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MAC Protocols for Wireless Sensor Networks

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Abstract

Background/Objectives: Wireless sensor network are the collection of individual nodes which are able to interact with physical environment statically or dynamically by sensing or controlling physical parameter. The design of an energy-efficient Medium Access efficient Control (MAC) protocol is one of the major issues in Wireless Sensor Networks (WSN). Most of these protocols take into account the energy efficiency as a main objective. There is much more innovative work should be done at the MAC layer to address the hard unsolved problems. **Methods/Statistical Analysis:** Wireless sensor network become a prominent in many applications like habitat, infrastructure and industrial automation. In this paper, we first outline and discuss the specific requirements and design trade-offs of a typical wireless sensor MAC protocol by describing the properties of WSN that affect the design of MAC layer protocols. Then, a typical collection of wireless sensor MAC protocols presented in the literature are surveyed, classified, and described emphasizing their advantages and disadvantages whenever possible. **Findings:** In this paper we study some characteristics of WSN that are important for the design of MAC layer protocols and give a brief introduction of some MAC protocols with reference to energy efficiency for WSN. In accordance with channel access policies, MAC protocols are classified into four types, which are cross layer protocols, TDMA-based, contention-based and hybrid. For the collection of recent wireless sensor real-time MAC protocols emphasizing their advantages and disadvantages whenever possible. One of the major constraints in Wireless Sensor Networks (WSNs) is power consumption. In recent years, a lot of efforts have been put into the design of Medium Access Control (MAC) protocols for WSN, in order to reduce energy consumption and enhance the network's lifetime. **Application/Improvement:** MAC protocol plays an important role in WSN energy performance and give result that there is no standard protocol which give better energy efficiency and enhances further research to design and develop application dependent and for usages.

Keywords: Energy Efficiency, Medium Access Control Protocol, Wireless Sensor Networks

1. Introduction

Communication in Wireless Sensor Networks is divided into several layers. Medium Access Control (MAC) layers protocol tries to avoid collisions by not allowing two interfering nodes to transmit at the same time. This will enables for the successful operation of the network.

The main design goal of a typical MAC protocols is to provide high throughput and QoS. On the other hand, wireless sensor MAC protocol gives higher priority to minimize energy consumption than QoS requirements. Energy gets wasted in traditional MAC layer protocols due to idle listening, collision, protocol overhead, and overhearing.

There are some MAC protocols that have been especially developed for wireless sensor networks. Typical examples include S-MAC, T-MAC, and D-MAC, etc. To maximize the battery life-time, sensor networks MAC protocols implement the variation of active/sleep mechanism.

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2. Properties of WSN

Common objective of wireless sensor network is to maximize the network lifetime. Properties of a well define MAC protocol for WSN is describing in Portion 2.1. To extract the activities of sensor network traffic, different types of communication patterns of WSN are used in the literature.

Categorization of communication pattern for wireless sensor network is described in Portion 2.2. Sensor nodes are disposed when they are out of battery to solve this problem we decrease the wastage of energy, and the reasons of energy wastage is reduced by the methods which we will be describe in Portion 2.3.

2.1 Characteristics of Energy Efficient MAC Protocol

- Energy efficiency - Since the WSN has battery constrained sensor nodes they cannot spend their energy to transmit and receive many control packets. Thus the MAC protocol should be designed such that it consumes energy efficiently to support network lifetime.
- Scalability and Adaptability - WSN protocol should be adaptable to changes in network size, density of node and topology since some nodes may stop functioning due to battery drain or link error or any other environmental problems.
- Latency - Latency gives network speed. In processing of network data several kinds of delays typically sustain. In a network, small delay times considered as low latency network connection. Whereas a high latency connection experience from long delays.
- Throughput - Amount of data which is able to flow throughout in a network refers to the network throughput. Throughput of the system should be high.
- Bandwidth utilization - Data rate in a networking is known as bandwidth. We can't restrict speed of a network by only the network bandwidth. Network should support higher bandwidth utilization.
- Fairness among sensor nodes - Fair distribution of resources in a network is determined by fairness. It is an important characteristic to take resources for communication between the nodes in a network like cluster head selection in a cluster.

