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# Energy-efficient MAC protocols for wireless sensor networks: a survey

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***Abstract***

*MAC Protocols enables sensor nodes of the same WSN to access a common shared communication channel. Many researchers have proposed different solutions explaining how to design and implement these protocols. The main goal of most MACs protocols is how to prolong lifetime of the WSN as long as possible by reducing energy consumption since it is often impossible to change or to recharge sensors' batteries. The majority of these protocols designed for WSN are based on "duty-cycle" technique. Every node of the WSN operates on two periods: active period and sleep period to save energy. Until now (to our knowledge) there is no ideal protocol for this purpose. The main reason relies on the lack of standardization at lower layers (physical layer) and (physical) sensor hardware. Therefore, the MAC protocol choice remains application-dependent. A useful MAC protocol should be able to adapt to network changes (topology, nodes density and network size). This paper surveys MAC protocols for WSNs and discusses the main characteristics, advantages and disadvantages of currently popular protocols.*

***Keywords**: duty-cycle, energy-efficiency, MAC protocol, wireless sensor networks*



## 1. Introduction

A WSN consists of spatially distributed autonomous and embedded devices that cooperatively monitor physical or environmental conditions. The data collected by each node (such as temperature, vibrations, sounds, movements etc.) is sent to a sink station in a hop-by-hop fashion using wireless transmissions as shown in Figure 1. This data can then be processed and analyzed for a better understanding of the monitored environment [1].

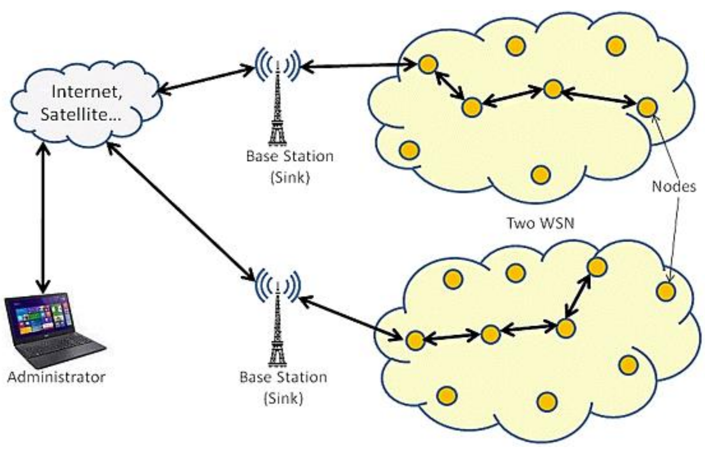


Figure 1. WSNs organization

WSNs have become very popular these days. This is due to advanced technology mainly in microelectronics where the sensors' prices have been considerably reduced. Recent technological advances have led to the emergence of distributed wireless sensor networks

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(WSNs) which are capable of observing the physical world, processing the data, making decisions based on the observations and performing appropriate actions. These networks can be an integral part of systems such as battlefield surveillance, microclimate control in buildings, nuclear, biological and chemical attack detection, home automation and environmental monitoring. In WSNs, the phenomena of sensing are performed by sensors. Sensors are low-cost, low power devices with limited sensing, computation, and wireless communication capabilities. Moreover, the number of sensor nodes deployed in a target area may be in the order of hundreds or thousands [2].

## 2. MAC Protocol Design Parameters

There are a number of parameters that influence the design of a MAC protocol. Among these parameters: collision avoidance, energy efficiency, scalability, and channel utilization [3].

– Collision avoidance

Collisions occur only in contention based MAC protocols which are based on CSMA/CA protocol. The basic task of these protocols is to reduce the number of collisions as much as possible.

– Energy efficiency

This is the most important parameter that affects WSN. In classical wireless networks, like Wi-Fi or Bluetooth, the design of MAC protocol focuses on throughput. But in WSN, the goal is to emphasize on extending its lifetime. The MAC protocol acts directly on radio frequency (RF) module which is a major energy consumer.

– Scalability and Adaptability

An acceptable MAC protocol should be able to accommodate to changes in network, such as: network size, node density and topology. These changes are due to the fact that some nodes may die over time, some new nodes may join later, and/or some nodes move to different locations.

