An Energy-Efficient MAC Protocol in Track-Based Wireless Sensor Networks

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Abstract: - This paper propose a MAC protocol for efficient energy utilization in wireless sensor network. For our protocol, a sensor network field is divided into multiple virtual areas called a track. In a track, only one sensor node is activated to participate in data forwarding and the other nodes in the track stay in sleep state for energy saving. Each node in the track can wake up at its own timeslot assigned to the track to transmit or receive data. The proposed scheme reduces unnecessary energy consumption due to collision and overhearing by allowing nodes to wake up and listen only during the timeslot assigned to the track.

Key-Words: - Wireless Sensor Networks, SMAC (Sensor MAC), Track-Based MAC

1 Introduction

Wireless Sensor Networks (WSN) based on smart-sensor technology are widely used in environments such as environment protection, medical treatment, military force, and home-network.

Many protocols and algorithms have been proposed for traditional wireless ad-hoc networks, but they are not well suited for the requirement of sensor network [3]. In the wireless ad-hoc networks, the Media Access Control (MAC) protocol focused on the maximum transmission, low delay, QoS, and etc. But, MAC in the wireless sensor networks mainly focused on minimization of wasted power. Power system planning in MAC protocol is one of the hottest issues in sensor networks. In MAC level the principal power waste elements are

- -collision: conflict during transmission will bring power waste and delay.
- -overhearing: sending packets to wrong nodes will require receive power
- -control packets: sending elaborate data complicates control packets which will use power from nodes
- -idle listening: watching the channel will waste power

Among these, the most dominant factor to result in power waste is the idle listening problem [5].

There have been many research works on designing suitable and efficient MAC protocols for WSN. 802.11 PSM (Power Save Mode), SMAC (Sensor MAC), and Timeout MAC (TMAC) are representative of energy-efficient MAC protocols proposed for wireless sensor networks. In these protocols, sensor nodes transit to sleep mode periodically in energy-efficient MAC protocols reduce energy consumption by collision, overhearing and idle listening.

SMAC proposed in [4], which is a modified version of the IEEE802.11 Distributed Coordinator Function (DCF), provides a tunable periodic active/sleep cycle for sensor nodes. It puts nodes to sleep at certain times to conserve energy [7]. However, periodic sleep may result in long sleep latency since the sending node has to wait until the receiving node wakes up in its listen period. TMAC alleviated the problems of SMAC by using an adaptive duty cycle. In TMAC, if a node does not observe any activity in the neighborhood for some time, it goes to sleep early. TMAC saves more energy under variable traffic loads, but it still has problems of long sleep latency and low throughput.

We propose a MAC protocol for efficient energy utilization in wireless sensor network. For our protocol, a sensor network field is divided into multiple virtual areas called a track. In a track, only one sensor node is activated to participate in data forwarding and the other nodes in the track stay in

sleep state for energy saving. Each node in the track can wake up at its own timeslot assigned to the track to transmit or receive data. The proposed scheme reduces unnecessary energy consumption due to collision and overhearing by allowing nodes to wake up and listen only during the timeslot assigned to the track. The proposed scheme has a shorter listen period than SMAC, which contributes to reducing the energy waste and thus improving the power efficiency.
The paper is organized as follows. Section 2 briefly reviews sensor MAC protocols. Section 3 provides a detailed description of our MAC protocol. Section 4 provides the performance evaluation of the protocol. Section 5 concludes and points out future work.

2 Related Works

Ye et al. [1] have proposed a single-frequency based protocol called SMAC (Sensor-MAC) to resolve the energy problem caused by idle listening. This scheme divides time into frames composed of two parts: active and sleeping periods. Because the frame size is fairly large, synchronization is not as critical as in TDMA-based protocols. Synchronization is done locally and possible discords are covered by maintaining neighbors' schedule information.[1].
After synchronization, SMAC period can be divided to control packet transmission time and data transmission time as shown in Fig.1. During the control packet transmission time, all the nods exchange their control packets. Two nodes participated in forwarding exchange RTS/CTS messages to avoid collision. The rest of nodes get on sleep mode to save waste power. Nodes can communicate with each other only in the active period and the event messages generated during the sleeping period are queued until the next active period. We can say that SMAC protocol essentially trades energy with latency and per-hop fairness.

