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Survey on Energy Efficiency MAC Protocols in Wireless Sensor Network

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Abstract

One of the dynamic and active research area for researchers is on Wireless sensor networks (WSNs) It is popular worldwide in the real time application such as Tracking target and tracking, monitoring in the field of environmental and industrial issues. Usually, deployed nodes work with restricted energy resources. So the parameter energy efficiency becomes one of the objects of exercise for these sensor nodes in the networks. To make WSN more energy efficient, researchers have developed quite a large number of MAC protocols. In this paper, description of various energy efficient MAC protocols of WSNs in three categories: contention based, scheduled based, hybrid are presented emphasizing their strengths and weaknesses. Design proposed by various MAC protocols is discussed. Comparison study is made with various protocols on attributes.

Keywords**:** *Energy Efficiency, MAC Protocol, WSN*

1. Introduction

WSNs have grown as one of the foremost trends in technology, [25] with potential usage in defense, scientific applications, [26] tracking and detecting targets and intrusions, monitoring habitats of wildlife, climatic conditions, disasters. [1][3]. A sensor network consists of sensor nodes. They are deployed heavily in a particular geographical area. The size of WSN can extend to several orders in scale compared to a traditional wireless networks. Sensor nodes are battery powered having low power capacity. So it should be recharge often. When they are deployed in a remote area, it is often impracticable to revive them. Obviously, network suffers from degradation resulting in the failure.

In WSNs protocols and architecture play an important role in developing design of the network [5]. Another main constraint in design is energy consumption due to drawback in power of nodes.

On the other hand, the traditional wireless network does not consider energy wastage. Most of them are application dependent On the other hand, most sensor networks are application oriented with diverse requirements.

Generally, every WSN application consists of the following. Sensor unit, processing unit, transceiver as shown in the figure 1[15]. An essential component is an environment that senses the data from and to a base station. Power can be produced through a natural source or from a battery to transmit the data across the channel.

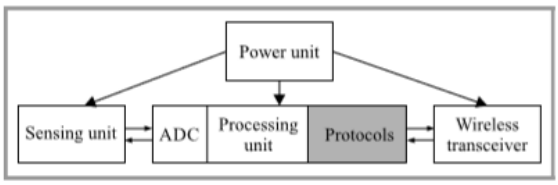

Figure 1: Architecture of a typical node in WSN.

A challenging issue arises when energy efficiency is considered. It is linked to traffic, life time of network. To overcome this suitable protocol stack should be designed. The basic structure of a WSN protocol stack contains five levels. They are physical – layer that concern with transmission of data, Data Link Layer [DLL] for low consumption of energy, Network – layer for

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communicating data, transport and application layer – layer providing reliability of data.

The main concern is on energy efficiency and maximizing the life time of the network. It can be achieved through designing better protocols. Hence, one such protocol is medium access control (MAC) protocol that depends on application that is a part of data link layer.

2. Reasons for Wastage of Energy at MAC Layer in WSN:

- **Idle listening**: Node keeps its transceiver in active mode always ready-to-receive all the time. It is unaware/expecting, when it receives of the message
- **Collisions**: A collision occurs when two packets/frames meet together, it leads to collision, eventually, is discarded. So retransmission of packets occurs that leads to loss of excess energy.
- **Overhearing:** In the swarming traffic network, sometimes the node may send a surplus packet. That is wrongly addressed. So this packet is treated as overhead packet and discarded. Retransmissions crop up to the given node, resulting in wastage of energy.
- **Control packet overhead**: Information about communication exists in Control packet. Minimal number of control packets should be used; else results in energy waste.
- **Over-emitting:** When destination node is sleeping or not in ready to receive data, such situation is termed as "over-emitting" that occurs during transmission.

3. Characteristics of MAC Protocol.

(i) **Energy Efficiency**: This means unit of energy consumed (sensing, data processing) for successful communication. Recharging of batteries are not beneficial than in replacing the nodes. So designed MAC protocol must conserve more energy to prolong its existence period.
(ii) **Scalability**: A MAC protocol must have the ability to accommodate the change that occurs in dynamic behavior on the size of the network.
(iii) **Adaptability**: Designed MAC protocol must have the capability and communicate to adjust to the changes made in network based topologies such as bus, tree, star, ring.
(iv) **Bandwidth Utilization**: For effective communication, MAC protocol during heavy flow of data should make use of the bandwidth appropriately.
(v) **Latency**: It is the holdup time/ delay when a sender sends a packet to sink/receiver.
(vi) **Throughput**: Data are measured in terms of bits or bytes per second transferred from source to destination. Throughput determines the quantity/amount of such data. It is application dependent.
(vii) **Fairness**: In every network design all nodes transfer data to the sink. So they equally share the channel for transmission. Sensor nodes should be fair enough to send data to the sink.