– Channel utilization

It reflects how well the entire bandwidth of the channel is utilized during the communication. It is also referred to as bandwidth utilization or channel capacity. It is an important issue in cell phone systems or wireless local area networks (LANs). The bandwidth is the most valuable resource in such systems and service providers want to accommodate as many users as possible. In contrast, the number of active nodes in sensor networks is primarily determined by the application. Channel utilization is normally a secondary goal in sensor networks.

## 3. Main Sources of Wasted Energy

The sources of energy consumption in WSNs are three units: microcontroller, sensor and radio transceiver. The sensor unit and the processing unit consume negligible amounts of power when compared with the radio unit [4].

- Overhearing: listen to messages (or frames) destined to other sensor nodes. Overhearing irrelevant frames can be avoided through a filtering based on their destination addresses. Two other forms of overhearing are the reception of redundant broadcast messages and the reception of the long preamble in preamble-sampling protocols.
- Collisions: they may happen when a node is within the transmission range of one or more nodes that are simultaneously transmitting so that it does not capture any frame. The energy drained in the transmission and reception of collided frames is just wasted.
- Idle Listening: it happens when a node does not know when it will be the receiver of a frame so that it keeps its radio on while listening to the channel waiting for potential data frames. The amount of energy wasted whilst the radio is on is considerable even when it is neither receiving nor transmitting frames.
- Overhead: The use of control frames like RTS, CTS, ACK and SYNC packets for synchronization, which are not data packets, consumes energy. Note that RTS/CTS exchange incurs high overhead, 40% to 75% of the channel capacity, because data frames are typically very small in sensor networks.

## 4. Protocols Classification

The protocols designed for sensor networks can be organized broadly into three classes as shown in Figure 2:

– Scheduled-based protocols.
– Contention-based protocols.
– Hybrid protocols.

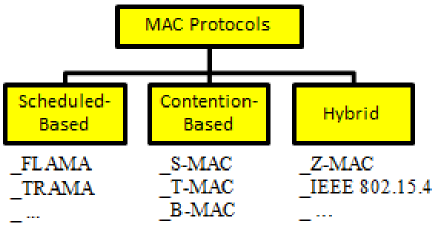


Figure 2. MAC Protocols classification

## 5. Contention Based Protocols

These protocols are based on CSMA/CA algorithm. All nodes are in competition to share the same common channel. It is allocated based on on-demand approach. A contention mechanism is employed to decide which node has the right to access the channel at any moment. They can easily adjust to the topology changes and have higher costs for message collisions, overhearing and idle listening. There are a number of contention based protocols described in the literature [5]. Typical examples are: S-MAC, T-MAC and B-MAC.

### 5.1. S-MAC (Sensor-MAC 2002)

The CSMA/CA technique has the disadvantage of requiring nodes to continuously sense the channel for inactivity. This requirement results in significant energy consumption, especially when nodes do not have any packets to transfer. In order to address this challenge, duty cycle operation has been introduced through the S-MAC protocol [6]. Using this operation, the activity of a node is scheduled according to a specific amount of time, called a frame. During this frame, as shown in Figure 3, a node sleeps for a specific amount of time and listens to the wireless channel for the rest of the frame. The ratio of the listen interval to the total duration of the frame is denoted as the duty-cycle. During the sleep interval, the radio of the node is switched off to save energy [7]. The basic scheme is shown in Figure 3. All nodes switch periodically between active (Listen) period and sleep period by setting a timer at the end of the active period to wake up the node. The Duty-cycle can be fixed for all the nodes according application type [6].

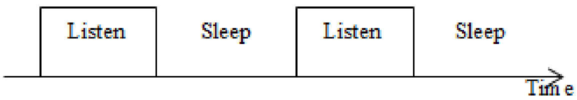


Figure 3. Periodic listen and sleep

Sleep and listen periods are predefined and constant. This means that the “duty-cycle” is fixed. Consequently the protocol S-MAC is not adaptable to traffic variation. In addition of using RTS, CTS and ACK packets, S-MAC uses SYNC packets also for synchronization. Another drawback of the protocol is the high number of overheads packets which represents a significant percentage of the total traffic [6].

In another paper [8], the authors assign a fixed active period size, 115 ms, with a variable sleep period. The length of the sleep period fixed the duty cycle of S-MAC. At the beginning of each active period, nodes exchange SYNC packets. The modification of the Duty-cycle affects Energy consumption and Latency. These two parameters are inversely proportional. A main characteristic of S-MAC is the mechanism called “message passing” which consists on splitting data packet into little pieces and then transmits them in a burst [8]. The S-MAC protocol essentially trades used energy for throughput and latency. Throughput is reduced because only the active part of the frame is used for communication as shown in Figure 4. Latency increases because a message-generating event may occur during sleep time. In that case, the message will be queued until the start of the next active part.

