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Intelligent MAC Protocol for Wireless Sensor Networks

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ABSTRACT: In Wireless Sensor Networks the common objective is to maximize the network lifetime. The sensor nodes are battery operated and hence the energy consumption by each node has to be minimized such that the network lifetime is increased. Hence appropriate Medium Access Control (MAC) protocol can be designed to achieve good throughput and to extend network lifetime. The main contribution to energy waste is idle listening and several MAC protocols have been proposed to overcome this drawback by scheduling the nodes sleep and active periods. As a next step MAC protocols employing adaptive duty cycles, where each and every node decides the duty cycle based on its own traffic load alone, emerged so as to further optimize the energy utilization. The nodes individual traffic and the state of other nodes are also considered in RL-MAC, a reinforcement learning based approach. This protocol provides good throughput and energy efficiency when compared to other protocols. In this paper the performance of RL-MAC has been improved further by the Active Queue Management which aims at reducing the network congestion and improving the end to end delay.

KEYWORDS: Wireless Sensor Network, Media Access Control, Reinforcement Learning, Active Queue Management.

I.INTRODUCTION

A Wireless Sensor Network consists of a large number of sensor nodes which are distributed over a certain area. Each sensor node is used to measure a physical phenomenon and this data is converted into an electrical signal. The collected data or information is sent to the Base Station directly or via other sensor nodes. Each sensor node consists of four modules namely the sensing unit, processing unit, transmission unit and power unit. The sensor nodes are equipped with limited power sources and hence the lifetime of the node is dependent on the battery lifetime. Usually Wireless sensor nodes are deployed in an unmanned environment and so replacing the battery is a tedious task. The major source of power consumption in a sensor node is wireless communication. Hence designing energy efficient algorithms for Wireless Sensor Network is a primary concern.

The MAC protocol which is employed in WSN employs three techniques which reduce the energy consumption of the network. The three concepts that have to be included in the MAC protocol are periodic listen and sleep, collision and over-hearing avoidance, message passing. These three components overcome the energy waste caused due to idle listening, collision, overhearing and control overhead.

So a good efficient MAC protocol has to improve the network lifetime and other attributes like latency, throughput also has to be considered according to the application.

II.RELATED WORK

The MAC layer plays a vital role in the design of energy efficient Wireless Sensor Networks. The first and foremost method of preserving power is to fix the duty cycle of each node. Several MAC protocols employing different types of duty cycling mechanisms have been proposed. Few MAC protocols, their advantages and disadvantages have been explained in this section.

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A. TDMA Based MACs

In Time Division Multiple Access protocol (TDMA), time is divided into frames and each frame is in turn divided into slots. Each node is allotted with a slot during which it can transmit. This results in collision free transmission, guarantees finite and predictable scheduling delays. It also increases the overall throughput in highly loaded networks.

The limitations of this protocol are as follows. The maintenance of the TDMA schedule is complex and memory consumption is also high. Allocation of slots requires coordination and the exact timing is critical. The idle slots results in waste of channel bandwidth and energy.

B. S-MAC

The Sensor-MAC (S-MAC) protocol employs the adaptive listening concept. Three concepts are used to minimize energy consumption and support self-configuration. First, the neighboring nodes are synchronized to go to sleep. Second, the neighboring nodes form virtual clusters so that a common schedule is set up. Third, message passing concept which helps to achieve energy saving by reducing communication overhead is employed [2].

In this protocol the cycle time is divided into sleeping period and wake up period. The wake up period consists of SYNC period, RTS/CTS period and data transmission period. During the SYNC period, the sensor nodes broadcast a SYNC packet to the neighboring nodes and this is used to synchronize with neighbor nodes in the network. This packet contains the next sleeping time of the sender which informs the receiving nodes about the next transmission. RTS/CTS is used for the requisition and grant for transmission.

The sleeping schedules reduce the energy waste caused due to idle listening thereby the network lifetime is increased which is the most important advantage of S-MAC protocol.

The drawback of S-MAC protocol is that it uses predefined sleep and listen periods for all nodes which tend to decrease the efficiency of the algorithm under variable traffic load. It induces energy waste in certain scenarios where several nodes require higher duty cycle than others, like the nodes that are situated near the sink.

