Optimized Medium Access Control for Wireless Sensor Network

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Summary
Medium access control for wireless sensor networks has been a very active research area in the recent years. The traditional wireless medium access control protocol such as IEEE 802.11 is not suitable for the sensor network application because these are battery powered. The recharging of these sensor nodes is expensive and also not possible. The most of the literature in the medium access for the sensor network focuses on the energy efficiency. The proposed MAC protocol solves the energy inefficiency caused by idle listening, control packet overhead and overhearing taking nodes latency into consideration based on the network traffic. Simulation experiments have been performed to demonstrate the effectiveness of the proposed approach. This protocol has been simulated in Network Simulator ns-2

Key words:

Wireless Sensor Network, Medium Access Control, Energy Efficiency, MAC Protocols

1. Introduction

Wireless Sensor Networks (WSNs) have become very popular in this current decade (2000-2010) due to their wide range of applications in different fields such as military and civilian use. These WSNs can be used for different purposes such as target tracking, intrusion detection, wildlife habitat monitoring, climate control and disaster management [1]. A typical node in the WSN consists of a sensor, embedded processor, moderate amount of memory and transmitter/receiver circuitry. These sensor nodes are normally battery powered and they coordinate among them selves to perform a common task.

Unlike standard wireless network, these WSNs have severe resource constrains and energy conservation is very essential. The radio in the sensor node consumes a significant amount of energy. Substantial research has been done on the design of low power electronic devices in order to reduce energy consumption of these sensor nodes. Because of hardware limitations further energy efficiency can be achieved through the design of energy efficient communication protocols.

Medium access control (MAC) is an important technique that enables the successful operation of the network. One of the main tasks of the MAC protocol is to avoid collisions from interfering nodes. The classical IEEE 802.11 MAC protocol for wireless local area network wastes a lot of energy because of idle listening. This *Idle Listening* problem in wireless sensor networks can be minimized by putting the radio into sleep mode.

Apart from the Idle Listening problem, the other source of overhead is *Collisions*. The collisions occur when two nodes transmit at the same time. The packets can get corrupted and it may be required to be retransmitted. So a lot of time and energy gets wasted during this transmission and reception. The other major problem is the *Control Packet Overhead*. These Control Packets does not contain any application data but are essential for the communication. The transmission and reception of these packets is overhead on the sensor network. The last problem is *Overhearing* in which a sensor node may receive packets that are not destined for it. This node could have turned off its radio to save its energy.

In order to design a good medium access control protocol for the wireless sensor networks, it is very important to consider the energy efficiency. As the sensor nodes are mostly battery powered so it is difficult to change or recharge the batteries. In the coming years we expect the sensor nodes to be cheap enough so that the nodes can be discarded rather than recharged. These sensor nodes are battery powered and it is often very difficult to change or recharge batteries for these nodes. After few years we may expect some nodes to be cheap enough so that they can be discarded rather than recharged.

The other important attributes of the wireless sensor network are fairness, latency, throughput and bandwidth. The medium access control scheme proposed in this paper is good for applications where apart from energy efficiency there is need for low latency.

The rest of the paper is organized as follows. Section 2 discusses the related work. In Section 3, the design description of the proposed MAC protocol is presented. This is followed by the experimental results. Finally, Section 4 concludes the paper.

Manuscript received February 5, 2008
Manuscript revised February 20, 2008

2. Related Work

Medium access control for the wireless sensor network is one of the active research areas for the researchers. The existing wireless MAC protocols such as IEEE 802.11 is not suitable for the sensor network application because these sensors are battery powered and recharging is expensive & also not possible. The medium access control protocols for the wireless sensor networks can be classified broadly into two categories: Contention based and Schedule based.

The schedule based protocol can avoid collisions, overhearing and idle listening by scheduling transmit & listen periods but have strict time synchronization requirements. The contention based protocols on the other hand relax time synchronization requirements and can easily adjust to the topology changes as some new nodes may join and others may die few years after deployment. These protocols are based on Carrier Sense Multiple Access (CSMA) technique and have higher costs for message collisions, overhearing and idle listening.