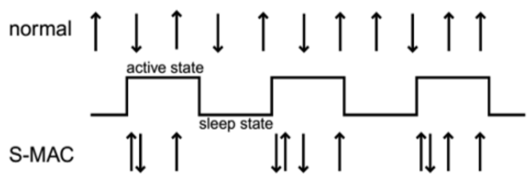


Figure 4. S-MAC duty-cycle; ↑: emission; ↓: reception

### 5.2. T-MAC (Timeout-MAC 2004)

T-Mac is based upon the basic features of S-MAC in optimizing power efficiency by sleeping during periodic network in activity. However, unlike S-MAC, T-MAC follows dynamic sleep schedule. The T-MAC protocol introduces an active timeout mechanism that decreases the idle listening overhead by dynamically adjusting the active period according to network traffic loads. T-MAC allows the nodes to sleep after sometime when all network traffic has completed, as shown in Figure 5.The end of traffic is signaled after monitoring an idle channel for an Adaptive Timeout (TA) period. If no activity occurs for this time duration, node switches off its radio and goes to sleep state [9]. To handle load variations in time and location T-MAC introduces an adaptive duty cycle in a novel way: by dynamically ending its active phase. This reduces the amount of energy wasted on idle listening, during which nodes wait for potentially incoming messages, while still maintaining a reasonable throughput [2].

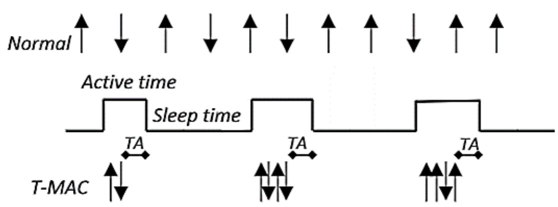


Figure 5. T-MAC protocol. ↑ : emission; ↓ : reception

T-MAC [2] performs better than S-MAC in terms of energy consumption because it uses a very short listening slot at the beginning of each active state. The two packets RTS and CTS are sent or received in a short window just after the synchronization step. If nothing appears in that period, the node switches off its radio and sleep. T-MAC outperforms S-MAC by using an adaptive duty-cycle and saves energy at a cost of minimized throughput and extra latency. At high traffic, T-MAC use the one fifth of S-MAC power, but when traffic is homogeneous, T-MAC and S-MAC are well energy-efficiency equally. T-MAC, like S-MAC, suffers from the complexity and scaling problems [8].

### 5.3. B-MAC (Berkley-MAC 2004)

B-MAC [8] has been designed at Berkeley University. B-MAC is based on two mechanisms: sleep–wake scheduling using low-power listening (LPL) and carrier sensing using Clear Channel Assessment (CCA). Both of these mechanisms improve the energy efficiency and channel utilization. Furthermore, B-MAC provides simple interfaces for the higher layer services to easily configure the underlying MAC operation. This enables rapid development of cross-layer solutions, which require the basic functionalities of a MAC Protocol [7]. B-MAC not only doesn't use the RTS-CTS packets but SYNC packets also. This makes B-MAC implementation simple.

When a node wakes up, it turns on its RF module and checks the channel state using CCA (Clear Channel Assessment). If there is no activity, the node goes to sleep (turn off its RF module). Otherwise, the node remains awake to receive packets. After reception, the node goes into inactive state, except if it has packet to relay to another node. Each packet transmission is preceded by a long preamble. A preamble consists of a specific pattern of bits to let a receiver know that a data frame will be transmitted [10]. Preamble size must be longer than the sample interval in order to be detected by all nearby nodes (next hope). In that way, the receiver node is informed, then wakes up to receive data packet as shown in Figure 6.

