MAC Protocols in Wireless Sensor Network: A Survey

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Abstract— Wireless Sensor Network (WSN) are collection of spatially distributed autonomous tiny, cheap, low power and smart sensors which cooperatively pass their data to a main location i.e. sink or base station through the network. Energy is the most important factor in WSN as sensor nodes have limited battery power and are deployed in regions where they are hard to recharge or replace. Thus, maximizing the lifetime of sensor network by minimizing energy consumption of various sensor node components is a common objective of sensor network research, since sensor nodes are dead when they are out of battery. A well designed MAC (Medium Access Control) protocol can prolong the overall network life by achieving desired energy efficiency. This paper provides a survey of various such MAC protocols proposed for energy efficient WSN.

Keywords: wireless sensor network, MAC; energy efficient; network lifetime.

I. INTRODUCTION TO WIRELESS SENSOR NETWORK

Wireless Sensor Networks (WSNs) has gained tremendous popularity these days, resulting from recent advances in micro electro-mechanical system (MEMS) technology, wireless communications, and digital electronics. It consists of a number of sensor nodes that are small in size, having limited processing and computing resources. These nodes depend on battery as the main power source, which get depleted at a fast rate because of the computation and communication operation that these nodes have to perform. In many cases, these sensor nodes are deployed in hostile regions, making it undesirable or impossible to recharge or replace the batteries. Thus, increasing overall network lifetime, while keeping delay reasonably low, is the major concern in WSN.

Researchers are working on the development of solutions in order to solve the energy-efficiency problems in WSN. A well designed MAC protocol can achieve the desired energy-efficiency, thus increasing overall network lifetime. In this paper, various such MAC protocols along with various energy saving mechanisms are discussed, which can be employed in order to conserve energy and minimize energy wastage as much as possible.

A. *Overview of key issues in WSN*

There exist three basic groups defining the range of tasks which make it enable for various sensor application to make use of sensor technology, as shown in Figure 1. The first one is the system. Every sensor node is an individual system. The second group is communication protocols, which enables communication between the application and sensors and also between the sensor nodes. The last group is services, developed in order to enhance the application, to improve system performance and to make network efficient. As sensor nodes are limited in terms of power, processing capacity, and storage capabilities, new communication protocols and services are needed to fulfill all these requirements.

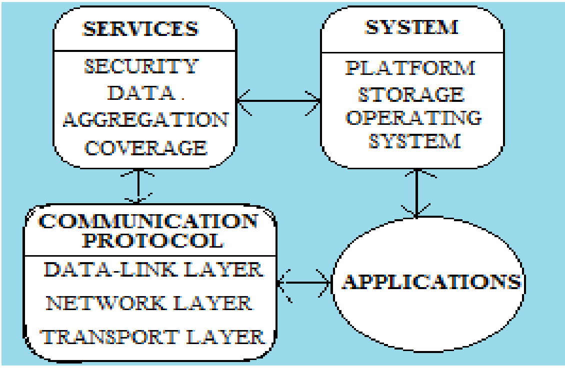

Figure 1: Broad Classification of various issues in WSN [1]

B. *Applications of WSN*

Applications of WSN falls under two categories- monitoring and tracking (Figure 2). Monitoring applications include health monitoring, environment monitoring, structural monitoring etc. Tracking applications include object tracking, animal tracking etc.

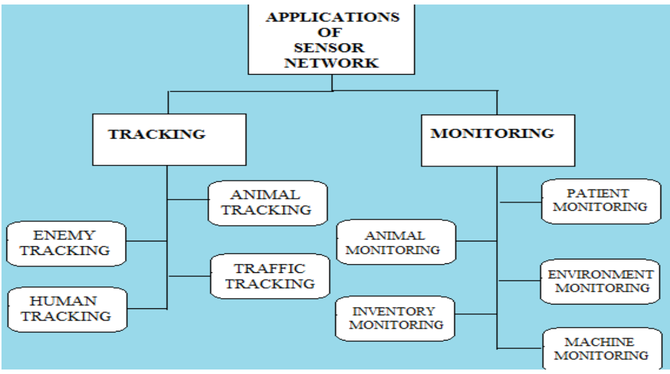

Figure 2: Overview of Sensor Applications [2]

C. *Importance of MAC layer*

The MAC layer act as a coordinator which is responsible for coordinating access to shared channel for collision-free transmissions by defining how and when a node can attempt transmission. The medium access procedure can be scheduled-based where a node can transmit only in its assigned timeslot or it can be a random in which node's attempt time is decided independently at each node. Hybrid approaches are also possible which will combine both techniques. There are many limitations in the design of MAC protocol for WSN e.g. low computational and synchronization capabilities of sensor nodes. Moreover, for being energy-efficient, the MAC layer design becomes an important issue, as it controls the transceiver operation, which is the main source of energy consumption in a sensor node. Therefore, the MAC layer must focus on the energy efficiency of the sensor nodes.

