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Study and Analysis of MAC Protocols Design Approach for Wireless Sensor Networks

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Abstract- **Wireless sensor networks have become an active research area for the researchers. Several researchers in Wireless sensor networks have led to many new protocols specifically designed for different kinds of applications where reliability and energy efficiency is an essential consideration. Most of the attention has been given to the Medium Access Control (MAC) protocols since they pay an important role in wireless communications and traditional MAC protocols are not suitable for Wireless sensor networks. The aim of the paper is to study the Reliable and energy efficient Medium Access Control (MAC) protocols design approach for wireless sensor network and to motivate the researcher, while showing the future aspects in the area of Wireless Sensor Networks.**

Keywords- **Reliability, energy efficiency, wireless sensor networks, Medium Access Control protocol**.

I. INTRODUCTION

Designing wireless sensor networks with the capability of prolonging network lifetime take the attention of many researchers in wireless network field. The wireless sensor networks (WSNs) are used in a wide range of applications to capture, gather and analyze live environmental data [1]. WSNs [2-5] are an emerging technology that has become one of the best growing areas in the communication industry. They consist of sensor nodes that use low power consumption which are powered by small replaceable batteries that collect real-world data, process it, and transmit the data by radio frequencies to their destination. The node has limited resources, like limited processing capability, Limited memory and limited battery, energy and etc.

Therefore, Energy management is a challenging problem in designing a Wireless Sensor networks protocols. The use of WSNs is increasing day by day and at the same time it faces the problems of low processing power of the nodes and high energy consumption but reliable delivery of data in the real time also needs proper attention. Unfortunately there is no in-depth study carried out in this area but some time critical applications require reliable delivery of data in real time. So many scholars have developed many new protocols specifically designed for different kinds of applications where energy efficiency is an essential consideration.

Major causes of energy waste in wireless sensor network are basically of four types [6]: Collision: The first one is the collision. When a transmitted packet is corrupted due to interference, it has to be discarded and the follow on retransmissions increase energy consumption. Collision increases latency also, Overhearing: The second is overhearing, meaning that a node picks up packets that are Destined to other nodes, Packet Overhead: The third cause is control packet overhead? Sending and receiving control packets consumes energy too and less useful data packets can be transmitted, Idle listening: The last major source of inefficiency is idle listening i.e., listening to receive possible traffic that is not sent. This is especially true in many sensor network applications. If nothing is sensed, the sensor node will be in idle state for most of the time. The main goal of any MAC protocol for sensor network is to minimize the energy waste due to idle listening, overhearing and collision but reliable data delivery in real time is more and more important issue in the WSNs Field. In this paper we represent numerous medium access control protocols design approaches for the wireless sensor networks, and highlight their potency and limitations wherever possible. In the end some future research directions are describe for the design of Reliable data delivery medium access control protocol for wireless sensor networks.

The rest of this paper is organized as follows. The characteristics of good MAC protocols are described in section II. Categories of MAC protocols design approach are described in section III. Performance matrices of MAC protocols are described section IV. Comparison of MAC design techniques are described in section V. In future direction is described in section VI and finally we conclude in section VII.

II. CHARACTERISTICSOFMAC PROTOCOLS

Wireless Sensor network provide a different communication infrastructure for wireless networks. Those differences create not only from their physical characteristics, but also from their typical applications. Typical applications include both for mass public and military for wireless networks.