4. Classification of WSN MAC Protocols

The protocols designed for sensor networks can be organized broadly into three classes. They are

*Contention-based protocols,

*Scheduled-based protocols,

*Hybrid protocols

Contension Based MAC Protocol

Contention Based Networks: Channel accessing is the most competing concept in WSNs. Data transmission happens only after node senses the carrier. if the carrier is idle, node starts its transmission else will postpone sending for random amount of time done by Back-off algorithm.

S-MAC [Sensor MAC Protocol]: It is energy efficient MAC protocol proposed by Ye et al [5]. Avoiding Collision for better scalability is the main goal of the scheme.

Proposed Scheme: Some of the mechanism used by the protocol to control energy wastage is listening session and sleeping session at regular period [6] that reduces the idle listening and sessions are selected by every node at their own choice. The deployed node that reside nearby synchronize together thereby reducing control overhead. Request To Send/Clear To Send are a well know mechanism used by the protocol to avoid frame collision and overhearing.

Message is a packet having collection of unified and organized data. The long messages are handled efficiently as message passing mechanism.

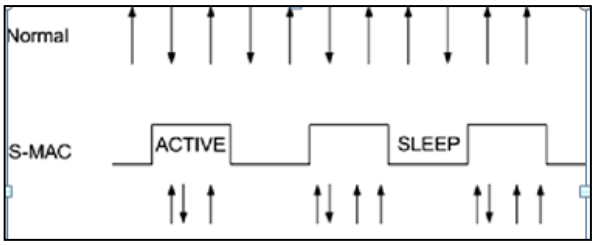

Figure 2: Periodic Listen and sleep in S MAC

Advantages: Sleep session schedule reduces wastage of energy and overhead caused due synchronization of an instance/time

Disadvantages: RTS/CTS mechanism is not used by broadcast data packets those results in increase of collision probability. In the adaptive listening, predefined sleep and listen periods are implemented. So the efficiency of the algorithm decreases on the load of the traffic. So overhearing or idle listening occurs. Predetermined duty cycles are used in SMAC.

T-MAC:

Timeout –MAC in WSNs are an energy - deficient adaptive MAC protocol proposed by Dam and Langendoen [5].

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Proposed Scheme*:* T-MAC overcomes the drawbacks of S-MAC in the performance of traffic load. It is based on dynamic duty cycle schedule to optimize power efficiency by sleeping during periodic active periods. When the network traffic load or activation event occurs in threshold time H, T-MAC allows the nodes to sleep. Adaptive timeout period (H) signals the end of the traffic by supervising the channel for inactiveness [9].

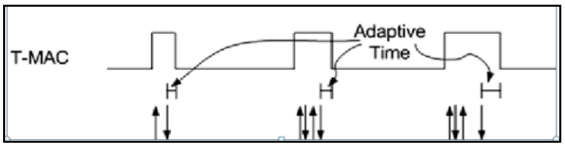

Figure 3: The T - MAC adaptive time periods

WISE-MAC

Wireless Sensor MAC [Wise MAC] is an energy – efficient MAC protocol proposed by Hoiydi et al. [5]. He proposed "Spatial TDMA and CSMA with Preamble Sampling" [14].

Proposed Scheme: All nodes in the network samples the given transmission medium at a specific interval of time. A node waits for the idle state to transmit the packet of data otherwise, wait or listens constantly till it receives. The idea of power consumption is carried out by transmitting a wake-up prelude in advance to each data packet. When traffic is less, this prelude modifies the receiving node.

Prelude length can be determined by a specific method offered by wise MAC. At the time of exchange of data, an ACK (acknowledgment) message is created that refreshes the sleep schedules. A schedule table is maintained by each node.

Wake-up prelude decrease the possibility of collisions caused by the particular start time, Clock drifts from source to destination that affects the wake-up prelude length [13].

