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# Analysis of Contention and Schedule based Energy-Saving MAC Protocols for Wireless Sensor Network

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***Abstract:*** This paper reviews a brief survey of the Medium Access Control (MAC) protocols for Wireless Sensor Networks (WSN) with the two broad categories namely contention based and scheduled based MAC protocols for wireless sensor networks. It describes pros and cons of some known solutions of the MAC protocols with emphasis on their energy efficiency. The main goal in WSN is prolonging the lifetime of the sensor node that is usually battery powered and can thus be achieved by designing energy-efficient MAC protocols..

***Keywords: WSN, Medium Access Control, MANET, Energy Saving, CDMA, TDMA.***

## I. INTRODUCTION

There are various types of wireless networks being used as; infrastructure-based WLAN, wireless Ad-hoc network, wireless personal area network (WPAN), wireless cellular network, satellite system, television network and wireless sensor network (WSN) etc. Each type of network uses slightly different techniques and algorithms from each other in all aspects including MAC algorithms as well. MAC plays vital role in wireless communication. A wireless sensor network (WSN) consists of a number of sensors spread across a geographical area. Each sensor has wireless communication capability and certain level of intelligence for signal processing and communication of the data.

Wireless sensor networks (WSNs) usually contain a large number of wireless battery-attached sensor nodes capable of sensing the environment and communicating in ad-hoc or structure fashion. Taking energy in consideration, there are three approaches that are usually used to achieve the energy-efficiency in MANETs [23]: Power-Control, Power-Save and Maximum-Lifetime routing [19]. Network lifetime is bound by limited battery capacity as replacing or recharging the batteries used in WSNs is often difficult, so reducing energy consumption is thus a challenge when designing a media access control (MAC) protocol for WSNs. A major source of energy consumption in a WSN is the idle listening mode in which a node remains awake for a long time when no actual data transmission is required by the network. A number of MAC protocols design approaches have been proposed to reduce idle listening energy, Kien Nguyen proposed the one of the most successful MAC in which a duty cycling scheme is applied.

The need for efficient power management due to the extremely limited resources has discussed by various protocols. There are a considerable number of MAC protocols which are implemented for different applications in WSN. Each protocol works on different techniques and at last all are targeted for energy efficiency.

The MAC layer main functions are transfer of data from upper layers, error protection (generally using frame check sequences), and arbitration of access to one channel shared by all nodes [24] along with frame delimiting and recognition, addressing. In WSN, MAC layer protocols must be energy efficient to maximize lifetime.

## II. COMPARISON OF MAC PROTOCOLS

Wireless sensor network suffer from a number of general research challenges. In Fig.1 [26], the communication architecture of a wireless sensor network, implemented by a protocol stack, is shown, with 5 layers namely Application Layer, Transport Layer, Network Layer, Data Link Layer, Physical Layer. Here, we are concentrating on MAC (Medium access protocol) layer reside in the Data Link Layer, which itself not only is responsible for a fair distribution of resources, but also for providing data stream multiplexing, frame detection and error control. The main goal of this paper is to discuss MAC protocols.

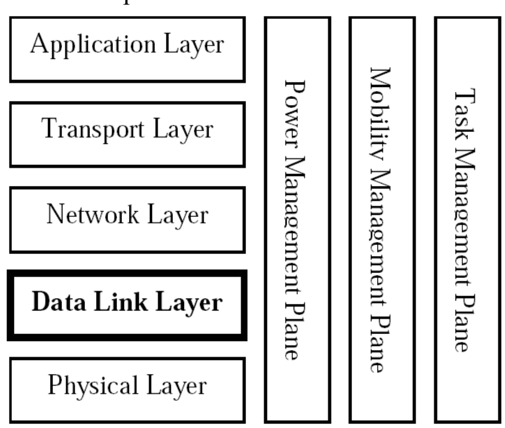


Fig. 1. WSN Protocol Stack [26]

WSN MAC protocols depending on how they allow nodes to access the channel can be classified into the general categories of contention based, scheduling based, channel polling based, and hybrid protocols [18].

This paper is concentrating on the two broad categories namely contention based and scheduled based MAC protocols for wireless sensor networks. The contention based protocols have relax time synchronization requirements and can easily adjust to the topology changes as some new nodes are joining to the network or some of the nodes are expired after deployment. These protocols are based on CSMA (Carrier Sense Multiple Access) technique and have higher costs for message collisions, overhearing and idle listening. The schedule based protocol collisions, avoids overhearing and idle listening by scheduling the transmission and listen periods under the strict time synchronization requirements.

## III. CONTENTION BASED MAC PROTOCOLS

### A. *Sensor MAC*

S-MAC is a medium-access control (MAC) protocol designed for wireless sensor networks. A network of battery-operated computing and sensing devices will collaborate for a common application such as environmental monitoring and expecting sensor networks to be deployed in an ad hoc manner with individual nodes remaining largely inactive for long periods of time and becoming suddenly active when something is detected. These characteristics of WSN and applications motivate a MAC that is different from traditional wireless MACs like IEEE 802.11 in almost every way - energy conservation and self-configuration are primary goals while per-node fairness and latency are less important.

