MAC Performance on Energy Efficient for Sensor Network

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Abstract — The main goal of this project is to design an energy-efficient and collision-free Medium Access Control protocol for wireless personal networks. Lots of research is going on in the design of Energy efficient MAC for Battery operated wireless network, because conserving the power in the battery operated wireless network is a paramount issue in design of MAC. So in this work, it is intended to design a novel energy efficient TDMA MAC Protocol. The protocol is based on Time Division Multiple Access (TDMA) principle and reduces energy consumption by avoiding overhearing, collision and idle listening. Nodes in the MAC protocol build schedules based on information about their neighborhood to determine when they can transmit to their neighbors and when they should listen to the channel or sleep. The MAC protocol proposes a novel resolution with neighborhood information to avoid energy consumption.

Keywords- Wireless Sensor Network; MAC, Self-organization; TDMA

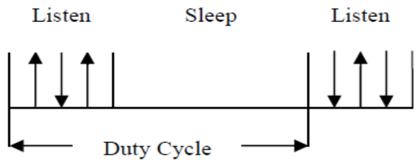
1. INTRODUCTION

Wireless sensors networks are gaining popularity across a diverse research community due to their potential usage in pervasive commercial, defense, and scientific applications. Sensor networks are composed of smart sensor nodes interconnected via wireless channels. Each sensor node consists of a sensor coupled with a processor, moderate amount of memory, and transmitter/receiver circuitry. Sensor nodes can sense the environment change and exchange data with its neighbors. Sensor networks are different from existing wireless communication networks in following aspects:

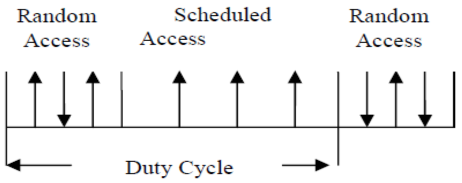
- Traffic rate is very low, typical communication frequency is at minutes or hours level.
- Sensor nodes are battery powered and recharging is usually unavailable, so energy is an extremely expensive resource.
- Sensor nodes are generally stationary after their deployment.
- Sensor nodes in the network coordinate with each other to implement a certain function, so traffic is not randomly generated as those in mobile ad hoc networks.

1.1 S- MAC AND TRAMA PROTOCOLS

In this paper, we first discuss techniques for self organizing sensor nodes and based on that design an efficient channel access protocol for sensor nodes to transmit/receive data. Several energy-efficient MAC protocols for wireless sensor networks have been proposed. One common observation of all these protocols is that the main source of power consumption is *idle listening.* it is shown that idle listening accounts for more than 90% of the power consumption. In [9] a protocol called S-MAC suggests that nodes follow a listen and sleep cycle, as shown in Figure 1a. Traffic is sent to a destination only during its listening period. To facilitate broadcasting, all nodes start listening at the same time. However, concentrating traffic to fixed periods also increases the contention probability and incurs unnecessary congestion. To resolve contention among simultaneous transmissions, SMAC proposes to perform the RTS/CTS handshake procedure defined in IEEE802.11 DCF operation.



a) S-MAC



b) TRAMA

Figure 1: S-MAC [9] and TRAMA [3] MAC resolve contention among simultaneous transmissions, SMAC proposes to perform the RTS/CTS handshake procedure defined in IEEE802.11 DCF operation. The duty rate or the portion of the listening period of S-MAC should be carefully chosen. If the listening period is long, too much energy would be wasted by idle listening. On the other hand, if the listening period is short, contention probability is high and energy would be wasted by retransmission efforts.