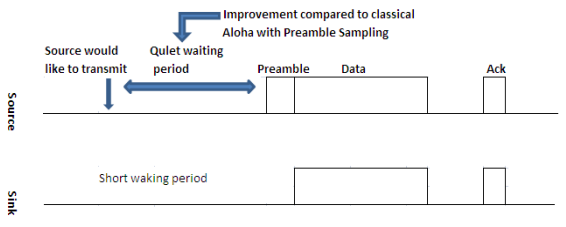

Figure 4: Wise-MAC prelude minimization

Advantages: Improvement of S-MAC is Wise-MAC. The sampling techniques offerless power under less traffic, also increases energy efficiency under elevated traffic condition.

Disadvantages: In broadcast communication, decentralized sleep–listen schedule results in diverse sleep and wake-up schedules for each neighbor of a node. This lead to high latency time and power consumption.

When a node starts to transmit the prelude to another node where the sender is not within range, hidden terminal problem arises resulting in collision.

B-MAC:

B-MAC (Berkley-MAC 2004) B-MAC [11] has been designed at Berkeley University. B-MAC [13] is a CSMA MAC protocol for WSNs. Low power consumption is achieved by combining CSMA with LPL.

Proposed Scheme*:* B-MAC is based on two mechanisms that improve the energy efficiency and channel utilization. (a) Sleep–wake scheduling and (b) CCA - Carrier sensing using Clear Channel Assessment. Furthermore, B-MAC uses (c) unsynchronized duty cycling – for long preamble to wake up receivers.

When nodes wake up, RF module is turned ON. It checks channel state using CCA. In the absence of activity, the node turns OFF it RF module or sleeps. 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 prelude. Transmission of data will be known in the prelude that has a unique bit pattern. The receiver recognizes the information from prelude [10]. Also the broadcast and unicast prelude are executed as expected [17].

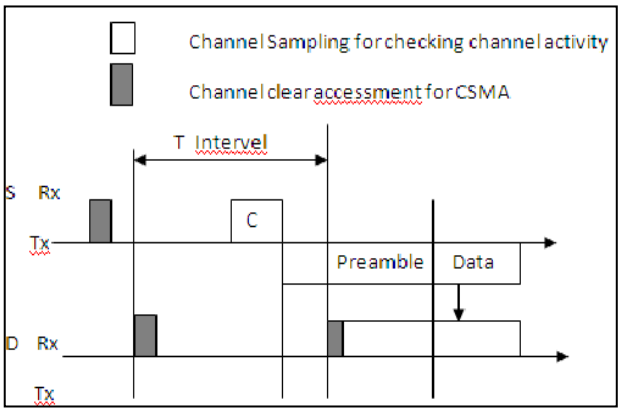

Figure 5: B-MAC Preamble

Advantages: Idle listening is reduced. Reduce duty cycle, low power communication, better than SMAC in implementation.

Disadvantages: Problem of power consumption persists. Leads to higher average latency due to lower duty cycle.

Scheduling based:

Collisions, idle listening and overhearing can be avoided by scheduling transmit & listen periods by protocols. Allocation is done on frequency, time and code as FDM, TDM and CDMA.

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TRAMA PROTOCOL

Traffic-Adaptive Medium Access Control (TRAMA) was proposed by Rajendran et al. [5]. It provides collision free channel access.

Proposed Scheme: When nodes in the WSNs are not transmitting /receiving data, they are switched to low power idle state. In TRAMA, channel reuse can be promoted by transmitter-election algorithm. It has the functionality of challenging the traffic in the region of a given source or receiver. Thus maintains throughput and fairness.

TRAMA protocol has an assumption of Single time slot channel. Its time alternates between random and scheduled access periods alternatively. Random period (signaling slot) pioneers for slot selection followed by scheduled access (transmission slot) as shown in the figure 7.

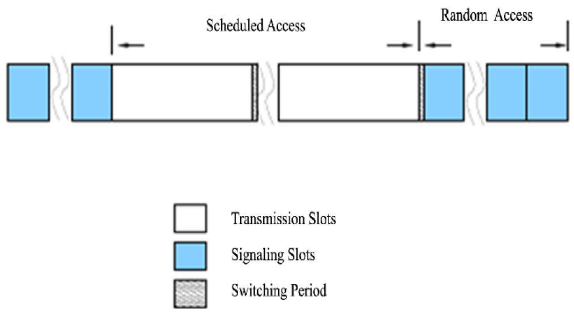

Figure 7: TRAMA time slot

The three components of TRAMA are: (i) NP- Neighbor Protocol, (ii) SEP - Schedule Exchange Protocol and (iii) Adaptive Election Algorithm (AEA). Both i and ii interacts with other nodes for their schedules and information in two hops. iii. For a given time slot it selects transmitters and receivers for low power. The table below is the result of simulator NS-2 [25].

