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COMPARISON OF TIME-BASED AND SMAC PROTOCOLS IN FLAT GRID WIRELESS SENSOR NETWORKS VER VARYING TRAFFIC DENSITY

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ABSTRACT

Wireless Sensor Networks (WSNs) are the networks of sensor nodes that are connected by a wireless channel. Sensors are usually deployed in an ad hoc fashion, resulting in self organized topology. Performances of WSNs are highly related to the Medium Access Layer (MAC) mechanism. These sensor MAC schemes are different from traditional wireless MAC such as IEEE 802.11. In literature there are many protocols available for WSNs but S-MAC is one of the most popularly and commonly used protocol for WSNs. This paper provides comprehensive performance analysis of the existing S-MAC protocol and Time-Based protocol (TDMA) used in WSNs. The paper presents a comparison of the performance of SMAC and TDMA on flat grid topology with a single sensor node as the sink. Here multi-hop transmission is considered and reveals fundamental tradeoffs on throughput, energy and latency. Simulation is done using NS2. Simulation result shows that TDMA has more energy savings, less latency and high throughput when compared with SMAC.

Index Terms: Energy Consumption, Latency, Medium Access Control (MAC), Time Division Multiple Access (TDMA), Throughput.

I. INTRODUCTION

Recent advancements in Micro Electro Mechanical Systems (MEMS) using Very Large Scale (VLSI) led to the development of low powered multifunctional sensor nodes which are small in size capable of communicating with each other. Thus Wireless Sensor Networks (WSNs) has large number of small, low cost, low-power, intelligent sensor nodes, which can be either densely or randomly distributed. Each node has limited resources like processing capability, memory and energy. The most challenging design constraint in WSNs is minimizing the energy consumption. As each sensor node is a microelectronic device it can only be equipped with limited energy source. Comparing with other wireless communication networks, it is very difficult to charge or replace the drained battery, which makes maximizing the life time as the primary objective of WSNs. Since the communication of sensor nodes will be more energy consuming than their computation, it is a primary concern that the communication is minimized while achieving the desired network operation. In the Open Systems Interconnection (OSI) layer model, we cite MAC (Medium Access Control) for consuming energy due to many reasons like idle listening, overhearing, collisions etc. But ideally, MAC protocol in sensor networks consumes more energy when transmitting and receiving packets. So an efficient MAC protocol helps the nodes to extend their lifetime and this makes an increase in the entire network's lifetime. MAC layer controls management and accessing of the wireless channels. Similar to energy consumption, latency gives an important design challenge for MAC in WSNs. Average packet latency is defined as the average time interval taken by the packets in order to reach the sink node Thus latency gives the overhead in time required to transfer data packet from sources to sinks. Hence, latency and energy consumption relies on various application scenarios.

MAC protocols used in WSNs have two major functions. The first function is the establishment of communication link between the various deployed sensor nodes. The second function is to share the medium efficiently and effectively. Factors causing energy wastage and qualities of a good MAC protocols are discussed below.

i). Factors causing Energy Wastage

Collision happens when the receiver node gets more than one packet at the same time. Packets which are under collisions have to be dropped and re-transmissions of these packets are required for reliable communication which causes the sensor nodes to consume more energy. Energy wastage can also take place by overhearing, which means that a node receives packets that are destined to various other nodes in the deployed environment. Also energy wastage occurs due to control packet overhead. Hence optimal number of control packets should be used for data transmission. Listening to an idle channel to receive possible traffic can also cause energy wastage. The last reason for energy wastage is over emitting, which is caused by the transmission of packets when the destination node is not ready. A good reliable MAC protocol should prevent these energy wastages.

ii) Performance Evaluation Parameters for MAC protocols

In order to design a MAC protocol for WSNs, some of the following performance parameters have to be considered even though it is application specific.

a) Energy Utilization: The sensor nodes are battery powered and it is often very difficult to change or recharge batteries for these sensor nodes. Sometimes it is beneficial to replace the sensor node rather than recharging them.

b) Average End to End Delay: It is application specific. In applications such as military surveillance, the events and sensor outputs must be sent to the sink node in real time as early as possible.

c) Throughput: It is defined as the rate at which the sink receives the packet generated from the transmitter. Networks having high throughput transfers the packets very effectively with less delay.

d) Fairness: For sensor network applications mostly bandwidth is limited, so it is very important to ensure that the sink gets information from all intended sending nodes.

However among all of the above aspects the energy efficiency and latency are the major aspects. Energy efficiency can be increased by minimizing the energy wastage. The main goal of any MAC protocol for sensor network is to minimize the energy wastage due to idle listening, overhearing and collision while providing minimum latency.