2.2 Communication Patterns

We defines four types of communication patterns in Wireless Sensor Networks:

- Broadcast - Base station uses these types of communication patterns to transmit information to all supplementary sensor nodes of the wireless sensor network. Queries of sensor nodes are used for broadcasting information among the network.
- Local gossip - In a network we transmit and receive messages and data between the sensors nodes is called local gossip and it is done in between the neighboring nodes within a specific range.
- Converge cast - In this communication pattern of WSN, collection/cluster of sensor nodes communicate via/to a leader node/cluster head.
- Multicast - In this type of communication pattern messages is sent to a particular division of sensor nodes.

2.3 Causes of Energy Depletion

- Collision - When more than one packet is received by a sensor node at the same time then the packets get corrupted during the transmission and need to be discarded retransmission of packet are required. This outcome in wastage of energy resources.
- Overhearing - Means node listens packets that are destined to some other node but not addressed to it.
- Control packet overhead - RTS and CTS signals are used as control packets which also consume energy so minimum number of control packets should be used to make a data transmission.
- Idle listening - It is happened when a node is continuously listening the channel to check the availability of the channel and this phenomenon consumes significant amount of energy collectively, even greater than the total energy consume in transmitting/receiving data packets in a large period.
- Over emitting - This is caused by transmission of message when destination node is not ready or sending rate is higher than receiving rate.

3. WSN Energy Efficient MAC Protocol

In WSN many or wide range of energy efficient MAC protocols are present in the literature some of them are discussed in this paper with their essential properties. We classified these MAC protocol into four categories[1].

3.1 Contention based MAC Protocol

Basic approach of contention based MAC protocols are Carrier Sense Multiple Access (CSMA) and Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA). To obtain wireless channel for sending data on network MAC protocol contend with each other to get wireless channel. The channel is accessed randomly so there is no need of coordination. When the chance of collision decreases in any network than it increases performance of network. Chance of collision is decreased if a station sense the medium before trying to use it by this approach the possibility of collision is reduced. If the channel is free we can send data on the channel but if channel is not free it will wait for random amount of time.

The principle of CSMA is "sense before transmit". CSMA/CA avoids the collision using three strategies: The Interface Space (IFS), the contention window and acknowledgement. Advantage of these MAC protocol is to increase scalability and adaptability. Under this category these protocols T-MAC, S-MAC, U-MAC are defined[2].

3.1.1 Sensor-MAC(S-MAC)

S-MAC[2] was based on IEEE 802.11. The function of S-MAC is to save energy. In S-MAC we divide time into frames. S-MAC protocol follows the method of periodic sleep – listen schedules. S-MAC has two stages, sleep stage and wake-up stage. Neighboring nodes setup a common sleep schedule from virtual cluster. When two neighboring node present in two different virtual clusters they will wake-up in a listen period of these two clusters which gives result in more energy consumption by idle listening and overhearing.

3.1.2 Timeout-MAC (T-MAC)

Bad results of S-MAC protocol are improved by T-MAC[2]. It reduces energy consumption on idle listening. It uses concept of adaptive duty cycle in which messages are transmitted in different length bursts and the lengths bursts is determined dynamically. S-MAC protocol, in their time-frame has two types of periods which are active and sleep periods. In a specific time period Ta if there is no activity occurs than active period ends. The time-frame Ta represents the smallest listening time.

3.1.3 Ultra Wide Band MAC (U-MAC)

U-Mac[3] is use to reduce energy consumption for wireless sensor network. It uses concept of SMAC protocol by which there are three improvements in this protocol. For example selective sleeping after broadcast, various duty-cycles, and utilization based tuning of duty-cycle.

3.2 TDMA based MAC

Time division multiple access is channel access method for shared medium network. In this method it is defined that the channel is dividing into time slots which is share among simultaneous users. In fixed TDMA the time slots are assigning to each terminal permanently. This result in a simple implementation but the time slot is wastage if there is no data to send.