Consequently, the requirements for the Medium Access Control (MAC) layer of a Wireless Sensor Network (WSN) are clearly different traditional networks. The major characteristics (requirements) for the MAC protocols in a WSN are as follows:-

1) Latency: Latency requirement basically depends on the application. In the sensor network applications, the detected events must be reported to the sink node in real time so that the appropriate action could be taken immediately.
2) Reliability: Reliability in wireless sensor networks can be examined from both the packet level and the event level. Packet level reliability refers to how many packets are successfully received at the final destination. Event level reliability refers to the delivery of certain data objects or events to the receiver.
3) Energy Efficiency: The sensor nodes are battery powered and it is often very difficult to change or recharge batteries for these sensor nodes.
4) Stability among various metrics: The MAC design for WSN needs to accomplish stability among a number of metrics. This stability capacity is more important than the performance on any individual metric. For example, a protocol can use a smart scheme to save power. However, if this scheme does not consider other metrics, such as the real-time guarantee or reliability of the packet delivery, It could not only hinder the performance on other metrics, but also degrade on the performance of power saving. For example, if the node turns off the radio component too often, some packets may be lost and more retransmissions could happen, which result in an even greater power consumption.
5) Fairness: In many sensor network applications when bandwidth is limited, it is necessary to ensure that the sink node receives information from all sensor nodes fairly. However among all of the above aspects the energy efficiency and throughput are the major aspects. Energy efficiency can be increased by minimizing the energy wastage.
6) Decentralized: Most algorithms running in wireless sensor network need to be decentralized. This is due to both the large scale of the network and the built-in unreliability of any single node in the network. Consequently, the MAC protocol needs to run decentralized algorithms.

III. CATEGORIESOFMAC PROTOCOLS DESIGN APPROCHES

The medium access control protocols for the sensor networks can be classified broadly into following categories:

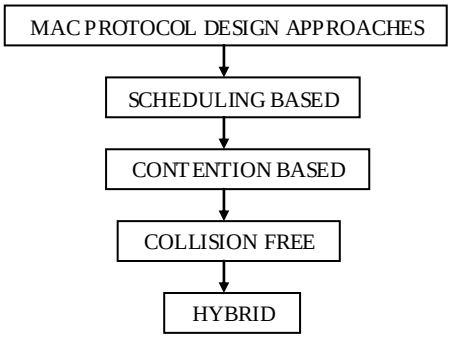

Fig. 1 Classification of MAC protocol design approach.

The above fig.1 show four types of MAC design approaches. It's described as below:

A. Contention Based Mac Protocols

The contention based protocols based on relax time synchronization and it is used when nodes are not assigned fixed time slot for sending request, and it is very useful when delivery of data is random rather than periodic. Contention schemes differ in principle from scheduled schemes since a transmitting user is not guaranteed to be successful. Contention based protocol usually carrier sense medium access /collision avoidance (CSMA/CA) are easy to deploy and have been the most used ones in wireless sensor network due to their simplicity and flexibility and robustness. Nodes do not need synchronization information or global topology information in order to access the medium access and send their information. And also node can get in get out of the network without major complications. Contention protocol has several advantages compared to schedule protocols. First because contention protocols allocate resources on demand, they can scan more easily across changes in node density or traffic load. Second, contention protocols can be more flexible as topologies change. There is no requirement to form communication clusters, and peer-to-peer communication is directly supported. Finally, contention protocols do not require fine- grained time synchronization as in TDMA protocols. The major disadvantage of a contention protocol is its inefficient usage of energy. Examples of contention based MAC protocols are: Sensor-MAC (S-MAC) [7], Timeout MAC (T-MAC) [8], CSMA/CA-based MAC (RMAC) [9], Probability Sensor-MAC (PS-MA) [10], Extended IEEE 802.11 based RAP MAC [11], Non-Persistent CSMA with preamble sample (NP-SCMA-PS) [12], (B-MAC) [13] etc.