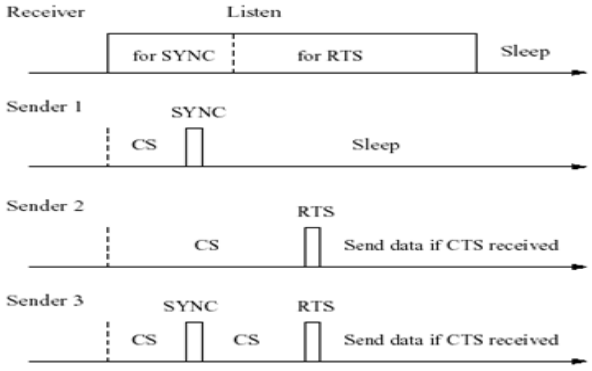

Fig. 1 S-MAC Messaging Scenario

C. TRAMA

TRaffic Adaptive MAC protocol (TRAMA) is an energy efficient, collision-free medium access control for wireless sensor networks [4]. This protocol is similar to Node Activation Multiple Access (NAMA) which was a distributed election algorithm where for each time slot, only one transmitter is elected per two hop neighborhood [9]. This results in collision free reception of data for the nodes in one hop neighborhood. But NAMA does not address energy efficiency and the nodes which are not transmitting switches to the receiver mode.

TRAMA addresses the energy issue by allowing the nodes to shift into sleep state if the particular node has no data to transmit or receive during a time slot. It uses an adaptive, dynamic approach using the current traffic load and accordingly switches to the low power mode. This protocol proves to be more energy efficient and to have good throughput. The drawback of TRAMA is latency. It is suitable for applications that are not delay sensitive.

D. T-MAC

Timeout-MAC (TMAC) is a contention based MAC protocol which is proposed to improve the results of S-MAC protocol under variable traffic loads. It uses an adaptive duty cycling algorithm based on network loads. The nodes

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form a virtual cluster and all the nodes get synchronized at the beginning of the frame. This protocol employs a timeout mechanism which is used to determine the end of the active period dynamically [3].

The timeout value consists of a small contention period and an RTS/CTS exchange. If the sensor node does not detect any activity during the TA interval it goes into sleep state. If it overhears a communication, the node starts a new timeout after the communication is over.

The drawback of T-MAC is the early sleeping of the nodes where the node goes to sleep state when a neighbor still has packets to deliver. To overcome this problem the adaptive timeout period has to be large [5].

III. ENHANCED REINFORCEMENT LEARNING WITH ACTIVE QUEUE MANAGEMENT MAC

Reinforcement Learning Medium Access Control (RL-MAC) is reinforcement learning based adaptive MAC protocol [8]. Several MAC protocols have been proposed for minimizing energy consumption by scheduling the nodes sleep and active periods. As a next step MAC protocols employing adaptive duty cycles, where each and every node decides the duty cycle based on its own traffic load alone, emerged so as to further optimize the energy utilization. RL-MAC which employs a reinforcement learning based approach considers both the nodes' individual traffic load and also the state of other nodes.

This protocol uses frame based timing and the special feature of this protocol is that the frame active time and duty cycle are dynamically varied with respect to the nodes traffic and based on the incoming traffic. The time is divided into frames and frames into slots namely active and sleep slot. At the start of each frame the active time duration is dynamically fixed. In this period the node listens to the channel and exchanges packets with its neighbors. As soon as the active time duration is over the node stops the exchange of data and moves into the sleep state.

This protocol utilizes the Markov Decision Process and employs Q-learning algorithm. The reward function is formulated based on two parameters-internal information of each node at time t and state of other nodes at time t+1.The protocol adapts itself to the incoming traffic by means of the early sleeping avoidance mechanism. A four bit field is included in the data packet header which reflects the delay due to the receivers early sleeping and this is included as a negative reward function. At the end of each frame the Q value gets updated by using the temporal difference value. Based on the traffic load learning rate is chosen and suppose if the load is found to be constant for a long interval then the learning process will be faster.

RL-MAC provides high throughput and high energy efficiency when compared to S-MAC. The end to end delay performance can be improved further by employing suitable queue management techniques.

The performance of RL-MAC is improved by incorporating the Active Queue Management (AQM) mechanism. The duty cycle is controlled by means of the queue management mechanism which aims at energy saving and reducing the delay. This scheme considers only the local queue length available at the node. Depending upon the queue length the sleep time of the node is varied dynamically. The sleep time is adapted to the varying traffic by restricting the queue length at a predetermined value. This helps to achieve minimum delay.

IV. SIMULATION RESULTS

To evaluate and compare algorithms the simulation is done using NS-2 software. The comparison is done for S-MAC, RL-MAC and enhanced RL-MAC with AQM mechanism based on the performance metrics like throughput, packet delivery ratio and end to end delay.