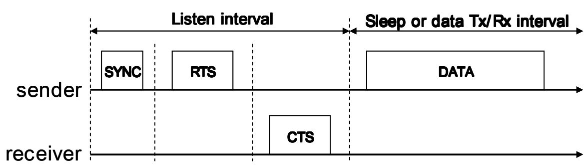

Fig. 1 SMAC period

TMAC is an improvement of SMAC. Unlike SMAC, it has an adaptive active period which is controlled using a timeout. The active period ends whenever the physical and virtual carrier sensing find the channel idle for the duration of the timeout. This scheme enhances energy efficiency but generates an early sleeping problem: a node goes to sleep while another node still has messages for it. TMAC covers this problem by lightly modifying the RTS/CTS scheme.
DMAC uses an adaptive duty cycle where the wake up schedule depends on the depth of a node in the data gathering tree. Additionally, it provides a low latency from source to sink. However, it does not take fairness into account. Thus the duty cycle assigned to a certain child node may not be proportional to the amount of data it needs to transmit when compared to another child of its parent node (called 'sibling node') [8].
For energy efficiency and ease of use, DMAC includes an adaptive duty cycle like TMAC. In addition, it provides low latency from node to sink, which is achieved by supporting one communication paradigm only: convergecast.[8].
DMAC divides time into rather short slots (around 10 ms) and run CSMA (with acknowledgements) within each slot to send or receive at most one message. Each node repeatedly executes a basic sequence of 1 receive, 1 send, n sleep slots. At setup, DMAC ensures that the sequences are staggered to match the structure of the convergecast tree rooting at the sink node. This arrangement allows a single message from a node at depth d in the tree to arrive at the sink with a latency of just d slot times, which is typically in the order of tens of milliseconds. DMAC includes an overflow mechanism to handle multiple messages in the tree. In essence a node will stay awake for one more slot after relaying a message, so in the case of two children contending for their parent's receive slot, the one losing will get a second chance, To account for interference, the overflow slot is not scheduled back to back with the send slot, but instead, receive slots are scheduled 5 slots apart. The overflow policy automatically takes care of adapting to the traffic load, much like TMAC's extension of the active period. The results reported in show that DMAC outperforms SMAC in terms of latency due to the staggered schedules, throughput energy-efficiency due to the adaptivity. It remains to be seen if DMAC can be enhanced to support communications other than convergecast equally well.[8]
Pattern MAC (PMAC) has adaptive sleep-wakeup schedule instead of fixed sleep-wakeup schedule. The schedules are determined based on a node's own traffic and that of its neighbors. In PMAC, a sensor node has to get information about the activity in its neighbor through patterns. If there is any activity in the neighborhood, a node is aware of this through the patterns then it wakes up [3].

3 Proposed Mac Protocol

As previously stated, despite of its many desirable characteristics, SMAC brings unnecessary power consumption since all nodes must work during the control packet send times.

In the proposed MAC protocol, a sensor network field is divided into multiple virtual areas called 'tracks'. In a track, only one sensor node is activated to participate in data forwarding and the other nodes in the track stay in sleep state for energy saving. Each node in the track can wake up at its own timeslot assigned to the track to transmit or receive data. The node wakes up and waits to receive data at the timeslot assigned to the track.

Assume that a node in track 1 to which timeslot 1 is assigned has data to forward to the sink as shown in Fig. 2. First, it wakes up and transmits data to track 2 at timeslot 1. At this time, a node in track 2 wakes up and receives data. Following this, a node in track 2 wakes up and transmits data at timeslot 2.

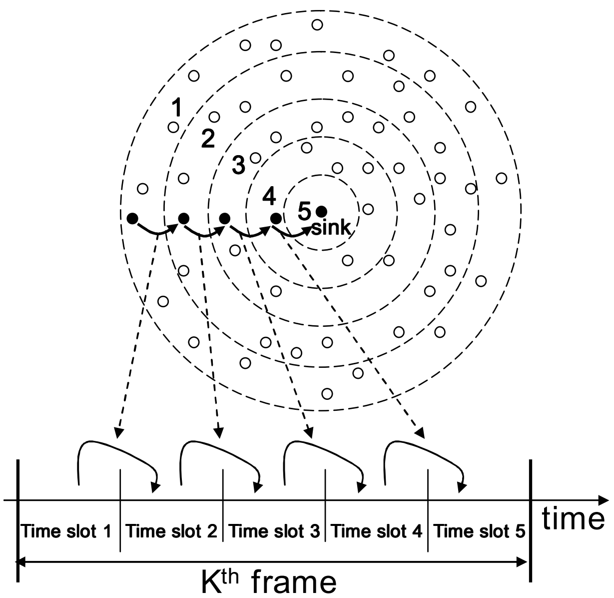

Fig. 2 Data delivery in the track-based MAC protocol

Fig. 3 shows the frame structure used in our MAC protocol. A frame consists of multiple timeslots each of which is assigned to a track. A timeslot again consists of listen interval and sleep or Tx/Rx interval. A sensor node wakes up at the timeslot assigned to its own track and waits for RTS during the listen interval. A sender wishing to forward data to the i-th track transmits an RTS at the listen interval of the i-th timeslot. RTS contains a destination track ID. A node in the i-th track transmits a CTS when it receives RTS. CTS also contain a destination track ID. The node sending CTS turns on its radio and receives data during the data Tx/Rx interval and the rest of sensor nodes are in sleep mode.