Sensor S-MAC [2] a contention based MAC protocol is modification of IEEE 802.11 protocol specially designed for the wireless sensor network in 2002. In this medium access control protocol sensor node periodically goes to the fixed listen/sleep cycle. A time frame in S-MAC is divided into to parts: one for a listening session and the other for a sleeping session. Only for a listen period, sensor nodes are able to communicate with other nodes and send some control packets such as SYNC, RTS (Request to Send), CTS (Clear to Send) and ACK (Acknowledgement). By a SYNC packet exchange all neighbouring nodes can synchronize together and using RTS/CTS exchange the two nodes can communicate with each other. A lot of energy is still wasted in this protocol during listen period as the sensor will be awake even if there is no reception/transmission.

Timeout T-MAC [3] is the protocol based on the S-MAC protocol in which the Active period is pre-empted and the sensor goes to the sleep period if no activation event has occurred for a time 'Ta'. The event can be reception of data, start of listen/sleep frame time etc. The time 'Ta' is the minimal amount of idle listening per frame. The interval $Ta > Tci + Trt + Tta + Tct$ where Tci is the length of the contention interval, Trt is the length of an RTS packet, Tta is the turn-around time (time between the end of the RTS packet and the beginning of the CTS packet) and Tct is the length of the CTS packet.

The energy consumption in T-MAC is less as compared to S-MAC. However the latency of T-MAC is more as compared to S-MAC. The proposed scheme takes in to account both energy consumption and latency.

3. Proposed MAC Protocol Design

In the proposed MAC protocol, the sensor duty cycle is changed based on the network load. If the traffic is more than the duty cycle will be more and for low traffic the duty cycle will be less. The network load is identified based on the messages in the queue pending at a particular sensor. The control packet overhead is minimized by reducing the number and size of the control packets as compared to those used in the S-MAC protocol.

3.1 Nodes Synchronization

The synchronization of the neighboring sensor nodes is done using the SYNC packet as is done in S-MAC [2] protocol. This SYNC packet contains the time of its next sleep. After deployment a sensor node starts by waiting and listening. If it hears nothing for a certain amount of time, it chooses a frame schedule and transmits a SYNC packet. If the node, during startup, hears a SYNC packet from another node, it follows the schedule in that SYNC packet and transmits its own SYNC accordingly. The synchronization table is maintained by all sensors for its neighboring nodes. Upon reception of the SYNC packet the synchronization table is updated and the timer is adjusted accordingly.

3.2 Modified Data and Control Packets

The data and control packets in the wireless sensor networks are broadcasted. These packets apart from the frame control, duration, cyclic redundancy check contains the source & destination address [6] which have been removed as every node is the recipient. The removal of the source and destination address minimizes the control packet overhead in the sensor network communication.

Moreover some of the control packets such as SYNC and RTS has been combined in to one control packet SYNCrts (Fig. 1(d)) generated by combining SYNC packet Fig. 1(b) and RTS packet Fig. 1(c).This reduces the packets overhead and finally contributes in the reduction of the energy consumption and latency.

Bytes 2	2	6	6	6	2	6	0-2312	4
Frame Ctrl	Duration	Addr1	Addr2	Addr3	Seq. Ctrl	Addr4	Data	CRC

Fig. 1(a) IEEE 802.11 MAC Frame Format

Bytes 2	6	7	2	4
Frame Ctrl	From Addr	Sleep Time	Duty Cycle	CRC

Fig. 1(b) SYNC Packet

Bytes 2	2	6	6	4
Frame Control	Duration (NAV)	To Addr	From Addr	CRC

Fig. 1(c) RTS Packet

Bytes 2	2	6	6	7	2	4
Frame Control	Duration (NAV)	To Addr	From Addr	Sleep Time	Duty Cycle	CRC

Fig. 1(d) SYNCrts Packet (Combined from Fig 1(b) and 2(c))