The various sources of energy waste can be classified into the following:

1. Idle Listening: Idle listening occurs when a node listen to the channel waiting for traffic. It is the major source of energy wastage in a sensor node, mainly due to the low traffic loads situations found in WSNs.
2. Collisions: When two (or more) nodes transmit at same time and interfere with each other's transmission, collision occurs. This results in wastage of sender's energy through transmitting and also of the receiver as it expands energy without any benefit, as senders may eventually retry transmission.
3. Overhearing: It occurs whenever a sensor node wastes energy receiving a packet that is not intended for it but for a different destination.
4. Overhead: In WSNs, data packets are usually small in size; therefore, headers and other types of additional overhead (such as control messages) implies a high level of energy waste for WSNs.
5. Traffic Fluctuation: In WSN, the fluctuations of the traffic load leads to wastage of energy in sensor nodes. Therefore, the protocol must be traffic adaptive.

The rest of this survey paper is organized as follows: in section II, various energy saving mechanisms are described which are being utilized by MAC protocols in order to conserve energy in WSN. Further, in section III, an overview to already existing MAC protocols is provided, especially designed for WSN scenario. Furthermore, in section IV, comparison between different MAC protocols is done in terms of various important factors such as energy, latency etc. using Table 1. Finally, the conclusions from the survey are summarized in section V, along with the future scope.

II. ENERGY SAVING MECHANISMS

In literature, number of energy saving mechanisms have been used and explored. Some of the energy saving mechanisms is:

(i) duty cycling,

(ii) scheduled rendezvous,

(iii) On-demand wake-up scheme.

Duty Cycling: Duty cycling is most common method used for energy saving in WSN. Authors [2, 3] have proposed duty cycling mechanisms in their MAC protocols. It applies suitable sleep/wake up mechanisms to conserve energy. It uses the fact that power consumption during sleep mode is much less than idle mode power consumption. Whenever there is no need for communication (reception/transmission), the radio is put to sleep mode.

Scheduled Rendezvous [4]: In this mechanism, rendezvous time is prescheduled at which point all neighboring nodes wake up together. A node wakes up periodically and sleeps until the next rendezvous time. Whenever a node is awake it is guaranteed that all of its neighbors are also awake so, it is easier to send/receive packets. Broadcasting a particular message to all neighbors is also simpler in these schemes.

On-Demand Wake-Up Scheme [5]: In this scheme, a node wakes up whenever it has some data to send or receive. MAC protocols uses radio signals to wake up a particular node from sleep state and make it communicate. A wake-up tone is used in order to wake up neighbors. The tone is broadcasted on special channel for a specified duration.

III. RELATED WORK

In [6], authors proposed S-MAC (Sensor-MAC), a medium-access control (MAC) protocol designed for wireless sensor networks. In S-MAC, to reduce energy consumption in listening to an idle channel, nodes periodically sleep. Neighboring nodes form virtual clusters in order to auto-synchronize on sleep schedules. S-MAC also sets the radio to sleep mode during transmissions of other nodes. It uses in-channel signaling. In order to reduce contention latency for those sensor network applications which requires store-and-forward processing, S-MAC applies message passing.

In [7], authors describe T-MAC (Timeout-MAC), a contention-based MAC protocol for WSN. In order to handle load variations in time and location, T-MAC introduced an adaptive duty cycle by dynamically ending the active part of it. This reduces the amount of energy wasted due to idle listening, while still maintaining a reasonable throughput. T-MAC and S-MAC achieve similar reductions in energy consumption compared to CSMA under homogeneous load, while in variable load; T-MAC outperforms S-MAC by a factor of 5.

In [8], TEEM (Traffic Aware, Energy Efficient MAC) is proposed which is inspired by the S-MAC protocol. TEEM is also based on the concept of 'listen/sleep modes cycle'. However, unlike S-MAC where the duration of listen and sleep modes are fixed, TEEM protocol makes the durations adaptive by utilizing the 'traffic information' of each and every node, and hence achieves a significant decrease in power consumption as compared to S-MAC.