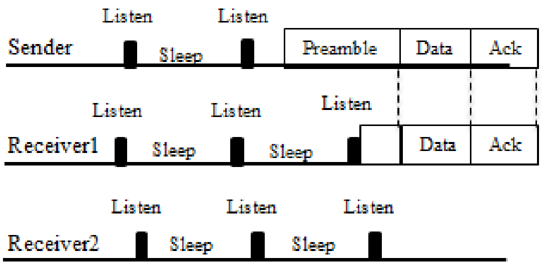


Figure 6. Preamble sampling

### 5.4. X-MAC (2006)

B-MAC is the default MAC protocol under Tiny-OS. It uses an extended preamble and preamble sampling. This asynchrone protocol B-MAC is easier and consumes less energy, but the long preamble leads to more latency at each hop, which is less suitable for energy consumption. Also there is energy wasted at receivers not concerned by transmission. The protocol X-MAC gives solutions to these problems by using a shorter Preamble technique that retains these advantages of Low Power Listening, particularly low power communication, simplicity and combining transmitter and receiver sleep schedules [11].

Similar to B-MAC, X-MAC proposes also the auto-adaptation sleep duration in function of traffic variation. X-MAC divides long preamble into many short preambles. In B-MAC, target address is located in data header (Data) but in X-MAC target address is inserted in every short preamble. When the sender receives acknowledgement, it knows that the target node which sent the acknowledgment is awake so it stops sending short preambles as shown in Figure 7.

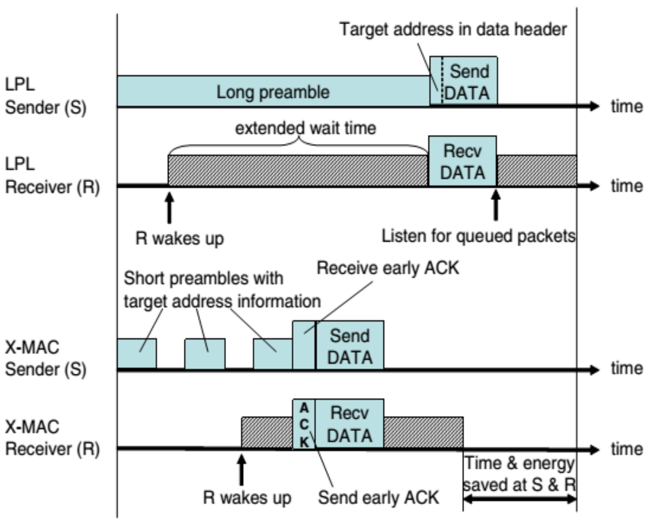


Figure 7. Comparison of the timelines between LPL's extended preamble and X-MAC's short preamble approach

In X-MAC, the overhearing problem is improved by dividing the one long preamble into a series of short preamble packets, each containing the ID of the target node, as indicated in Figure 7. The stream of short preamble packets effectively constitutes a single long preamble. When a node wakes up and receives a short preamble packet, it looks at the target node ID that is included in the packet. If the node is not the intended recipient, the node returns to sleep immediately and continues its duty cycling as if the medium had been idle. If the node is the intended recipient, it remains awake for the subsequent data packet. As shown in Figure 7, a node can quickly return to sleep, thus avoiding the overhearing problem.

## 6. Scheduled-Based Protocols

These protocols are based on TDMA technique. TDMA-based protocols are naturally energy preserving, because they have a duty cycle built-in, and do not suffer from collisions. However, maintaining a TDMA schedule in an ad-hoc network is not an easy task and requires a certain complexity in the nodes. Each node must keep a list of its neighbor's schedules which takes valuable memory capacity. Reserving TDMA slots is a difficult problem that requires coordination between nodes. Also, as TDMA splits frame into very short slots, the effect of clock shifting can be catastrophic; exact synchronization is critical [2].

The time is divided into slots. Each node knows when to transmit. Reservation-based protocols have the advantage of collision-free communication since each node transmits data during its reserved slot. Hence, the duty cycle of the nodes is decreased resulting in further energy efficiency. On other hand they are not adaptable to traffic volume or topology change and need synchronization.

Recently, TDMA-based protocols have been proposed in the literature. Generally, these protocols follow common principles, where each node communicates according to a specific super-frame structure. This super-frame structure, generally, consists of two main parts as shown in Figure 8 [7].

The reservation period is used by the nodes to reserve their time slots for communication through a central agent, i.e., cluster head or with other nodes. The data period consists of multiple time slots that are used by each sensor for transmitting information. Among the proposed TDMA schemes, the contention schemes for reservation protocols, the slot allocation principles, the frame size, and clustering approaches differ in each protocol [7]. TRAMA and FLAMA are typical examples of these protocols.