Table 1: Comparison of TRAMA AND S-MAC

	TRAMA	**S-MAC**
Fixed duty cycle	6% sleep more for light traffic 18% more high traffic	80% with light and heavy traffic
Simulation	Higher delivery ratio of 40% to 60% in high traffic	In high traffic no data is sent
Latency	10 times high	Reduces for energy saving

Advantages: when compared to CSMA, Sleep time is high with less collision.
Disadvantages: Transmission slots are longer than random access period[13] . Duty cycle is very high. It suffers from higher latency.

FLAMA

Flow-Aware Medium Access Control-FLAMA [14] is improvement over TRAMA.

Proposed Scheme: FLAMA prevents idle listening, data collisions and over emitting to achieve energy efficiency. Application adapts medium access schedules to exhibit the traffic flows. Nodes can run FLAMA protocol for the following attributes -limited processing, memory, communication, and power capabilities.

Distribute delection algorithm is used in FLAMA protocol to have collision-Free transmissions made on the assumption – restricted number of sensing nodes for memory source and processing.

Advantages: Avoids hidden terminal problem, FLAMA is traffic adaptive. Higher reliability than SMAC.

Disadvantages: Queuing delay persists during election algorithm. Compared to TRAMA upto 75times it is less.[23]. In scheduled access, less information is exchanged in FLAMA than TRAMA. [23]

Hybrid Protocols

Other approaches define hybrid mechanisms that switch between different protocols categories depending on the traffic load. Normally, TDMA-like approach at high loads and a more lightweight protocol at low loads are used [15]. The combination of schemes such as random access and reservation-based access TDMA is hybrid protocol. The evasion of collision and improvement of performance can be achieved in hybrid. One of the good examples of hybrid solutions developed for WSNs [7] is Z-MAC.

Z-MAC

Zebra MAC is protocol proposed by Rhee et al. [5]. Z-MAC is the combination of the strengths of TDMA and CSMA. Hence the named as hybrid. Z-MAC operates as TDMA protocol in heavy traffic and as CSMA protocol in low traffic.

Proposed Scheme: Z-MAC consists of two modes. (a) setup phase mode and (b) transmission phase mode. In Setup phase mode, Z-MAC finds the node in and around, allots the available slot to the node, exchanges the frame and synchronizes the time globally. All these setups are performed periodically.

In transmission phase mode, allotted time is sliced into ‘time slot’ where the nodes perform its communication. They are termed as ‘owner’. High priority is given to them to access the channel compared to other nodes (‘non owners’, without slots).Unlike TDMA, a node can send and transmit many messages in one slot with any time. After Carrier sensing by a node for clearance, packet is transmitted in the stipulated slot.

Advantages: Z-MAC performance during errors is robust as it merges the ideas of CSMA with TDMA. Some of the errors are time sync, failure in assignining slot, unstable channel and topological variations. Better use of channel with the dual behavior of CSMA and TDMA.Z-MAC

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execute with low latency, Accomplish better performance than BMAC

Disadvantages: At low contention, performance is worst, in terms of energy efficiency.

SCP MAC Protocol:

SCP MAC protocol belongs to hybrid MAC protocol as it combines with S-MAC,T-MAC, LEACH and TRAMA, BMAC and WISE MAC.

Proposed Scheme: Preamble and scheduling methods are merged. Nearby and surrounding node are synched with its wakeup time. It has the improved version of SMAC in performance. Some of the attributes that contribute for energy depletion are overhearing, collision and idle listening. SCP MAC protocol avoids depletion to a considerable level. The author has implemented SCP in NS-2.35.

Advantages: Energy efficiency is high. Minimizes the length of preamble is minimized

Disadvantages: Problem of overhearing is more as all nodes wakes up simultaneously. Contention is increased to gain channel, undergo collision with congestion. So depletion of energy and throughput happens. In multi-hop situations delays of larges magnitude occurs.

Cross layer approach:

As per the standard OSI layer model there is a standard layer that have virtual boundaries. The main intension is to have energy efficiency at all layers. A single layer may not be efficient for entire network. So a cross layer design structure is presented in [18]. Information is shared between layers to obtain high adaptability [19]. Every layer has a concern to optimize with a optimal value.