In this paper we compare the latency and average energy consumed by TDMA and SMAC protocols under varying traffic load for flat grid topology. Section II describes the related works in MAC layer protocols. Then, Section III gives brief discussion on simulation methodology. Results and discussions regarding the performance comparison of SMAC and TDMA under NS2 simulation is described in Section IV. Finally, the paper concludes with Section V.

II. RELATED WORKS

In WSNs, MAC layer is used to control the access of active nodes in a shared channel medium. Energy, latency and throughput of MAC protocols affect the overall behavior of WSNs. So MAC protocols provide tradeoff between these performance parameters. MAC protocols used in WSNs can be divided into two main categories: contention based protocols and scheduled based protocols.

A).Contention-Based Protocols

In CSMA (Carrier Sense Multiple Access) [2] each node will continuously look for a free channel for transmitting the packets. In CSMA, collision may occur due to contention for the single channel. Hence, transmission delays and latency will be increased. Based on CSMA, several MAC protocols were proposed as energy efficient MAC protocols for WSNs. Researchers focused on improving CSMA to reduce the energy loss and to minimize the latency. One of the best-known contention-based protocols developed specifically for WSN is SMAC [3]. SMAC achieves energy conservation through the methods described below:

a) Listen and sleep schedules: In WSNs most of the nodes will be in idle listening state. So in order to reduce the energy consumption in idle listening for long periods SMAC makes the nodes go to sleep state periodically. In sleep state radio of the node will be turned off, and hence it consumes only less amount of energy. SYNC packets which are periodically exchanged between the nodes helps to achieve the synchronization between neighboring nodes. So nodes create a cluster sharing the same sleep wake –up schedule. This helps SMAC to reduce control packets overhead. Each node listens for sufficient time to hear an existing schedule, if not available the node selects its own schedule and broadcasts it its neighbors as shown in Fig. 1.

b) Minimal Overhearing: Nodes turn off their radios if the shared media is used for transmitting messages between other nodes neighboring to current node.

c) Message passing scheme: It is used to minimize the contention latency for WSNs requiring store-and-forward mechanism as data are moved within the network [4].

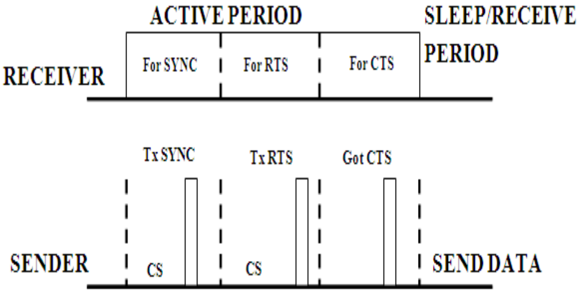

Figure 1. SMAC protocol

Thus according to SMAC, sensor node consumes minimum possible energy when it is in sleep state. The node wakes-up only if it is intended to execute a certain operation. Also S-MAC protocol controls the transmission of data through the sensor node, allowing it to take critical decisions when the sensor node enters to the sleep or wake-up schedules.

Also authors of SMAC introduced an adaptive listening approach for reducing the delay in packets [5]. Also TEEM [6] is a well known MAC protocol developed from SMAC. There are also research works that are closely associated to SMAC. One of them with respect to low duty cycle is piconet [7], an architecture designed for low-power ad hoc networks the best quoted one. Properties for the sensor network that are crucial for the design of MAC layer protocols are outlined in [8]. Even though various MAC protocols are proposed for sensor networks, none of the protocols is accepted as standard. After moving through the existing literature it is found that even though there are many MAC layer protocols for WSNs, S-MAC is the most popularly used contention based protocol.

B).Scheduled-Based Protocols

There are three popular scheduled-based schemes adopted for sharing the medium access control in wireless networks. They are Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA), Time-Based Protocol: Time Division Multiple Access (TDMA) and each of them is described below.

a). FDMA

This method divides the entire bandwidth of the frequency spectrum and is then allocated to different channels. Each node communicates with other nodes using the frequency channel allocated to it. Hence, all the nodes can communicate simultaneously within the network and this reduces the chance for collision. If a lower bandwidth is allocated to FDMA network, then the power consumption will be increased. The latency caused by time-based mechanism is eliminated by FDMA. However one of the limitations of FDMA introduced in WSNs is that all the nodes should be equipped with highly complex radio subsystem which is capable of capturing the multiple channels.

b). CDMA

This technique uses a sequence of pseudorandom code for communication. Each node has its own pseudorandom code and hence simultaneous transmissions with minimal interference are possible. So CDMA is a better choice for sensor networks with secure communications. But CDMA requires large memory size to support the code sequences in each node. Moreover complexity cost of CDMA radio circuitry is high.