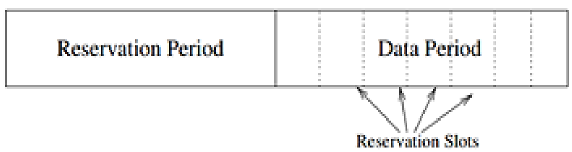


Figure 8. General frame structure for TDMA-based MAC protocols

### 6.1. TRAMA protocol (Traffic-Adaptive Medium Access Control 2003)

TRAMA [12] employs a traffic adaptive distributed election scheme that selects receivers based on schedules announced by transmitters. Nodes using TRAMA exchange their two hops neighborhood information and the transmission schedules specifying which nodes are the intended receivers of their traffic in chronological order, and then select the nodes that should transmit and receive during each time slot. Accordingly, TRAMA consists of three components: the Neighbor Protocol (NP) and the Schedule Exchange Protocol (SEP), which allow nodes to exchange two-hops neighbor information and their schedules; and the Adaptive Election Algorithm (AEA), which uses neighborhood and schedule information to select the transmitters and receivers for the current time slot, leaving all other nodes the freedom to switch to low-power mode.

The Super-frame structure [7] of TRAMA is shown in Figure 9. The frame consists of signaling slots in the reservation period and transmission slots in the data period. TRAMA operation consists of three phases:

- Each node gets information about its every two-hop neighbor using NP.
- The traffic information of each node is gathered by SEP using signaling slots, i.e., the reservation period.
- Based on this information, each node calculates its priority and decides using AEA which time slot to use. Nodes sleep during their allocated slots if they do not have any packets to send or receive [7].

Compared to S-MAC [13] with 10% duty cycle, TRAMA is more energy-efficient. S-MAC has a fixed duty cycle, so it has a constant percentage of sleep time, i.e. around 80% during both light and heavy traffic. Nodes with TRAMA sleep 6% more than S-MAC when the traffic is light, but wake up 18% more when the traffic load is high to achieve high delivery ratio. The simulation results in [13] have shown that TRAMA achieves higher delivery ratio, which is around 40% to 60% over S-MAC when the traffic load increases. However, as other schedule-based protocols, TRAMA suffers from higher latency, which is around 10 times higher than S-MAC [13].

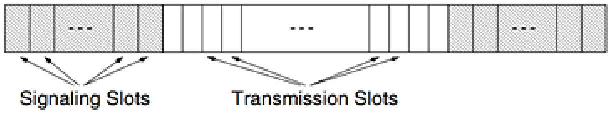


Figure 9. Super-frame structure of TRAMA

### 6.2. FLAMA protocol (Flow-Aware Medium Access Control 2003)

FLAMA [14] is an improvement of TRAMA. FLAMA achieves energy efficiency by preventing idle listening, data collisions and transmissions to a node that is not ready to receive packets. It adapts medium access schedules to the traffic flows exhibited by the application. FLAMA is simple enough so that it can be run by nodes with limited processing, memory, communication, and power capabilities.

## 7. Hybrid Protocols

Other approaches define hybrid mechanisms that switch between different protocol categories depending, in most cases, on the traffic load. Normally, they use a TDMA-like approach at high loads and a more lightweight protocol at low loads [15]. Hybrid schemes in MAC protocols aim to leverage the tradeoff introduced in channel allocation by combining random access schemes with reservation-based access TDMA approaches. Hybrid solutions provide performance enhancements in terms of collision avoidance and energy efficiency due to improved channel organization and adaptability to dynamic traffic load. Z-MAC and the standard IEEE 802.15.4 are good examples of hybrid solutions developed for WSNs [7].

### 7.1. Z-MAC (Zebra MAC 2005)

Z-MAC combines the strengths of TDMA and CSMA while offsetting their weaknesses. According to the traffic level in the network, Z-MAC operates in two modes. It behaves like TDMA protocol under high traffic and like CSMA protocol under low traffic. It is also robust to dynamic topology changes and time synchronization failures commonly occurring in sensor networks [16]. Z-MAC uses DRAND [17], an efficient scalable channel scheduling algorithm for allocating slots to nodes. Unlike TDMA, a node can send many messages in one slot and may transmit during any time slot in Z-MAC. Before a node transmits during a slot (not necessarily at the beginning of the slot), it always performs carrier-sensing and transmits a packet when the channel is clear [16].