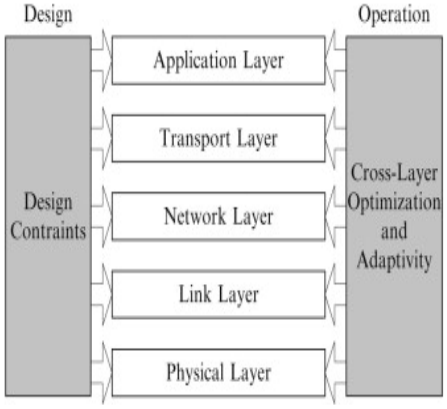

Figure 8: Cross Layer Optimization

Table 2: Comparison of Protocols

Protocol	**Energy conservation factor**	**Attributes**	**Type**	**Technique to control energy wastage**
S-MAC	Collision avoidance, Overhearing	Good scalability, latency	Unicast	Low power duty cycling, Adaptive listening, periodic sleep, virtual clustering RTS/CTS
T-MAC	Idle listening, collision avoidance	Reliability	Single-hop	Dynamic duty cycle. RTS-CTS-DATA-ACK sequence
WISE MAC	Idle listening, Collision avoidance	Energy efficiency	Multi-hop, broadcast	Preamble sampling, Wake up preamble length minimization
B-MAC	Idle listening Collision avoidance	Highly scalable	Single-hop Broad cast	Sleep wake scheduling, Adaptive preamble sampling
TRAMA	Collision avoidance,	Good throughput Latency Fairness	Multi-hop	Transmitter election algorithm,
FLAMA	Idle listening, collision free	High Reliability, latency	Single-hop	Distributed election algorithm
Z-MAC	Reduces chance of collision on slots	Better performance	Single-hop	Time slot assignment.
SCP MAC	Idle listening, overhearing, collision	Better performance, throughput	Single-hop	Preamble sampling , scheduling technique

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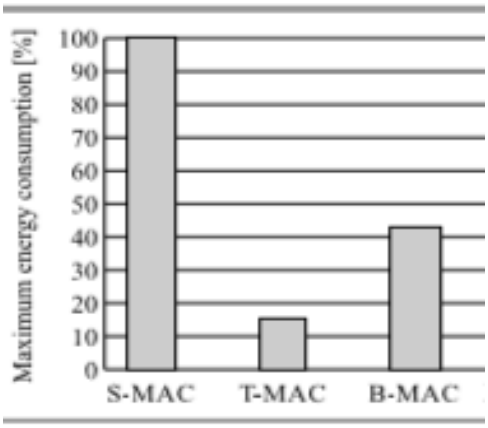

Figure 6: Comparison of SMAC, TMAC, BMAC [15]

Table 3: Comparison of Protocols with Parameters

Protocol Name	Energy efficiency	Throughput	Latency	Delay
S-MAC	Higher than ZMAC,TMAC,BMAC	High	Low	High
T-MAC	Higher than BMAC	Low	High	Medium
WISE MAC	Higher than SMAC	Low	Low	Medium
B-MAC	Low	Medium	Low	Medium
TRAMA	Higher	High	High	High
Z-MAC	Higher than TMAC, BMAC	Medium	Low	High
FLAMA	Higher than SMAC	High	Low	Low
SCP MAC	Higher than SMAC	High	Low	Low

5. Open Research Issues

In this paper, discussion about various MAC layer protocols is made. Even though researchers have made study on much protocol on energy efficiency, none of the protocol is standardized. Study on Application independent protocol is yet to be studied.

The present scenario is the MAC protocol is application dependent. Especially variants such as mobility and topology become the factors. Standardization is still lacking at physical layer as well as upper layers. There is more scope of research in these areas. So better efficiency of a system can be drawn overall from all layers. Authors in paper [19], says a protocol is developed to substitute the traditional layered framework for WSNs.

6. Conclusion

In the paper, energy-efficient MAC protocols are surveyed depending on their classification with its advantages and disadvantages. Reader is provided with a comprehensive comparison study of protocols with its attributes and type. From this study, paper concludes by emphasizing on the cross layer approach. Overall energy efficiency can be obtained by considering the performance of all the layers of protocol stack instead of traditional approach. The paper is concluded with the discussion open for integration of the layers with a single protocol for research in WSN.

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