c). TDMA

The basic approach of TDMA for energy efficiency in WSNs is proposed in [9, 10, 11]. The entire time is divided into a specific number of slots and each node within the network can transmit or receive packets during the specific slot given to it. Hence it does not suffer from collision and gives good energy conservation. But time slot allocation and maintenance of a correct synchronized schedule seems to be the drawback of TDMA in sensor networks. It requires a central element for maintaining scheduling schemes as well as for overcoming the clock drift problems. This approach takes advantage of the energy saving mechanism of S-MAC protocol and extends it to minimize the end-to-end delay. The major drawback of the S-MAC protocol is that the nodes are forced to wait until the next wake-up for the next hop in order to forward a packet. Hence the end to end delay depends on the number and time of intermediate sleeps periods of each node. On the contrary in TDMA, all nodes in the sensor network get synchronized to sleep and wake schedule in the same time frame. Here, the nodes do not send the entire message during the wake-up time, but instead they send a short wake-up packet. Nodes that receive this wake-up packet remains in idle state, whereas, nodes that do not get the wake-up packet gets into the sleep state. The first nodes in the wake-up path should be given a timeslot earlier than the nodes that follows them. Besides, collisions can be a reduced provided nodes that receives simultaneously the packets, are not one-hop neighbors. Timeslots scheduling scheme should consider the routing paths and the neighborhood information. These limitations make distributed TDMA scheduling schemes less efficient, as they do not consider the transmission order specified. TDMA protocol usually requires the nodes to form clusters, like Blue-tooth [12], and LEACH [13]. Minimizing inter-cluster interference is not an easy task and when the number of nodes within a cluster varies, it is difficult for TDMA protocol to dynamically adjust its frame length and time slot assignment. So its scalability is normally not as good as that of a contention-based protocol. To summarize TDMA protocols are based on reservation and scheduling.

TABLE I: IMPORTANT SIMULATION PARAMETERS

Parameter	Value
Simulation Area	120m x 120m
Simulation Time	60 seconds
Maximum Queue Length	50 Bytes
Antenna	Omni directional
Transmission Frequency	914Mhz
Routing Protocol	DSR
Beacon Length	12 Bytes
Initial Energy	50 J
Idle Power	.0135W
Transmit Power	.0312 W
Received Power	.0222 W
Sleep Power	.0001W
Transition Time	.00247 sec

III. SIMULATION METHODOLOGY

This section describes the work which has been done using NS-2 simulator. We compared the performance of SMAC protocol with TDMA protocol with respect to different parameters like energy consumption, average end-to-end delay and throughput by varying message-inter arrival period. Later this paper reveals the fundamental tradeoffs on energy, delay and throughput on a sensor node with the two protocols discussed above.

Table 1 shows the important simulation parameters used in the simulation process. The simulation is done in a 5 x 5 flat grid topology having 25 sensor nodes which act as transceiver and one node as the sink node. The antenna was set to a height of 1.5 m with a transmitting frequency of 914MHz. CBR (Constant Bit Rate) was used for establishing communications between nodes to the sink node. Initial energy for each node was taken as 50 J, which is equal to a battery source with 3.6 V giving a current of 3.85mA per hour.

Also we varied the traffic load will by varying the message inter-arrival period. The packet size was set to 4800 Bytes. We run the simulation for 120 seconds and message inter-arrival was varied between 1 and 10 seconds.

IV. RESULTS & DISCUSSIONS

We compared SMAC and TDMA under varying traffic load in flat grid topology. The average latency for the flat topology with varying traffic for SMAC and TDMA is shown in Fig. 2. For high density traffic (less than 4 sec) the delay remains almost constant. This is because at this time the idle listening period is minimum. Since large numbers of nodes are in active state, more packets will be in the queue and hence latency is high. As traffic density decreases the generated packets will be reduced and the SMAC can deliver the packets with less latency. In TDMA latency decreases as the traffic load decreases .Variation of latency shown by TDMA is high for high traffic density, where as it is low for light traffic scenarios. From Fig. 2, it can be concluded that the latency offered by TDMA is less under high traffic density when compared to SMAC.