Similar to many reservation-based protocols, Z-MAC consists of a setup phase and a communication phase. During the setup phase the Z-MAC runs the following operations in sequence: neighbor discovery, slot assignment, local frame exchange and global time synchronization. These operations run only once during the setup phase and do not run until a significant change in the network topology (such as physical relocation of sensors) occurs [16].
Z-MAC performances are better than B-MAC when network traffic load is high, but less than B-MAC when network traffic load is low [16].

**7.2. IEEE 802.15.4 (2003)**

The IEEE 802.15.4 is the most widespread used protocol for WSNs. It is being used as a baseline for several higher layer protocols such as ZigBee, 6LoWPAN and Wireless HART. The IEEE 802.15.4 standard [18] specifies the Physical Layer and Media Access Control for Low-Rate Wireless Personal Area Networks (LR-WPANs). This MAC protocol features two operating modes: a non-beacon-enabled mode, in which nodes access the channel using a classic (un-slotted) CSMA/CA mechanism and a beacon-enabled mode (Duty-cycled mode) in which time is subdivided into Super-frames, with a slotted CSMA/CA mechanism. When nodes operate in beacon-enabled mode, they subdivide their time into beacon intervals that are delimited by beacon frames periodically broadcasted by each coordinator. Each beacon interval is divided into an active period, called Super-Frame, and an inactive period, during which nodes do not transmit and may enter low-power states as shown in Figure 10. The duration of these periods determines the nodes' duty cycle.

When used in the beacon-enabled mode, the IEEE 802.15.4 protocol supports collision-free time slots, called Guaranteed Time Slots (GTS), which can be exploited for transmitting real-time traffic. The allocation of one or more GTSs guarantees a defined bandwidth and a maximum access delay for a node. Two different device types can participate in an LR-WPAN network; a full-function device (FFD) and a reduced-function device (RFD). The FFD can operate in three modes serving as a personal area network (PAN) coordinator, a coordinator, or a device. An FFD can talk to RFDs or other FFDs, while an RFD can talk only to an FFD. An RFD is intended for applications that are extremely simple, such as a light switch or a passive infrared sensor [19].

The IEEE 802.15.4 protocol supports three different topologies as depicted in Figure 11: star, mesh, and cluster-tree. However, the beacon-enabled mode (and hence, support for the Contention-Free Period) only works in star or cluster-tree networks. In the cluster tree topology, the network comprises multiple coordinators, also called ZigBee Routers (henceforth referred to as "routers"), which establish parent-child relationships so as to form a tree rooted at the PAN coordinator [18].