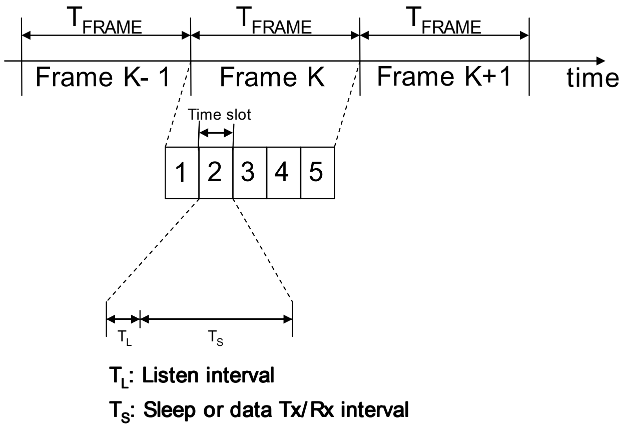

Fig. 3 Frame structure

5 Simulations

We evaluate the performance of our MAC protocol through computer simulation. The simulation parameters used for simulation are listed in Table 1. To simplify the simulation, we assume that the radio link propagation delay is zero without transmission error. Energy consumption model is based on real nodes: 0.016mW while sleeping, 12.36mW while idle listening, 12.50mW while receiving and 14.88mW while transmitting a data packet [2]. The simulation is conducted in a static network which is divided into 10 tracks. We assume that the traffic flows only one way from the outermost sensor nodes to the sink through a unicast path.

Table 1. Simulation parameters

Radio bandwidth	20 kbps
Data packet size	150 Bytes
RTS, CTS, ACK size	20 Bytes
Duration of beacon	25ms
Frame interval	625ms

Fig. 4 shows the amount of energy consumed by all nodes in the network until the end of simulation runs. To evaluate the total energy consumption, we measure the amount of time that each node has spent in different modes: sleep, idle, receiving or transmitting. The energy consumption in each mode is then calculated by multiplying the time with the required power to operate in that mode. We compare the total energy consumption with SMAC protocol under different traffic loads [6]. For comparison, we implement a simple SMAC with adaptive listening. But, we did not take its synchronization and message passing into account. In the SMAC, each node is assumed to operate 10% duty cycle, and listen duration is given 62.5ms. This figure shows that SMAC consumes more energy than our track-based MAC.

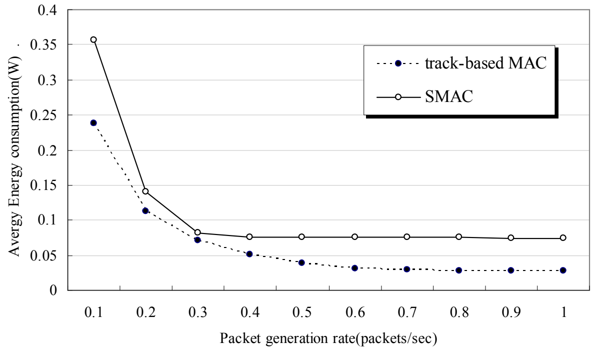

Fig 4. Total energy consumption

We evaluate the power efficiency which is defined as the throughput achieved per unit of energy consumed. Fig. 5 shows that our MAC protocol provides a much better power efficiency than SMAC when the traffic load is heavy. This improvement is due to the feature of our MAC protocol that it gives separate wakeup slots to each sensor node.

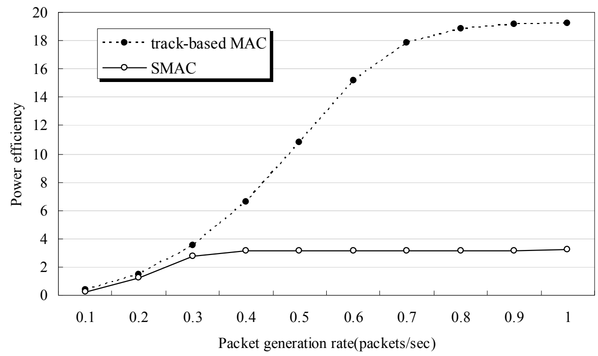

Fig. 5. Power efficiency

Fig. 6 shows throughput performance. We can see that our MAC protocol provides a much higher throughput than SMAC in high traffic intensities. This is because the traffic loads from many sensor nodes are distributed into separate wakeup slots in our MAC protocol. In periodic sleep MAC, it has a limitation of achievable throughput due to the sleep time. Also, we find out that our MAC protocol makes the best use of sleep time by allocating separate wakeup slots to each node.

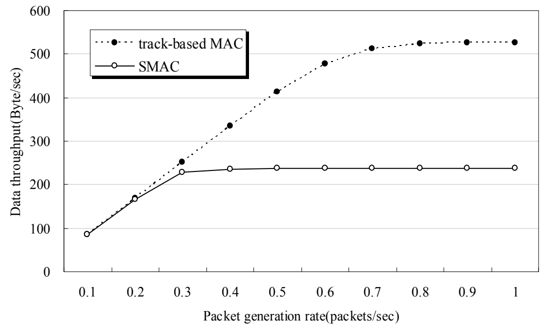

Fig. 6. Data throughput

5 Conclusion

In this paper, we proposed and evaluated an energy-efficient track-based MAC protocol for wireless sensor networks. The proposed scheme reduces the unnecessary energy consumption due to collision and overhearing by allowing nodes to wake up and listen only at the timeslot assigned to the track where the nodes are located. Simulation results demonstrate that the performance improvement of the proposed scheme when compared to the existing SMAC.

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