Another category of protocols is based on scheduling, e.g. TRAMA protocol suggested in [3]. In scheduling based protocols, data transmissions are scheduled in advance to avoid contention. In TRAMA, contention-free “scheduled access” and contention-based “random access” are performed alternatively, as shown in Figure 1b. Data transmission is performed in “scheduled access” slot and neighbor information exchange is performed in “random access” slot. The main advantage of

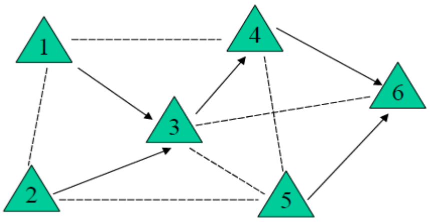
TRAMA over S-MAC is improvement in channel utilization. However, the tradeoff is longer delay and higher energy consumption compared with 10% S-MAC.

The behavior of S-MAC and TRAMA protocols is similar to opening the door periodically and seeing whether there is a guest outside. Another more natural approach is to let the guests knock at the door upon their arrival. As the traffic rate in sensor network is relatively low, we can have fix timings for door knocking for each node. In the following we outline this idea in further detail by employing the Time Division Multiple Access (TDMA) principle. We refer to the resulting protocol as TDMA-W, which stands for TDMA-wakeup.

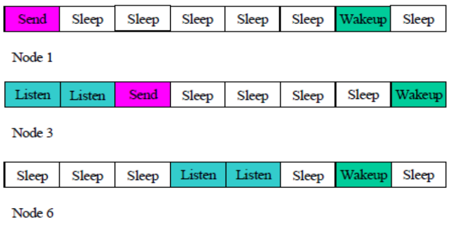
In the case of proposed TDMA-W protocol, all the nodes in the sensor network are considered *admitted.* Each node is assigned two slots in a TDMA frame, the Transmit/Send slot (s-slot) and the Wakeup slot (w-slot). A node always listens the channel during the w-slot and transmits in the s-slot, if needed. To avoid overhearing, only destination nodes need to listen to the transmitter. After receiving the wakeup packet, the destination identifies the source node and starts listening during the s-slot associated with the source node.

For example, consider a sensor network consisting of six nodes, namely, node 1 to node 6, as shown in Figure 2. Let's assume that the application running on this network is to collect data from all the nodes at node 6. The TDMA-W frame consists of 8 slots, namely, slots 1 to slots 8. Each node is assigned two slots, an s-slot and a w-slot. Several nodes can share a w-slot. In this example, nodes 1, 4 and 5 are assigned slot 7 as their w-slot and nodes 2, 3 and 6 are assigned slot 8 as their w-slot. The procedure to determine these assignments is part of the self organization protocol. In order to collect data from all the stations, nodes 1 and 2 send their data to node 3, and then node 3 combines these data items with its own data and sends it to node 4. Then node 4 and 5 send their data to node 6. However, though node 3 cannot decode the source of the wakeup packet, it can search for all of the neighbors, namely, nodes 1, 2, 4 and 5, to find out the incoming traffic. After a while, node 3 finds out that no data is coming from nodes 4 and 5 and then it only listens to nodes 1 and 2. The channel activities of nodes 1, 3 and 6 are illustrated in Figure 2b. For node 1, since there is no incoming data, it only sends data in slot 1 and listens to the wakeup packets in slot 7. For intermediate node 3, it needs to listen to slots 1 and 2 to collect data from nodes 1 and 2, and transmit in slot 3. It also listens to slot 8 for wakeup packets. Node 6, only listens during slots 4, 5 and 7 and does not transmit anything in this example scenario.

The rest of the paper is organized as follows: Section II describes the channel and traffic assumption. The self organization procedure and proposed medium access protocol TDMA-W is presented in section III. Simulation results are given in section IV and section V concludes the paper.



a) Sensor Network Topology



Send	Sleep	Sleep	Sleep	Sleep	Sleep	Wakeup	Sleep
Node 1							
Listen	Listen	Send	Sleep	Sleep	Sleep	Sleep	Wakeup
Node 3							
Sleep	Sleep	Sleep	Listen	Listen	Sleep	Wakeup	Sleep
Node 6							

b) Slot Assignments

Figure 2: An Illustration of TDMA-W protocol

2. CHANNEL AND TRAFFIC ASSUMPTION

Let us consider a simplest wireless channel model where all nodes share a single radio frequency. Both data and control packets are sent and received using this channel. Each node has a fixed communication range. All the nodes within the communication range of a node can receive or decode packets from that node without any error if there is no contention. The communication range needs not to be a circle and can be direction dependent. Also, the communication channel is bidirectional and reciprocal. We consider three types of traffic pattern: one-to-all broadcast, all-to-one reduction, and one-hop random traffic.