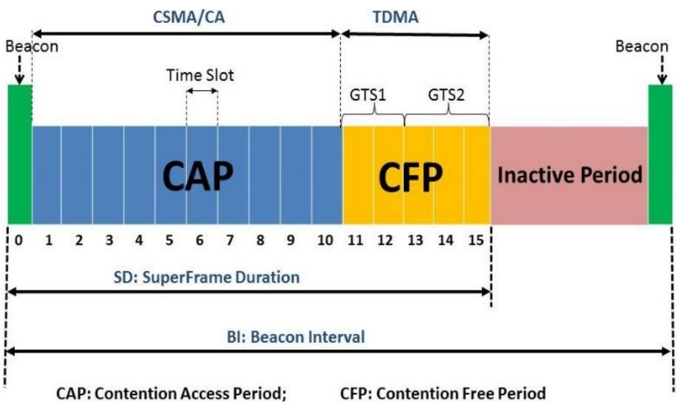


Figure 10. Super-Frame structure of IEEE 802.15.4

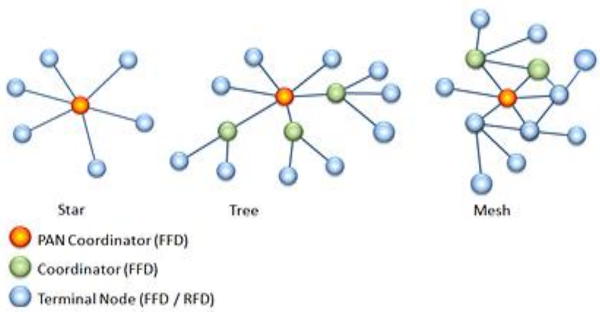


Figure 11. Topologies supported by IEEE 802.15.4 protocol

## 8. Protocols Comparison

Scheduled-based protocols outperform contention-based protocols in terms of energy saving for the reason that the duty-cycle is reduced. Furthermore, there are no collisions and no control packets (overhead) for this class. However, employing TDMA protocol usually needed nodes to be organized into real communication clusters, like Bluetooth [20] and LEACH [21]. Managing communication between clusters and resolving interference problems is a difficult task. Moreover, if the cluster density changes then it is almost impossible for TDMA protocol to dynamically modify its frame length and time slot assignment. Consequently contention-based protocols are more flexible than scheduled-based protocols. For example, Bluetooth network needs at maximum eight nodes to form cluster [6].

Generally, contention-based protocols provide scalability and lower delay, when compared to the reservation-based protocols. On the other hand, the energy consumption is significantly higher than the reservation-based (or TDMA-based) approaches due to collisions and collision avoidance schemes. Moreover, contention-based protocols are more adaptive to changes in the traffic volume and hence useful to applications with burst traffic such as event-based applications. Furthermore, the synchronization and clustering requirements of reservation-based protocols make contention-based ones more favorable in scenarios where such requirements cannot be fulfilled [7].

Network scalability is another important area of research and the TDMA schedules must be able to accommodate high node densities that are characteristic of sensor networks. As the channel capacity in TDMA is fixed, only slot durations or a number of slots in a frame may be changed keeping in mind the number of users and their respective traffic types. In addition, TDMA-based protocols result in high latency due to the frame structure. Hence, TDMA-based MAC protocols may not be suitable for some WSN applications where delay is important in estimating event features and the traffic has a burst nature. Moreover, since time-slotted communication is performed in the clusters, inter-cluster interference has to be minimized such that nodes with overlapping schedules in different clusters do not collide with each other. Finally, time synchronization is an important part of the TDMA-based protocols and synchronization algorithms [7].

## 9. MAC Protocols Summary

The Figure 12 classifies WSN MAC protocols into four categories: Synchronous, Asynchronous, Scheduled-based and Hybrid [22]. The classification aims at identifying the research trend of WSN MAC protocols based on the used techniques. The Table 1, inspired from paper B. Rajesh Shyamala [23], summarizes the protocols presented in this paper. The performances of these protocols are evaluated in terms of three aspects: The Latency time describing the average delay for a single packet from node to sink, The Throughput which is defined as the number of packets delivered at the sink node per time unit in the Network, and Energy-Efficiency representing energy consumed by the node or the network. We consider only energy efficiency in WSN MAC protocols. Energy saving by putting nodes into low-power sleep mode periodically is a fundamental mechanism in WSN MAC protocols.

Asynchronous MAC protocols have integrated the prediction mechanism to estimate the best wake-up time for sending. Recently, the responsibility of establishing communication has gradually shifted from the sender side to the receiver side. Although the transition is reasonable since only when the receiver is ready to receive the sending is effective, quick and proper response to link breaks and target receivers' leave is a potential issue. It is also challenging to minimize the idle listening of senders while guaranteeing that the sender will not miss the beacon of the receiver. In other words, although LPP-based MAC protocols provide higher throughput, the energy efficiency is generally lower than that of LPL-based MAC protocols in light traffic load scenarios because channel sampling duration is short in LPL-based MAC protocols but idle listening duration for beacon is slightly longer. Which one is more appropriate is application dependent. In asynchronous MAC protocols, nodes' random and independent schedules result in a long initial delay for event report. These are the potential research directions in asynchronous MAC protocols.

Synchronous MAC protocols synchronize a cluster of nodes to a common schedule. The trend in this branch is to move data delivery from the common active period to the sleep period. The common active period is used for arranging data transmission in the sleep period.

Current scheduling methods are good at delay reduction for individual packets but are very vulnerable to interference. It is highly recommended to design a more robust scheduling scheme that could efficiently utilize the sleep period for data transmission [25].