In [9], authors present the EM-MAC (Efficient Multichannel MAC) protocol, which introduces different mechanisms for adaptive receiver-initiated multichannel rendezvous and for predictive wake-up scheduling. EM-MAC enhances channel utilization and transmission efficiency while resisting the wireless interference and jamming. EM-MAC achieves high energy efficiency by enabling the sender to predict the receiver’s wake-up channel and wake-up time. EM-MAC outperformed other MAC protocols studied earlier. EM-MAC maintained the lowest sender and receiver duty cycles, the lowest packet delivery latency, and 100% packet delivery ratio across the experiments.

Authors in [10] proposed DE-MAC (Distributed Energy Aware MAC) which exploits the inherent features of TDMA (Time Division Multiple Access) in order to avoid energy loss due to collision and control packet overhead.DE-MAC uses the concept of periodic listen and sleep in order to avoid idle listening and overhearing. However, unlike many existing MAC- protocols, DE-MAC treats the critical nodes differently in a distributed manner. It is motivated by the idea that weaker node should be used less frequently in order to accomplish load balancing. DE-MAC performs local election procedure in order to choose the worst off nodes and makes them sleep more than the other neighboring nodes.

In [11], authors proposed energy efficient TDMA protocol, PACT (Power Aware Clustered TDMA) that adapts the duty cycle to the user traffic. Moreover, it also applied passive clustering to take advantage of the redundant dense topology and to prolong entire network's lifetime even further. At a given point of time, only a subset of network nodes participates in the communication.

In [12], authors present EMAC (Eyes Medium Access Protocol), designed especially for WSN which consists of a self-organizing and fully distributed TDMA scheme, where each active node periodically listens to the channel and then broadcasts a short control message. Information present in this control message is used in order to create a maximal independent set of nodes, which then creates a connected network and nodes in the set are active nodes, while the rest of the nodes are passive and save their energy by using the infrastructure created by the connected network. The protocol is able to extend network lifetime 30% to 55% as compared to S-MAC in a static network topology and prolongs the network lifetime with a factor 2.9 to 4.2 in a dynamic network topology.

In [13], authors present LMAC (Lightweight Medium Access Protocol), designed especially for WSN. The protocol uses TDMA for collision-free communication; the network is self-organizing in terms of synchronization and time slot assignment. The main goal of this protocol is to minimize overhead of the physical layer. For achieving this, the protocol reduces the number of overall transceiver state switches and hence the energy wastage is reduced occurring due to preamble transmissions. The protocol is able to extend the network lifetime as compared to EMACs and SMAC respectively.

In [14], authors proposed energy adaptive WSN MAC protocol, GMAC (Gateway MAC), which implements cluster-centric paradigm to distribute cluster energy resources and extend lifetime of the network. G-MAC's centralized cluster management function offers energy savings by leveraging the advantages of both contention-based and contention-free protocols. A centralized gateway node collects all transmission-related requirements during a contention-based period and then schedules their distributions during a contention-free period.

IV. COMPARISON OF MAC PROTOCOLS

Table 1 shows comparison between different MAC protocols in terms of various important factors such as energy awareness, latency, their type i.e. contention-based or contention-free, QoS (Quality of Service) etc.

The S-MAC protocol uses periodic listening and sleeping schemes to increase network lifetime. It uses fixed duty cycle due to which a node will consume most of its energy in idle state under low traffic load, thus low energy efficiency.

In TMAC, the timeout value is used to finish the active period of a node. At high traffic loads, the transmission suffers from delay and QoS also decreases because multiple nodes try in order to access the channel and the loosing nodes have to wait for the entire frame to get access to the channel.

In TEEM protocol; duty cycle is adaptive according to the traffic information. It provides one hop forwarding per transmission cycle which may increase the transmission delay in multi-hop networks and decrease the network's QoS thus, making TEEM MAC a good choice in small networks.

EM-MAC is a multichannel, predictive, asynchronous duty-cycling MAC protocol which enhances transmission efficiency by enabling every sensor node to optimize the selection of wireless channels. It uses no control channel. EM-MAC achieves very high energy efficiency; maintains lowest duty cycles, and lowest packet delivery latency.