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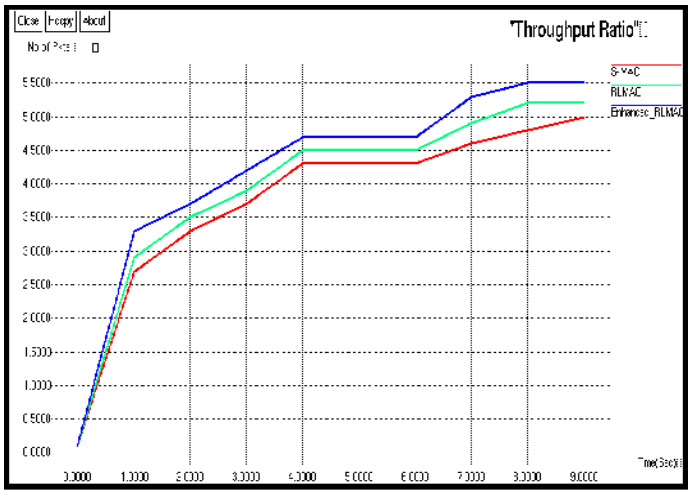

Fig.2 Throughput Ratio

Throughput is defined as the number of packets delivered at sink node per time unit. The throughput must be high for a better system performance. Here the enhanced RL-MAC which employs active queue management shows a better performance when compared to S-MAC and RL-MAC.

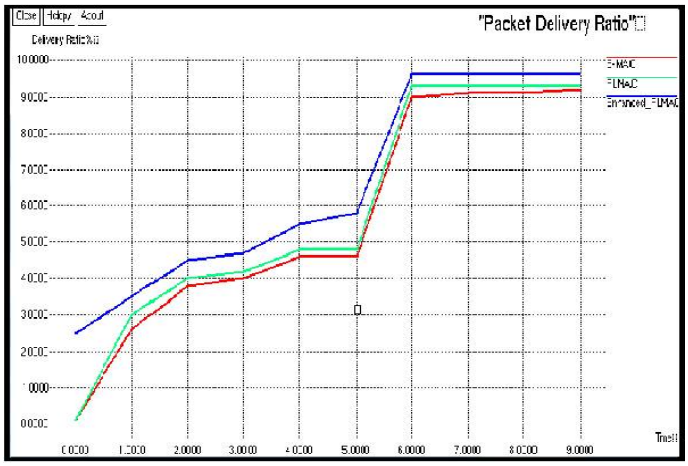

Fig.3 Packet Delivery Ratio

Packet Delivery ratio is the percentage of the ratio between total number of data packets successfully delivered to the total number of data packets sent. The enhanced RL-MAC has the highest packet delivery ratio when compared to the other two protocols.

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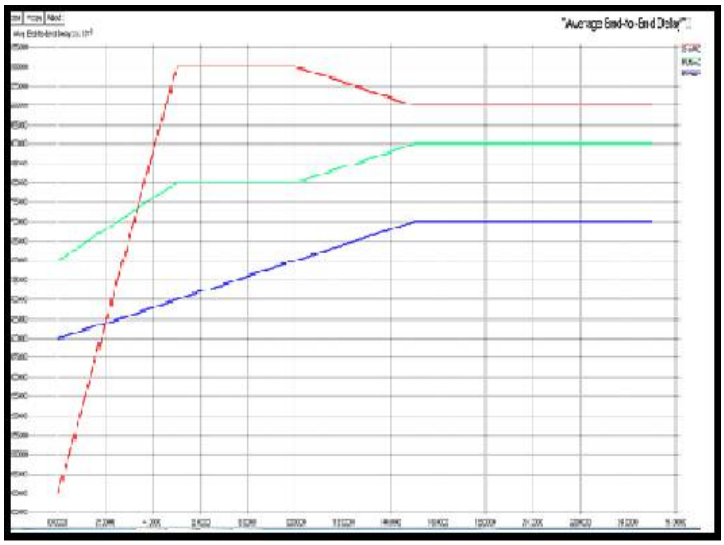

Fig.4 Average End to End Delay

End to End delay is defined as the ratio between the sum of individual data packet delay to the total number of data packets delivered. The end-to-end delay has significantly reduced by employing the active queue management technique which shows that enhanced RL-MAC is suitable for applications where delay should be minimal.

V. CONCLUSION

In this paper S-MAC, RL-MAC and RL-MAC with AQM mechanism have been analyzed. RL-MAC has proved to be energy efficient and more delay tolerant when compared to S-MAC. RL-MAC with Active Queue Management scheme has been analyzed based on throughput and end-to-end delay metric. Among the three protocols enhanced RL-MAC has good throughput, Packet Delivery Ratio and minimized delay. For varying traffic loads enhanced RL-MAC provides a good output.

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