Table 1. Summary of the Reviewed MAC Protocols

| Type | Protocol | Duty-cycle | Latency | Energy-Efficiency | Through put | Advantage | Disadvantage |
|---|---|---|---|---|---|---|---|
| Contention-Based | S-MAC | Fixed | Low | Medium | Low | Low energy consumption when traffic is low | Sleep latency, Control packets overhead |
| | T-MAC | Adaptive | High | High under Variable traffic | Low | Adaptive active time | Early sleep, Control packets overhead |
| | B-MAC | Adaptive | High | Low | Medium | Simple to implement, Consumes less power | Overhearing, Bad performance at heavy traffic |
| | X-MAC | Adaptive | Low [11] | High [11] | Low [11] | Less energy consumption and latency | Not optimal for all Traffic types |
| Scheduled-Based | TRAMA | ----- | Low | Low | High | Higher energy efficiency and Throughput | Time is divided into random access period |
| | FLAMA | ----- | Low | Medium[14] | High | Reduce idle listening overhead from neighborhood traffic information exchange | Time is divided into random access period |
| Hybrid | IEEE 802.15.4 (Beacon Mode) | Adaptive | Low | High | Low | Adaptable Duty-cycle (100% to 0%) | Low Data Rates (20-250 kbps) |
| | Z-MAC | ----- | Low [24] | Low | High [24] | Performs better than B-MAC when load is high[16] | Acceptable latency in low traffic |

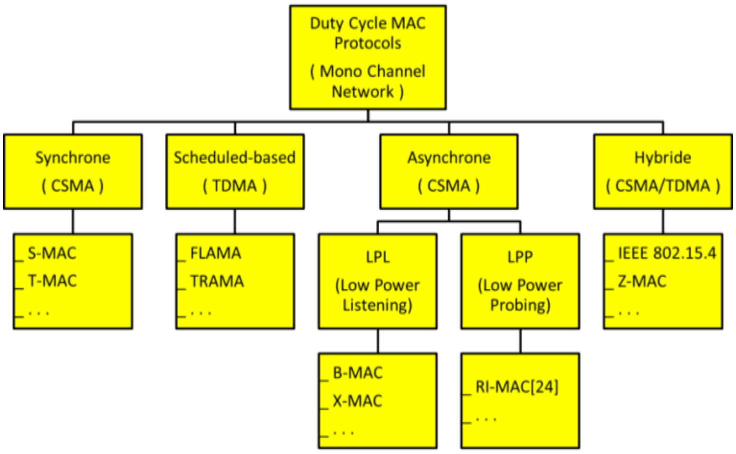


Figure 12. Advanced classification of studied MAC protocols [22]

## 10. MAC Protocols Energy Efficiency

The authors in [9] compare CSMA based MAC protocols with respect to their energy consumption and found that in general, X-MAC protocol performs better than all other protocols that were considered. Protocols based on preamble sampling consume less energy than protocols based on static or dynamic sleep schedule. This paper also presented the advantages and disadvantages of these protocols when traffic is high and when it is low. Such analysis may be used to configure the network as per user requirements.

Thus, In S-MAC and T-MAC, energy savings at high traffic is due to overhearing avoidance. More neighbor nodes sleep for more time on hearing RTS and CTS when traffic is high, at low traffic they do not hear RTS/CTS thus wasting energy in idle listening during fixed duty cycle. Such observation is not seen in BMAC, XMAC and WiseMAC [26]. Thus, the order of energy consumption is:

X-MAC < WiseMAC < B-MAC < T-MAC < S-MAC.

## 11. Conclusion

In the last decade, we saw the developments in Mac protocols design that extended from energy saving to QoS (Quality of Service). The main objective of this paper is to present main MAC protocols which are able to minimize energy consumption. The basic technique to save energy is “Duty-cycle” operation of the nodes. Accordingly, it’s important to indicate that the Quality of Service (QoS) (here means high throughput, low latency, less lost packets and less energy consumption) needs still more research works in the future [27]. Most of the work on the MAC protocols focuses primarily on the energy efficiency in the sensor networks. However, still a lot of work has to be done in the other areas at the MAC layer such as: Sensor Network Security [28], Nodes Mobility [29], Evaluation on Real Sensor Platforms, Real Time Systems [30], Underground WSN, Underwater WSN and Multi-media WSN [31].

The authors in [32] propose other open issues that need to be addressed such as Cross-layer solutions and multi-hop MAC protocols for enhancing the performance of MAC protocols. Recently, a new direction of researches on WSN have appeared, including Healthcare monitoring with new kind of WSN called WBAN (Wireless Body Area Networks) [33, 34]. Finally, the paper provides a vision on future trends of the short and long-term research on WSNs.

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