Table 1: Comparison of different MAC protocols [15]

Protocols	Energy' Awareness			Contention based or Contention free	Quality of Service Support	Control Packet		Latency
	Low-	Moderate	High			Required	Not Required	
S-MAC[6]	Low due to fixed duty cycle			Contention Based	Low due to fixed duty cycle	Control Packet is required		High due to fixed duty cycle
TMAC[7]	High when there is variation in traffic			Contention Based	Decreases in heavy traffic	Required		Increases when traffic load is high
TEEM[8]	High when traffic load is low			Contention Based	Better when network is small	Required when any node wants to communicate		Increases in multi- hop networks
EM-MAC[9]	High energy efficiency			Contention Based	Improves QoS	No control channel required		Low latency
DE-MAC[10]	Low in high traffic			Contention Free	Decreases in dense network	Control packet is required to elect the leader		Increases in high traffic
PACT[11]	Moderate in large networks			Contention Free	Improves QoS through passive clustering	Control packet is required to elect gateways and cluster heads.		Communicatio n delay is reduced by using passive clustering
EMAC[12]	Moderate in multi-hop network.			Contention Free	Provides low QoS	Control packet is required for MAC operation		Increases as node has to wait for its time slot for transmission
LMAC[13]	Energy efficiency is low			Contention Free	Provides low QoS	Control packet is required		Increases because a node has to wait for its time slot
GMAC[14]	Moderate as energy adaptive			Hybrid	Improves QoS	Required		Low due to clustering

The DE-MAC protocol treats the nodes on the basis of their energy level. DE-MAC uses an election process which can increase the delay in communication. In dense network with high load, the election process will occur frequently which will decrease the QoS. In DE-MAC, the energy consumption of a node can also be increased as nodes have to wake up during the time slots of its neighbors in order to receive the data.
PACT is a TDMA-based protocol used for large multi-hop WSNs. It uses adaptive duty cycles based on the current traffic density in order to decrease the energy consumption. It decreases communication delay through passive clustering, which also improves the QoS support. In PACT, each node has to listen to control packets from other nodes to get the control information. This may lead to some energy consumption.
EMAC protocol is a TDMA-based MAC protocol where each node has one slot for transmission in a frame. It saves energy by exploiting the infrastructure created using the connected network of active nodes. In EMAC, each node has to wait for its specific time slot, thus increase is latency is detected.
LMAC is a protocol which adapts the switching-state to traffic fluctuations. Here, each node has to wait for its own time slot for communication, which results in an increase in latency. Moreover, each node has to listen in the control section of each and every frame which may lead to waste of energy.
In GMAC, cluster-centric paradigm is implemented in order to increase network lifetime. It utilizes the merits of both contention-based and contention-free protocol, offering energy savings in the network.

V. CONCLUSION AND FUTURE WORK

In this paper, a comparative survey of various MAC protocols is presented. Table 1 shows the comparison of different MAC protocols based on the various important requirements such as energy awareness and QoS support.
According to the comparison table, the contention-free PACT protocol provides a reasonable solution in terms of QoS and low latency through the use of passive clustering. It also uses an adaptive duty cycle to increase overall network life time. The EMAC protocol is contention free protocol, requires control packet for MAC operation and is also used to piggy bag various other information at low energy costs. Here latency increases as nodes have to wait for their desired time slot. LMAC protocol provides collision free communication but the latency can increase because a node has to wait for its time slot. It extends network lifetime as compared to S-MAC and EMAC. DEMAC takes the individual node’s energy levels into account and thus providing a solution in terms of energy awareness. Contention-based protocols like, S-MAC, TMAC, TEEM and EM-MAC, use periodic listening and sleeping scheme in order to prolong the network lifetime. The TEEM protocol provides more sleeping time to nodes in comparison to S-MAC and TMAC. EM-MAC substantially outperformed other MAC protocols studied in terms of energy-efficiency. GMAC is a hybrid protocol having advantages of both contention-based and contention-free protocols in it.
In contention-based protocols, transmission suffers from collisions because each node is allowed to access the shared medium at any time. This results in increased delays and reduced QoS support.
In contention-free protocols, like LMAC, EMAC, DEMAC and PACT, collision-free communication and increased QoS is provided. Each node has pre-assigned time slots for transmission of data but in order to synchronize; each node has to listen to the time slots of its neighbors. This may increase the energy consumption. A contention-free protocol suffers from clock drift problems and requires tight synchronization.
Many existing MAC protocols deal with the energy requirement of WSNs. Nevertheless, new researches are still required on protocols that focus on a combination of energy awareness and QoS aspects with reasonably low delays, in order to meet the requirement of various sensor network applications.

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