B. Collision Free Mac Protocols

An important performance standard in data centric wireless sensor network is timeliness. There are some collision free MAC protocols developed by wireless sensor networks. Example, the traffic adaptive medium access control (TRAMA) [14], mobility adaptive, collision-free medium

access control protocol (MMAC) [15], Bit-MAC [16], Spatial TDMA [17] etc. TRAMA [13] is an energy efficient collision-free channel access protocol for WSN. TRAMA reduces energy consumption by ensuring that uncast, multicast, and broadcast transmissions have no collisions, and by allowing nodes to switch to a low-power, idle state whenever they are not transmitting or receiving. TRAMA assumes that time is slotted and uses a distributed election scheme based on intonation about the traffic at each node to determine which node can transmit at a particular time slot. TRAMA avoids the assignment of time slots to nodes with no traffic to send, and also allows nodes to determine when they can become idle and not listen to the channel using traffic information. TRAMA is shown in [12] to be fair and correct. In that no idle node is an intended receiver and no receiver suffers collisions. The performance of TRAMA is evaluated through extensive simulations using both synthetic- as w ell as sensor-network scenario. The results indicate that TRAMA out performs contention based protocols as well as scheduling-based protocols with significant energy savings. MMAC [15] is a scheduling based protocol and thus it guarantees collision avoidance. MMAC allows nodes the transmission rights at particular timeslots based on the traffic information and mobility pattern of the nodes. The Bit-MAC [14], is a deterministic, collision-free, and robust protocol for dense wireless sensor networks. Bit-MAC is based on an "or" channel, where synchronized senders can transmit concurrently, such that a receiver hears the bitwise "or" of the transmissions.

C. Scheduling Based MAC Protocols

In scheduling-based MAC protocols, the time at which a node can transmit is determined by a scheduling algorithm, So that multiple nodes can transmit simultaneously without interference on the wireless channel. The time is usually divided into slots, and slots are further organized into frames. Within each frame, a node is assigned at least one slot to transmit. A scheduling algorithm usually finds the shortest possible frame so as to achieve high spatial reuse and low packet latency. A large amount of work-has been focused on Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA), and Energy Efficient MAC Protocol for Sensor Networks (EMACS) etc. TDMA allows several users to share the same frequency channel by dividing the signal into different time-slots. It has a natural advantage of collision free medium access. It supports low duty cycle operation: a node only needs to turn on its radio during the slot that it is assigned to transmit or receive. The limits with TDMA systems are synchronization of the nodes and adaptation to topology changes. The slot assignments, therefore, should be done with regard to such possibilities. However, it is not easy to change the slot assignment within a decentralized environment for traditional TDMA, since all nodes must agree on the slot assignments [18]. FDMA allocates users with different carrier frequencies of the radio spectrum. It is another scheme that offers a collision-free medium, but it requires additional hardware to dynamically communicate with different radio channels. This increases the cost of the sensor nodes, which is in contrast with the philosophy of sensor network systems [15]. CDMA employs spread spectrum technology and a special coding scheme to allow multiple users to be multiplexed over the same physical channel. EMACS [18] is also a TDMA based MAC scheme. The Data–Gathering Medium Access Control (DMAC) [19] is a schedule based MAC protocol which has been designed and optimized for tree based data gathering (converge cast communication) in wireless sensor network.

D. HYBRID protocol MAC protocols

Hybrid protocol is a grouping of contention based and Schedule based protocol. Several MAC protocols have been proposed to combine the features of CSMA and TDMA protocols [20, 21] with the aim to include the Benefits from both of them. In these hybrid protocols, Active/sleep duty cycles are applied by dividing time into frames during which a node spends a portion of the time for communication and sleep for the rest time to reduce the energy-wastage caused by idle listening. Several MAC protocols, Zebra MAC (Z-MAC), Hybrid TDM-FDM MAC, etc can be viewed as hybrid schemes. Zebra MAC (Z-MAC) [22] is a hybrid protocol based upon CSMA. ZMAC uses CSMA at the base but follows TDMA depending on the contention level. The overhead of Z-MAC protocol is the setup phase, which is done at the beginning. In the setup phase, the nodes are assigned with the timeslots for the data transmission. The node is called the owner of a time slot if it wins the access of the transmission medium; otherwise the node is known as non-owner. Thus Z-MAC for sensor network can dynamically adjust the behavior of MAC between CSMA and TDMA depending on the level of contention that is whether it is high or low. Thus under high contention it behaves like TDMA and under low contention it behaves like CSMA. Thus CSMA is to hidden terminals. And on the other hand TDMA is naturally avoiding collision but there is somewhat complexity in maintaining scheduling. A hybrid TDM-FDM MAC is proposed in [23] where both time and frequency are divided into transmission slots.

