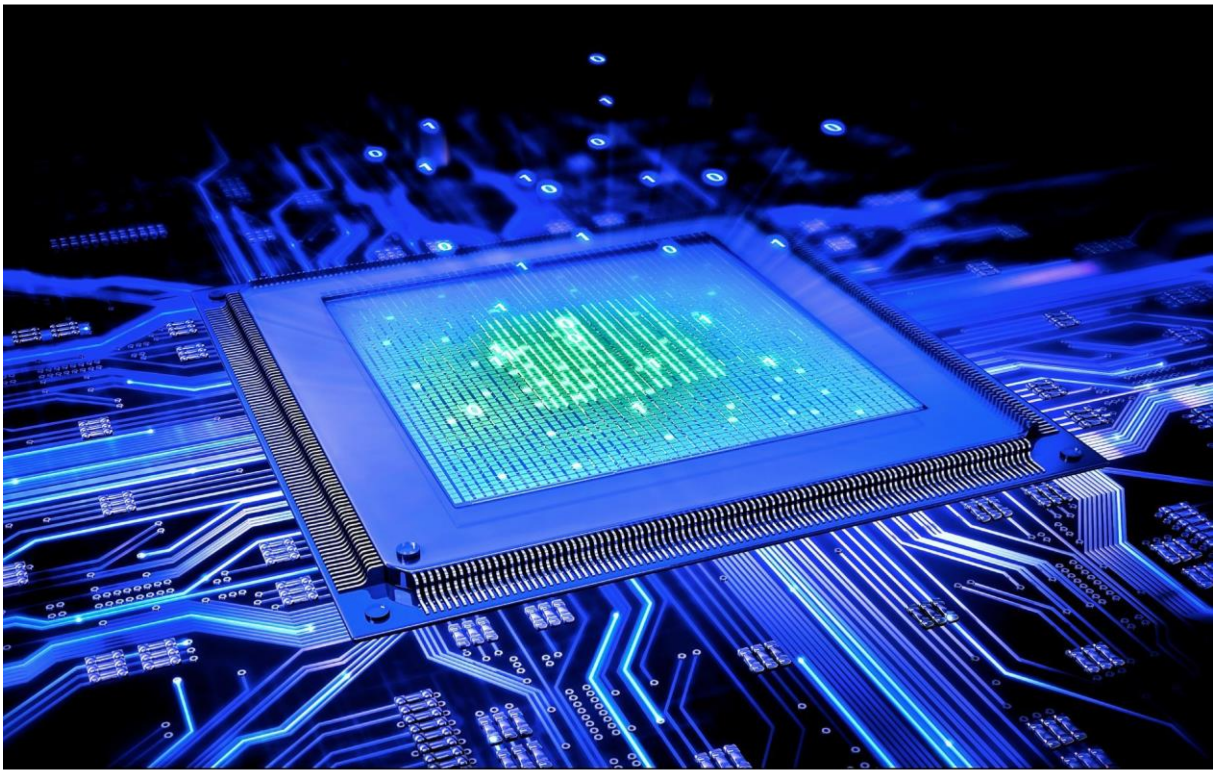
MAC protocols dedicated to WSN and IoT



Channelization

To describe better the different MAC protocols, it is important to qualify the several channel access methods that can be used. Channelization is a multiple-access method in which the available bandwidth of a link is shared in time, frequency, or through code, between different stations. Three different methods will be treated in this part: Frequency-Division Multiple Access (FDMA), Time-Division Multiple Access (TDMA) and Code-Division Multiple Access (CDMA). An evaluation of the advantages and disadvantages of each of those three methods will also be made. There exist other methods that will not be deeply treated here but might be mentioned and briefly explained if a protocol presented later does not use of the three following.

Frequency-Division Multiple Access (FDMA)

In FDMA, the transmission medium is divided into N separate frequency bands.

Advantages	Disadvantages
It allocates dedicated frequencies to different stations. Moreover, there are separate bands for both uplink and downlink. Hence stations transmit and receive continuously at their allocated frequencies.	In FDMA, frequencies are allocated permanently and hence spectrum will be wasted when stations are not transmitting or receiving.
It is simple to implement with respect to hardware resources.	Network and spectrum planning are cumbersome and time consuming.
FDMA is efficient when constant traffic is required to be managed with a smaller number of user population.	It uses guard bands to prevent interference. This wastes frequency resources.