In dynamic TDMA when there is request by a terminal, time slots are assigned by central station. To implement this, a separate signaling slot is mandatory to broadcast request for slots. TDMA methods are based on scheduling in which an inherent collision-free scheme is used for transmit or receive data messages to each and every node but as compared with contention-based MAC, time slots are uniquely assigned. TDMA has an important advantage is that clashing between adjacent node is avoided. By this collision is avoided, so energy wastage due to collision is reduced.

TDMA can also solve the problem of hidden terminal without using of additional data message overhead because in TDMA neighboring nodes transmit at different time slots. TDMA-based MAC protocols are μ-MAC, DEE-MAC, SPARE MAC[4].

3.2.1 μ-MAC

High sleep ratios are obtained by μ-MAC[5] which is retaining the message reliability and latency. It is based on a schedule-based approach by which shared medium is accessed, which is predicted by behavior of traffic. Single time-slotted channel is used in μ-MAC protocol. Operations of this protocol alternate between a contention-free period and contention period.

3.2.2 DEE-MAC

It uses a method of synchronization which is done at cluster head in which by forcing the idle listening modes to sleep mode the energy consumption is reduced. Cluster is based on the knowledge of remaining power as all nodes contend to be the cluster head which is done dynamically. The operations of DEE-MAC based on rounds. These rounds consist of two phases which is cluster formation phase and a transmission phase[6]. Cluster formation phase, decides that whether the node become the cluster head or not and it is based on remaining power and in the transmission phase consists of a different types of sessions and every session comprises of two type of period a data transmission period and other is contention period.

3.2.3 SPARE MAC

This protocol is used for data diffusion in WSN. By limiting the reasons of overhearing and idle listening SPARE MAC[5] is used to conserve the energy. Distributed scheduling solution is taken to implement this, in which we assign each sensor node to a specific time slots. This protocol reduces the problem of collisions and idle listening.

3.3 Hybrid MAC

It is integration of contention-based MAC and TDMA-based MAC. We take all the advantages of these two methods and make a better solution which is hybrid MAC. Hybrid protocol divides the channel into two parts, channel control packets and data packets, in channel control packets data is sent in the random access and in data packets data are transmitted in the scheduled channel. The hybrid protocols can save higher energy and supply better scalability and flexibility in comparison to these two methods. Hybrid protocols are A-MAC, IEEE 802.15.4 and Z-MAC[2].

3.3.1 Z-MAC

This protocol improves contention resolution by integrating TDMA and CSMA. Z-MAC[6] is based on the concept of owner slot. Owner slot is accessed in TDMA style and other slots are access in CSMA style. Z-MAC has two basic components. First is called neighbor detection and slot assignment, and the other one local framing and synchronization. By this, collisions are increasingly reduced and decrease the energy conservation.

3.3.2 A-MAC

It is proposed for no-overhearing, collision-free and fewer idle-listening transmission services. This is used in the applications like long-term surveillance and monitoring. A-MAC[7] is based on the concept in which when receivers wants to receive the packets nodes are notified in advance. When the nodes want to receive or send the packets they are activated and during other time they go to sleep mode. By this method wastage of energy is unseen on idle listening and overhearing. It is also enhancing the accessibility of the wireless channel.

3.3.3 IEEE 802.15.4

It is a low-rate Wireless Personal Area Networks (WPAN). To maintain the synchronization of time-frames it takes coordinator which is operating in the beaconed mode. It has concept of super-frame structure, in this we use TDMA-based period for access, and we use a contention-based period for non-guaranteed access. All nodes enter into the sleep state when they are not used. It can also work in ad-hoc based mode[8]. For energy conservation there is no special design method except a typical duty cycle controlling scheme.