As described above, the wireless channel is organized as TDMA-W frames. A TDMA-W frame lasts for *Tframe* seconds. This parameter is known to all nodes and is preset before deployment. A TDMA-W frame is divided into slots and each node is assigned one slot for transmission and one slot for wakeup. Networks can be synchronized or non-synchronized. If a network is not synchronized, a node may occupy two slots for transmission or wakeup. Guard time is kept between two consecutive slots. For simplification, in the following discussion we assume networks are synchronized.

3. TDMA-W: DETAILS

A. Self-Organization

The first step in enabling TDMA-W scheme for sensor networks is to assign time slots to the sensors within each TDMA-W frame. This has to be accomplished in a distributed framework. In the following we present an efficient self organizing scheme where nodes identify their neighbors and select a proper time slot for transmission and wakeup as part of the protocol.

Let's assume that sensor networks use this rate. Under this assumption, transmission of a 512 byte packet occupies the channel for about 3.9 *msec*. If we assume a TDMA-W frame of 1 second divided into 256 slots, each slot is of 3.9 *msec* duration, thus capable of communicating 512 bytes. We propose that let nodes randomly select their favorite s-slots and then negotiate if two neighboring nodes select the same slot. This problem has resemblance to the graph-coloring problem; however, in our case we cannot assign the same slot to the two hop neighbors either, due to the "hidden terminal" problem. In the following, We outline the proposed self-organization scheme.

1. Each node randomly selects a slot with uniform probability among all slots to be its s-slot (transmit/send slot).
2. During its selected s-slot, each node broadcasts its node ID, its s-slot number, its one-hop neighbors' IDs and their s-slot assignments. It also broadcasts the slot number of any s-slot during which this node has identified a collision.
3. When a node is not transmitting, it turns on its receiver circuit and listens to the traffic from neighbors. The node should record all the information being broadcast by all its neighbors, i.e. their s-slot assignments and their node IDs, and the slot number of any slot being broadcast as a collision-prone slot.
4. If a node determines that it is involved in a collision or finds out that one of its two-hop neighbors has the same s-slot, it then randomly selects an unused slot and go to step 2.
5. If no new nodes are joining in, or s-slot assignments are not changing, or no collisions are detected for a certain period, it implies all neighbor nodes are found and all the s-slots are final.
6. Each node broadcasts the s-slot selections of their two hop neighbors. Each node identifies an unused slot or any s-slot being used by the nodes beyond its two-hop neighbors and declares it as its w-slot (wakeup slot).Note that w-slots need not be unique.
7. Each node broadcasts its w-slot and the self organization is complete.

B. The TDMA-W Channel Access Protocol

After the network is successfully set up, the channel access protocol can be described by the following procedure:

1. Each node maintains a pair of counters (outgoing and incoming) for every neighbor; these counters are preset to an initial value.
2. If no outgoing data is sent to a node in a TDMA-W frame, the node decrements the corresponding outgoing counter by one; otherwise it resets the counter to the initial value.
3. If no incoming data is received from a neighboring node in a TDMA-W frame, the node decrements the corresponding incoming counter by one. If the counter is less than or equal to zero, the node stop listening to that slot starting from next TDMA-W frame.
4. If an outgoing data transmission request arrives, the node first checks the outgoing counter, if the counter is greater than zero, then the link is considered active and the packet can be sent out during the s-slot. If the counter is less than or equal to zero, a wakeup packet is sent out during the w-slot of the destination node prior to the data transmission.