S-MAC uses three novel techniques to reduce energy consumption and support self-configuration. Nodes periodically sleep, to reduce energy consumption in listening to an idle channel. Neighboring nodes form virtual clusters to auto-synchronize on sleep schedules. Like PAMAS, S-MAC also sets the radio to sleep during transmissions of other nodes. In contrast to PAMAS, it only uses in-channel signaling. In brief, S-MAC applies message passing to reduce contention latency for sensor-network applications that require store-and-forward processing as data move through the network. The experiment performs at University of California, Berkeley with S-MAC over a sample sensor node show that, an 802.11-like MAC consumes 2--6 times more energy than S-MAC for traffic load with messages sent every 1--10s.

Nodes form virtual clusters with one common sleep schedule, in S-MAC protocol, all the clusters wake up and start communicating at the same time. This channel is divided into an active and sleeping period. Potential energy saving is calculated by the ratio between the active and passive periods during the active period. The node starting a synchronization sequence is called synchronizer. It emits an SYNC packet which synchronizes all nodes inside the virtual cluster. Collision avoidance is achieved by the carrier sense and by the data exchange schemes RTS/CTS/ DATA/ACK. This protocol has one major problem. It is addressed to border nodes which are located at the cross-section of two virtual clusters. In order to connect virtual clusters in one network, these nodes have to transmit all traffic from one cluster to another towards the sink node; therefore, they need to follow both sleeping schedules. Consequently, these nodes can quickly deplete their batteries. This problem can be solved by frequently changing synchronizer allocation inside virtual clusters which causes borders to move between clusters. Energy efficiency in S-MAC is proportional to the ratio between active and sleeping periods. This ratio is constant regardless of traffic intensity. When traffic is low, most of the active-period nodes listen to an idle channel. When traffic is heavy, only some of nodes can use active period so they buffer data which they cannot send. This problem increases the packet latency.

### B. *TMAC*

The TMAC protocol is an extension of the SMAC protocol for the time-division based approach. Weakness of the SMAC protocol can be solved by introducing an adaptive active period. All communication during the active period is done in one burst. When all communications are over, nodes still listen to the medium ta seconds for any communication demand left. After that they go into an early.[11]

The TMAC protocol introduces an active timeout mechanism that decreases the idle listening overhead by dynamically adjusting the active period according to network traffic loads. TMAC allows the nodes to sleep after sometime when all network traffic has completed [20]

Ilker Demirkol et al. describes several MAC Protocols proposed (S-MAC/T-MAC/DSMAC, WiseMAC, TRAMA, Sift, DMAC) for sensor networks, emphasizing their strengths and weaknesses [4].

### C. *WiseMAC*

Hoiydi proposed the Spatial TDMA and CSMA with Preamble Sampling protocol in which all sensor nodes are defined to have two communication channels [6]. The data channel is accessed using TDMA, whereas the control channel is accessed by CSMA. The WiseMAC [7] protocol is similar to Hoiydi’s work [6], but requires only a single-channel. WiseMAC protocol uses nonpersistent CSMA (np-CSMA) with preamble sampling as in [6] to decrease idle listening. A preamble precedes each data packet for alerting the receiving node, in the preamble sampling technique. All nodes in a network sample the medium with a common period, but their relative schedule offsets are independent. If a node finds the medium busy after it wakes up and samples the medium, it continues to listen until it receives a data packet or the medium becomes idle again. The size of the preamble is initially set to be equal to the sampling period. However, the receiver may not be ready at the end of the preamble, due to factors such as interference, which causes the possibility of overemitting-type energy waste. Moreover, overemitting is

increased with the length of the preamble and the data packet, since no handshake is done with the intended receiver.
To reduce the power consumption incurred by the predetermined fixed-length preamble, WiseMAC offers a method to dynamically determine the length of the preamble. [A. El-Hoiydi,]

### *D. B-MAC*

B-MAC is a pure lightweight MAC protocol. B-MAC [10] is a carrier sense MAC protocol that employs an adaptive preamble sampling scheme to reduce duty cycle and minimize idle listening.
It does not offer additional services like node organization, synchronization, and routing. It uses a Clear Channel Assessment (CCA) to determine whether the channel is clear. B-MAC duty cycles the radio through periodic channel sampling that is called Low Power Listening (LPL). The preamble length is matched to the interval that the channel is checked for activity

## IV. TDMA BASED MAC PROTOCOLS

TDMA-based protocols are naturally energy preserving, because they have a duty cycle built-in, and do not suffer from collisions [22]. However, maintaining a TDMA schedule in an ad-hoc network is not an easy task and requires much complexity in the nodes by keeping a list of neighbor's schedules takes valuable memory capacity. Allocating TDMA slots is a complex problem that requires coordination. Furthermore, as TDMA divides time into very small slots, as the effect of clock drift can be disastrous; exact timing is critical.