Time-Division Multiple Access (TDMA)

In TDMA, the entire bandwidth capacity is a single channel with its capacity shared in time between N stations. Furthermore, a node with this method must always wait for its turn until its slot time arrives. Even if the node is the only one that need to send a frame, it must wait.

Advantages	Disadvantages
The operational costs of TDMA networks are lower compare to traditional FDMA network. ⇨ The different types of traffic such as voice, data and video are transmitted using TDMA technique as this require different data rates which can be easily achieved using allocation of multiple time slots.	Network and spectrum planning require more efforts.

Code-Division Multiple Access (CDMA)

In CDMA, one channel only carries all transmissions simultaneously. All the stations code their signal by specific codes before transmission. Then, the receiver uses these codes to recover the data for the desired station.

Advantages	Disadvantages
The CDMA does not require any synchronization.	The system is more complicated.
It has a greater number of users can share the same bandwidth	As the number of users increases, the overall quality of services decreases.
Due to code word allocated to each user, interference is reduced.	
Efficient practical utilization of fixed frequency spectrum.	

Protocols

Now that we discussed the different channelization methods, we can treat different types of MAC protocol that can use some of the previously seen channel access methods.

B-MAC

The protocol B-MAC, which is also known as Low Power Listening, is one of the mostly know protocol for wireless sensor networks. A major advantage of working with this protocol is that it does not require any synchronization and is known for obtaining ultra-low power operations. What the protocol does is allowing a sensor to listen to a channel activity but only periodically.

If sensors do not have any packet to transmit, sensors switch OFF their receivers for certain amount of time and waking it up at regular intervals to check for ongoing transmissions. Otherwise, if devices found the channel is busy during the channel sensing process, the nodes turn ON their receivers until receive data packet or after a certain time out period. The transmission procedure is also interesting since the sender must send first a shorter packet that is called preamble. As soon as the receiver detects the preamble, it stays awake until receiving the whole preamble. Once this preamble has been transmitted, the sender can send the data and go back to sleep.

When it comes to channel access, B-MAC uses the Clear Channel Assessment (CCA). This method is dedicated to evaluating the noise that can be present depending on the environment. It treats the signal to make it look clearer and then determines whether the transmission should be made (clear then transmit, busy then back off).

S-MAC

S-MAC stands for Sensor-MAC. This protocol is based on locally managed synchronizations and on periodic sleep-listen schedules that are based on these synchronizations. Using this protocol, nodes are placed in a state that listens to the medium; if a node hears nothing it sends a SYNC packet with a schedule defining listen and sleep periods. All nodes hearing this packet will adopt the schedule. Nodes may adopt two or more schedules (if different neighbours have different schedules). Nodes keep tables with the schedules of their neighbours. If a node is not part of a conversation, it enters a sleep state leaving the implicated nodes sending data packets.

One of the advantages of S-MAC is sleeping that can help reducing power consumption. This protocol can also easily adapt its topology. Disadvantages of S-MAC include the need to maintain loose synchronization for the schedules to work properly. Clock drift in the nodes can result in nodes becoming unsynchronized.

When it comes to channel access, S-MAC uses the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). The CSMA / CA method tries to reduce the frequency of collisions and at the same time provides a plan, a structure on how to proceed in the event of a collision.

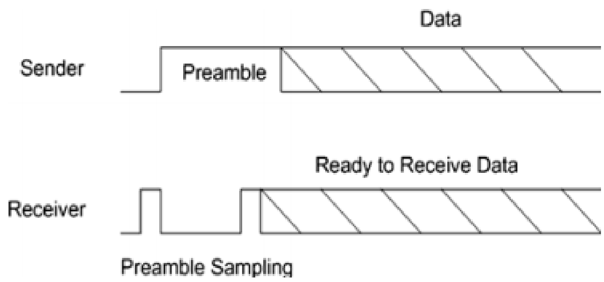
T-MAC

Timeout T-MAC is the protocol based on the S-MAC protocol in which the active period is pre-emptied, and the sensor goes to the sleep period if no activation event has occurred for a time. The event can be reception of data, start of listen/sleep frame time etc. The Timeout-MAC (T-MAC) protocol introduces the idea of having an adaptive active/inactive (listening/sleeping) duty cycle to minimize the idle listening problem and improve the energy savings over the classic CSMA and S-MAC fixed duty cycle-based protocols. The T-MAC protocol, however, suffers from the known early sleep problem, which can reduce throughput.