The wakeup packet contains only the source and the destination information. The data packet may only contain the destination information and omit source ID since the source ID is determined by the s-slot. If a data packet is to be broadcast to multiple nodes, the destination address contains a special identifier to mark it as a broadcast message. In the case when multiple users share the same w-slot, the destination field of the wakeup message should also be set to a broadcast address.

4. SIMULATION RESULTS

To verify the performance of the proposed protocol, we have simulated the protocol using MATLAB communication toolbox. For comparison purposes we have also simulated the S-MAC protocol. Nodes are deployed randomly in a 500x500 sq. ft. area. The communication range is 100 feet for all nodes. The slot length is set to be 4 milliseconds, which is long enough for transmitting a 512-byte packet. *Tframe* is set to be one second, so a TDMA frame has 250 slots.

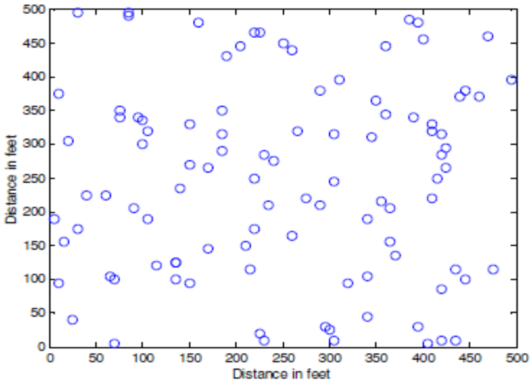


FIG 3 sample deployment of 100 nodes

First we have simulated the proposed self-organization scheme. We show the results for self-organizing of 50, 100 and 200 nodes in the square area. Each case is simulated by 500 different deployments and results are averaged. The simulation results are shown in Table 1. Since sensor networks are likely to be static and relatively less mobile in nature, the self-organization times are acceptable even for dense networks. Next we compare the power consumption and delay performance of the proposed TDMA-W protocol. We have modeled the power consumption of transmission, receiving/listening and sleeping as 1.83, 1 and 0.001, respectively.

We use normalized power consumption of the receiving mode as the basis for comparison. That is, if a node keeps listening to the channel, the average power consumption is one.

Number of Nodes	Average Time for Self-Organization (Second)	Average Number of One-hop neighbors	Average number of Two-hop neighbors
50	1.628	5.12	10.84
100	2.408	10.41	26.13
200	3.626	20.87	58.47

Table 1: Simulation results of self-organization protocol.

We simulate the 10% S-MAC and set the active/sleep period to be one second. we assume the energy consumption for transmitting and receiving a control packet is equal to 1/10 of that of a data packet. The initial value for counters is set to 3 and transmission buffer length is set to 50 packets.