3.4 Cross Layer MAC

Without considering the correlation of all layers in WSN the above energy efficient MAC protocols based on the single MAC layer design, means using only the useful information for MAC layer. In a simple network protocol stack, we cannot obtain good flexibility and high efficiency. In Cross Layer MAC, we maintain the relation between each layer for improving consumption of energy. It is use in finding of the awake/sleep periods and Forward Error Correction (FEC) coding in a cross layer design of Wireless Sensor Networks to find the narrowband[7]. We design this by integrating the characteristics of the physical layer and the MAC layers. Here it is introduced new Cross Layer MAC protocol MAC-CROSS and CLMAC.

3.4.1 MAC-CROSS

This protocol improved energy efficiency by combining the characteristics of MAC layer and routing layer. At the network layer to maximize sleep duration of each node we use, routing information. We exploited direct interactions between the application layer and the MAC/physical layers[2].

3.4.2 CLMAC

In this for simplification of this protocol stack we removed network layer and transport layer. Functionality of these two layers is merged into Application layer and the MAC/physical layers. In B-MAC it includes routing distance in the preamble field. CLMAC protocol does the function which is similar to the B-MAC protocol. It enables nodes to reduce control traffic routing overhead without routing table.

To support the optimization mechanisms in cross layer design among protocol layer only valuable information should be transmitted and shared. The routing assessment will modify the contention level at the MAC layer. So we use correct wireless links at routing layer to send data packets to the target node. Cross layer method is a realistic way to improve the quality of MAC protocols[2].

4. Routing and MAC Protocols

Routing in sensor networks has some challenges that are not present in general wireless networks. The two main challenges are the varying topology nature of sensor networks, and the low power requirement on sensor networks[9–12]. In[13], the authors proposed a medium access protocol for ad-hoc wireless sensor networks. They emphasized in their design that the main objective in wireless sensor networks in the power consumption rather than fairness, throughput, or delay, which are the main concern in user-oriented networks. In their design, they assumed that the network consists of many small nodes scattered in an ad-hoc fashion in order to collect some information about the environment. The nodes usually are in the idle mode until some event occurs; in this case, they record the event and send messages to other nodes. Other nodes may process the messages before forwarding it to a monitoring station.

The protocols are dependent on the RTS/CTS mechanism of the IEEE802.11 to avoid collisions. However in their protocol nodes alternate between listening and sleeping according to a specific schedule. Each node either determines its own schedule and broadcasts it, or follows the broadcast schedule of a neighboring node. They implemented their protocol on the UCB Motes[14], using the Atmel AT90LS8535 microcontroller with 8K bytes of programmable flash and 512 bytes of data memory and they showed that their protocol consumes 2-6 times less power than IEEE802.11.

In[15] the authors proposed a power control extension to the IEEE802.11 MAC protocol. They used a concept similar to the power control in CDMA networks. Their simulation shows an improvement in both energy consumption and network throughput. In[16], the authors investigated the effect of low energy routing on delay-constrained data, they also proposed a new energy-aware constrained routing for sensor networks. In addition, they used multihop routing to minimize transmission energy. The authors also used a weighted fair queuing packet scheduling methodology in order to achieve a soft real time guarantees. The problem of repositioning the base stations for enhancing the network performance. Although many research projects in both industry and universities are being pursued. There is a lot of work to be done in the area of wireless networks protocols. Most of the work in sensor networks assumed the 5 layer TCP model which is very popular for wireline and wireless networks. However, there is no indication that this is the best model for sensor networks. This is almost unexplored area and a lot of work needs to be done especially at the application layer level.

5. Conclusion

In this paper we examine the characteristics of the WSN. We discussed various type of energy efficient MAC protocol of WSN which is prominence on the energy efficiency; it is a critical issue for WSN. Because sensor nodes are hold batteries for control power in network. For application in WSN, reduction in energy consumption is essential, and the MAC protocol in WSN is the most important influential aspect in WSN energy performance[1]. So the key problem is designing an energy efficient MAC protocol. One of the causes behind is the MAC protocol selection resolve, in a wide-ranging, application-dependent. This will give result that there is no standard protocol which give better energy efficiency. Hence enhances the scope of further research to design and develop more energy efficient protocols to satisfy their WSN application requirements and usages.

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