### *A. TRAMA*

TRAMA (TRaffic-Adaptive Medium Access Protocol): TRAMA [8] is a traffic-adaptive, energy- aware channel access protocol for wireless sensor networks. This MAC protocol tries to achieve efficient energy management by avoiding receiver collisions at the packet level through the usage of TDMA scheduling, and by employing a low power mode for nodes which are neither expected to send nor receive. The usage of this low power mode is dynamically determined and adapted.
TRAMA reduces the energy consumption by avoiding the collisions of transmitted data packets and it allows the nodes to switch low power mode whenever they are not in transmitting and receiving mode. It avoids the collisions due to hidden terminals.
The TRAMA is a collision-free MAC protocol [9] that uses a distributed election scheme to determine particular time slots. TRAMA distinguishes between random access slots that are contention-based and used for signalling, and scheduled access periods that are used for collision-free data exchange. In other words, TRAMA uses the traffic based schedules and avoids the wasting slots and switch the nodes to low power mode when there is no data to send and they are intended receivers of traffic. By the extensive simulations on TRAMA, it shows significant energy savings and results nodes can sleep 87% of its time when compared with scheduled and contention based MAC protocols depending on the offered load. Also, TRAMA have higher throughputs around 40% over S-MAC and CSMA and 20% over 802.11. TRAMA protocol is more suitable for applications like with not delay sensitive and produce high energy efficiency [21].

### *B. TRACE*

TRACE (Time Reservation using Adaptive Control for Energy efficiency) [18] is explicitly developed for real time data broadcasting. TRACE, a TDMA-based MAC protocol for energy efficient real-time packetized voice broadcasting in a single-hop radio network. Network lifetime is maximized in TRACE using dynamic controller switching and automatic backup mechanisms. Two features of TRACE make it an energy efficient protocol: 1) scheduling and 2) receiver- based listening cluster creation via information summarization slots. Separation of the contention and data transmission is the determining factor in high throughput, low delay and stability under a very wide range of data traffic. Different QoS levels are also supported in TRACE via priority [27].

### *C. TDMA-W*

TDMA-W [16] (TDMA-Wakeup) uses a special “wake up” slot in order to minimize the idle listening time of a node. By introducing this dedicated time slot, nodes only have to be awake during their allocated slots for transmission and reception, and the wake-up slot where they get information if and when they can expect transmissions from any other nodes.

### *D. EMACS*

EMACS is introduced shortly in [12] as a distributed and self-organizing TDMA scheme which is easy to integrate with higher layer protocols.
EMACS is capable of transmitting the additional routing messages in the mobile scenario at little additional cost. In the static scenario the EMACs protocol suffers from the fact that the roles active and passive are not changed, while in the mobile scenarios these roles are often changed, resulting in a better spreading of the energy consumption throughout the network and the lifetime of the network can be improved to large extends [25].

### *E. GANGS*

The GANGS protocol [13] is based on a cluster topology, where dedicated cluster heads form the sensor net backbone. Generally, TDMA is only used for the traffic amongst cluster heads while the sensor nodes communicate with the head of their cluster by means of a contention-based scheme.

### *F. BTODS/ODS*

BTODS/ODS, short for Busy-Tone On-Demand Scheduling and On-Demand Scheduling respectively, is presented in [15] and is targeted at sensor networks which use dedicated "sink" nodes where data from a large number of ordinary sensor nodes is aggregated. Their goal is to schedule additional transmissions to these sinks without disrupting the existing data flows between the remaining nodes.

### *G. LMAC*

Two versions of LMAC have been implemented LMAC V1 and LMAC V2. Version-1 (LMAC V1) is done as close as possible to the LMAC [17]. Interferences, bit errors and a working synchronization decrease energy saving effects substantially. Small, but unrealistic networks in a five meter range work smoothly with highly energy efficient timing parameters. But it was not possible to setup a network with lager distances between nodes using LMAC V1. To compensate this problems caused by interferences LMAC Version 2 (LMAC V2) has an additional CRC.

## V. CONCLUSION

This paper gives a short overview of the research in the field of CSMA and TDMA based medium access control protocols for the special field of wireless sensor networks. There are both advantages and disadvantages that come along with the choice of a time multiplexed scheduling. While the protocol divides the shared medium evenly in a fair way and the scheduling algorithm attached to the protocol avoids (most) packet collisions and thereby power consuming retransmitting of packets, most of the current TDMA based MAC protocol suggestions are nevertheless still impractical for usage in real world wireless sensor networks. The lack of distributed scheduling algorithms results in the frequent requirement of global information in all nodes about all the other nodes, a demand simple unrealistic to meet in the highly changeable sensor nets. The focus of future research should be on trying to find the balance between being able to predict delay, guarantee some kind of QoS, minimising communication overhead and lastly, optimise power usage; a combination of requirements characteristic for wireless sensor networks.

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