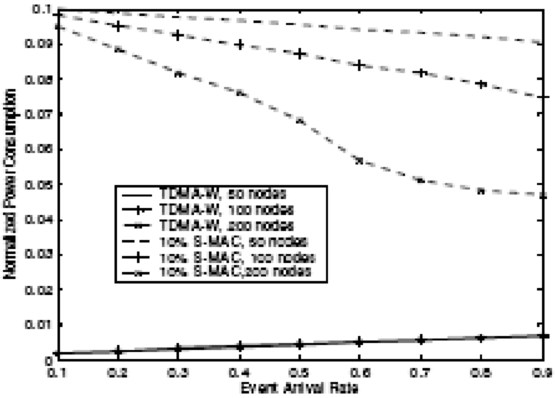


Fig 4 power consumption of one hop random traffic

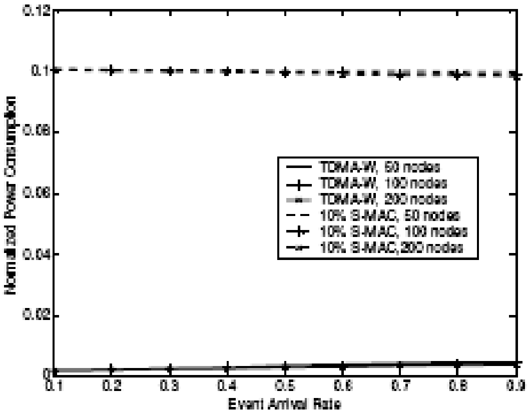


Fig 5 power consumption of one to all broadcast operation traffic

Both TDMAW and S-MAC are run for 10 minutes (600 sec). From these figures we observe that in all the cases, power consumption of the proposed protocol is much lower than 10% S-MAC. For all three types of traffic, the power consumption of TDMA-W ranges from 0.16% to 0.7%. While for 10% S-MAC, energy consumption ranges from 4.7% to 10.1%. So the power consumption of TDMA-W is only 1.5%-15% as much as SMAC.In other words, the lifetime of TDMA-W networks is 6-67 times longer than 10% S-MAC. Also we observe that the power consumption of TDMA-W increases linearly with the event arrival rate. (Illustrated in Figure 4) This is natural because when event arrival rate increases, more traffic needs to be transmitted and received. However, for random and reduction operations traffic, the average energy consumption when the event arrival rate and node density increases

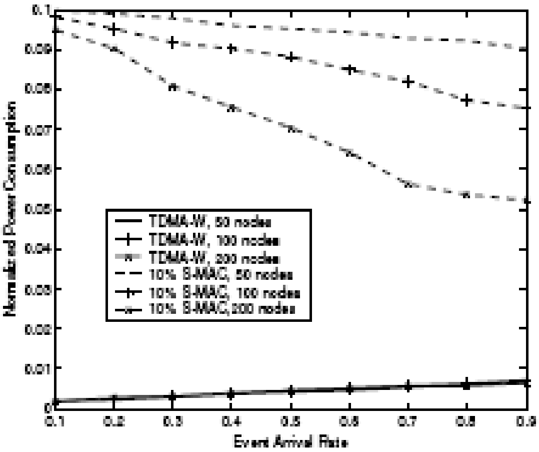


Fig 6 power consumption of all to one reduction operation traffic

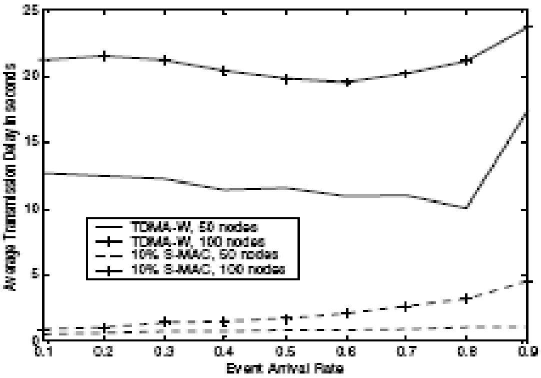


Fig 7 delay all to one reduction operation traffic

This is because when traffic load is low, most of the time no traffic is in the air, so every node keeps listening to the clear channel. While when traffic load is high, there is always traffic in the air and when a node receives an RTS or CTS packet with a destination address of other nodes, it can shut down the receiver and save energy. Reduction / second still can be achieved since the network operates in a pipelined fashion. We can see the time for TDMA-W to complete a reduction is much higher than S-MAC. So the delay depends on the depth of the spanning tree used for reduction. Note that although reduction traffic suffers long delay, throughput close to 1 reduction/second still can be achieved since the network operates in a pipelined fashion.

CONCLUSION

In this paper, we have proposed efficient protocols for self organization and channel access control in wireless sensor networks. The protocols, referred to as TDMA-W, employ the well-known TDMA principle. The proposed protocols were verified using extensive simulations. We have shown that the proposed protocol only consumes 1.5% to 15% power of 10%

S-MAC. We also show the proposed scheme responds to the event with a delay comparable to S-MAC for one-hop traffic. The proposed protocol is collision free for data traffic so reliable transmission is guaranteed for all types of traffic.

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