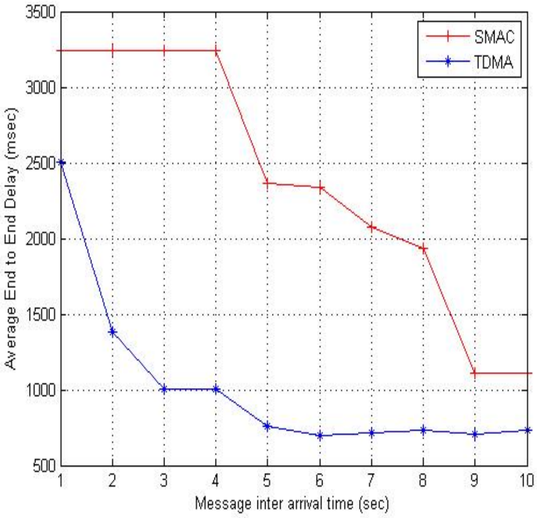

Figure 2. Average End to End Delay

Fig. 3 shows the packet delivery ratio with different traffic density for SMAC and TDMA protocols. For SMAC packet delivery fraction remains almost constant for high density traffic, where as for light loads the delivery ratio increases. In TDMA the delivery ratio increases as the traffic density decreases. For light loads difference in packet delivery ratio is small for SMAC and TDMA, but TDMA outperforms SMAC at high traffic density.

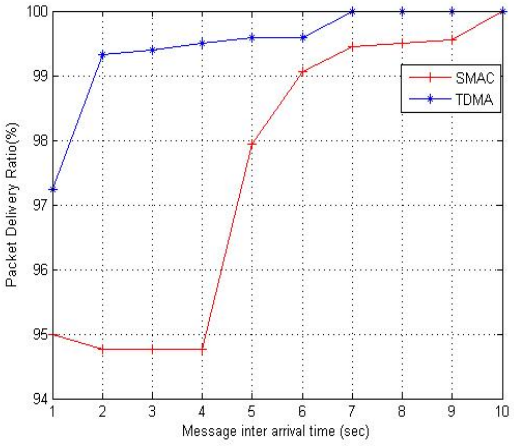

Figure 3. Packet Delivery Ratio

The average energy consumption under varying message interval time for SMAC and TDMA is plotted in Fig. 4. Variation of energy consumption in TDMA under high density is less than that of SMAC. From Fig. 4, it can be inferred that TDMA outperforms SMAC both under light and high traffic densities.

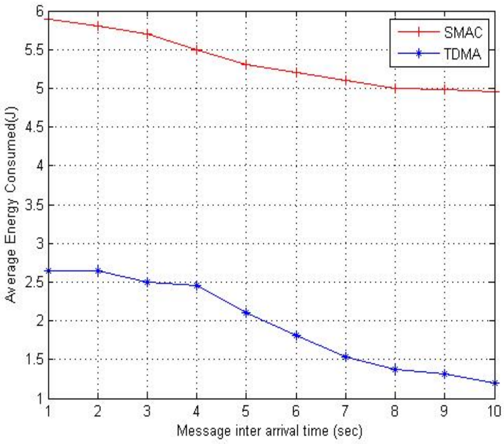

Figure 4. Average Energy Consumption

Fig. 5 shows the average throughput with different traffic density for SMAC and TDMA protocols. For TDMA throughput remains almost constant for high and low density traffic. In SMAC the throughput function decreases as the traffic density decreases, because in low density traffic less number of packets is generated and hence the rate at which the sink receives the packets is also decreased. Here TDMA outperforms SMAC in all traffic densities.

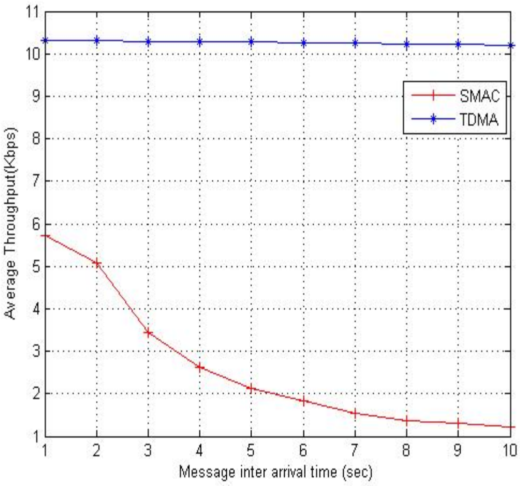

Figure 5. Average Throughput

V. CONCLUSION

Over the past decade researchers have proposed several MAC layer protocols for the WSNs. The MAC protocols in general will be application specific and hence no protocol has been accepted as standard. We have examined MAC protocols for WSNs with respect to various performance metrics such as energy conservation, latency, and throughput and delivery ratio. We described some of the well known MAC schemes available in the literature. Next, we have compared SMAC and TDMA protocols under varying traffic density. Through NS2 simulations, it's shown that SMAC and TDMA variations for delivery ratio and latency are almost small at light density traffic load. Result shows that throughput variation shown by SMAC is higher than that of TDMA under varying traffic density. Our simulation shows that TDMA outperforms SMAC by considering various performance metrics such as energy consumption, latency and throughput.

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