However, there is a response possible against this problem. T-MAC introduces a FRTS (Future request to send) mechanism and full buffer priority, to avoid early sleeping. When a node which has a data to send overhears a Clear to Send (CTS) packet, it broadcasts a FRTS. The duration of the data is stored in this new FRTS packet. The receiver of the FRTS sets its Network allocation vector (NAV) and goes to sleep. After the communication, node again wakes up to receive the data the sender of FRTS. In full buffer priority, when the sending buffer of a node is full and it receives a Request to Send (RTS) from some node, then instead of replying with CTS, node transmits its own RTS thus taking the priority. When it has completed the data sending, only then it replies with CTS to the original RTS request it received. So, this mechanism also introduces the flow control in the data flow.

WiseMAC

The Wise MAC protocol which combines TDMA and CSMA techniques in order to determine the length of the preamble dynamically to reduce the power consumption and thus it results better performance under especially variable traffic conditions. The Wise MAC protocol seems to perform better than the S-MAC protocol because the possible adjustment of its preamble length gives it an edge.



Using this protocol, all sensor nodes are defined to have two communication channels. There is a data channel that can be accessed with TDMA method and on the other hand, the control channel is accessed with CSMA method. However, the protocol itself uses non-persistent CSMA (np-CSMA) to decrease idle listening. The fact that this protocol can adapt the size of the preamble comes directly from the knowledge of each node’s direct neighbour characteristics. The nodes learn the sleep schedule of their neighbours at each data exchange. Then, Wise-MAC can schedule transmission so the preamble and the node’s sampling time match perfectly.

The main drawback of this protocol is that decentralized sleep-listen scheduling results in different sleep and wake-up times for each neighbour of a node. This can become a problem when it comes to broadcasting because the transmitted data packet will be delivered many times as each neighbour wakes up. This redundancy can lead to a larger latency and more power consumption.

TRAMA

The Traffic-adaptive medium access (TRAMA) protocol is a distributed TDMA mechanism that allows for flexible and self-motivated scheduling of time slots. This protocol provides the energy-saving advantages of schedule-based mechanisms without the disadvantages of having a node as the main controller. TRAMA consists of three components that assign time slots only to stations that have traffic to send while being implemented in a distributed fashion. Further, it performs better than other mechanisms because the slot assignment allows to prevent collisions. The main issue of this protocol is its lack of energy-efficiency due to overhearing.

In this protocol, time is divided into random-access and scheduled-access periods. A random-access period is used to establish two-hop topology information where channel access is contention-based. An assumption is made that says that, when the information passes by the application layer, the MAC layer can calculate how long will be the time duration needed. After that, the node calculates the number of slots for which it will have the highest priority among two-hop neighbours within the next period. The node announces the slots it will use as well as the intended receivers for these slots with a data packet called the “schedule packet”. Additionally, the node announces the slots among those but that will not be used. The schedule packet indicates the intended receiver. Since the receivers of those messages have the exact list and identities of the one-hop neighbours, they find out the intended receiver. From a latency point of view, this protocol’s delays seem higher compared to contention-based protocols due to higher percentage of sleep times.

The main advantage of this protocol is that it has a higher percentage of sleep time and a smaller probability of collisions when you compare it to a CSMA based protocol. Another going point for this protocol is that, because the receivers are found more easily, the communication for multicast or broadcast is lower. The drawback is that the duty cycle must be quite important to allow the nodes to define themselves to each other.

Comparison

As a conclusion, the following table recaps the different characteristics of each protocol.

	Time Synchronization Needed	Type	Adaptivity to Changes
B-MAC	No	CCA	Medium
S-MAC / T-MAC	Locally or No	CSMA / CA	Good
WiseMAC	No	np-CSMA	Good
TRAMA	Yes	TDMA / CSMA	Good