IV. PERFORMANCEMATRICES OFMAC PROTOCOLS

The research community considers the following matrices in order to evaluate and compare the performance of energy conscious MAC protocols.

A. *Energy Consumption per Bit*: The energy efficiency of the sensor nodes can be defined as the total energy consumed total bits transmitted. The unit of energy efficiency is joules/bit. The lesser the number, the

better is the efficiency of a protocol in transmitting the information in the network. This performance matrices gets affected by all the major sources of energy waste in wireless sensor network such as idle listening, collisions, control packet overhead and overhearing.

B. *Average Delivery Ratio:* The average packet delivery ratio is the number of packets received to the number of packets sent averaged overall the nodes.

C. *Average Packet Latency:* The average packet latency is the average time taken by the packets to reach to the sink node.

D. *Network Throughput:* The network throughput is defined as the total number of packets delivered at the sink node per time unit.

V. COMPARISON OF MAC DESIGN TECHNIQUES

This table shows the comparison of different MAC protocols Designing approaches in terms of reliability and energy efficiency for real time communication:

Approach	Protocols	Reliability support	Energy efficiency	Real time communication
Contention Based	S-MAC T-MAC RMAC PS-MAC NP-SCMA-PS etc.	Good	High	Moderate
Collision Free	TRAMA MMAC Bit-MAC etc.	Good	Moderate	Moderate
Scheduling Based	EMACS FDMA CDMA etc.	Good	Low	Low
Hybrid	Z-MAC Hybrid TDM-FDM MAC etc.	Good	High	Good

Table 1. Shows the comparison of different MAC Design Approaches

We conclude that, Contention-based protocols frequently have difficulty in providing real-time guarantees. As mentioned above, collisions also waste energy. This could be useful in some applications where predictability is less critical and power consumption is the main concern. On the other hand, for the collision-based protocols to be successfully used in sensor networks, a well-defined statistical bound is still needed. Collision-free protocols are surely striking because they save power by eliminating collisions. A good collision- free protocol can also potentially increase the throughput, reduce the delay, and provide real-time guarantee. Scheduling Based (TDMA based) is a capable technology because it provides fair usage of the channel and, if set with an adequate scheduling algorithm, could also avoid collisions. But many TDMA protocols use global information to do scheduling, which render those protocols to be impractical in general sensor networks. As well, some of the protocols still have collisions, and it is quite difficult to control the collisions to the degree that does not hurt the guarantee of timeliness.

These issues make it difficult for existing TDMA protocols to be broadly used in sensor networks. And the hybrid protocols, integrating more than one approach's advantages, may be useful in meeting the requirements in WSN

VI. FUTURE DIRECTION

In the recent years a large number of medium access control (MAC) protocols for the wireless sensor network have been published by the researchers using different-different approaches. The detailed study reveals that up to now we have no such approach that honestly useful for deign protocols that supports both the reliability and energy efficiency in real time communication. This shows that it will be more fruitful to develop such a protocol that will provide simultaneously both reliability and energy efficiency in real time communication.

VII. CONCLUSIONS

Recently several medium access control protocols for the wireless sensor network have been proposed by the researchers using different-different approaches. We have studied the basic categories of MAC protocol; Contention Based, Collision Free, Scheduling Based and Hybrid in terms of reliability, latency, QoS and energy efficiency. Although several designs may have good energy efficiency and delay performance, for real time service support, there are still many challenges. The Hybrid MAC protocols show better and efficient features for real time applications but there are still many more challenges that need to be solved in the sensor networks there is still need to find out the suitable solution for real time communication and energy efficiency. The simultaneous Support both reliability and energy efficient for real time communication in WSNs will be a challenging and interesting area in the coming years for researchers.

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