Bytes 2	2	6	4
Frame Control	Duration (NAV)	To Addr	CRC

Fig. 1(e) CTS Packet

Bytes 2	2	6	4
Frame Control	Duration (NAV)	To Addr	CRC

Fig. 1(f) ACK Packet

3.3 Adaptive Duty Cycle

The S-MAC protocol which has fixed duty cycle is energy efficient but this efficiency is achieved at the expense of compromise in the latency. In the proposed protocol each sensor keeps track of the traffic load based on the number of messages in its queue. When a message is received, the counter is increased and when it is transmitted the counter is decreased. If the message counter is greater than a threshold (COUNTthres), then the duty cycle is increased and the changed duty cycle is reported to the neighbouring sensor in the SYNCrts packet. The neighbouring sensor on the reception of SYNCrts packet checks if its queue also contains message more than the COUNTthres, it also increases it duty cycle. If not, it simply updates the synchronization table and continues with the original duty cycle. When the traffic is less and so when message counter is less than COUNTthres, the duty cycle is decreased. The sensor node intimates the changed duty cycle to its neighbouring nodes.

In this proposed scheme it is not necessary for all the sensor nodes to maintain the same duty cycle. The original duty cycle is still valid as the new duty cycle is multiple of the original duty cycle. If the original duty cycle is 15%, the increased new duty cycle will be 30%.Similarly when the load is less the duty cycle will be reduced from 30% to 15%.

The synchronization of the sensor nodes in the S-MAC protocol is done by maintaining the common sleep-listen cycle i.e fixed duty cycle. In the proposed MAC protocol all the sensor nodes on deployment have the basic duty cycle as shown in Fig. 2(a). Once the traffic on a sensor becomes high it automatically increases it duty cycle by listening again during sleep time as shown in Fig. 2(b). So the sensor gets more time to receive the packets. The original listen time remains unchanged. When the traffic is low, its duty cycle is decreased and the sensor stops sensing the channel during sleep interval. So it starts maintaining its original listen-sleep cycle.

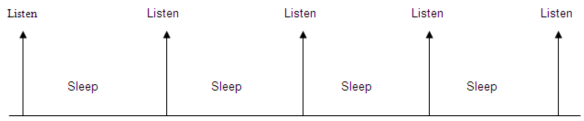

Fig. 2 (a) Original Duty Cycle

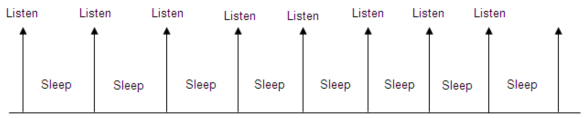

Fig. 2 (b) Increased Duty Cycle

3.4 Evaluation and Simulation Results

We have simulated the above proposed scheme in the Network Simulator ns-2 [7] version 2.30.The performance of the proposed MAC protocol is evaluated based upon energy consumption and latency. In the simulation, no mobility is assumed. In our experimental simulation we performed test on a simple two-hop network topology as illustrated in Fig. 3. We vary the traffic load by changing the packet inter-arrival time on the source node. The packet inter-arrival time changes from 1 Sec to 12 Sec. Under each traffic condition, the simulation is independently carried out for 10 times. In our simulations we evaluate the performance of our scheme and compared it with the standard S-MAC with 15% duty cycle & T-MAC protocol. The parameters for the implementation of MAC protocol on network simulator (ns-2) are given in Table 1.

Table 1. Parameters of MAC Implementation on NS-2

S.No	Parameter Name	Value
1.	Channel Bandwidth	20 kbps
2.	Control packet length	10 bytes
3.	Data packet length	Up to 250 bytes
4.	MAC header length	10 bytes
5.	Contention window for SYNCrts	31 slots
6.	Contention window for data	63 slots
7.	Slot Time	1 ms
8.	Power consumption for transmission	36 mW
9.	Power consumption for reception	14.4 mW
10.	Power consumption for sleep	15 μW

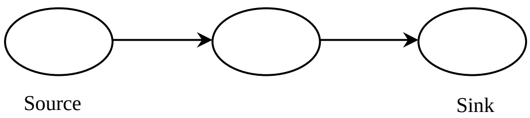

Fig. 3 Two-hop Network Topology Used in Experiment

(a) Energy Consumption

The comparative aggregate energy consumption of the source and destination nodes for the three different MAC protocols is shown in Fig. 4. It is evident from the results that the energy consumption of the proposed MAC protocol is less than S-MAC protocol. This is because of the reduction in the size and number of the control packets.

The reduction in the size of the data and control packets reduces the overhead by 1% for IEEE 802.11 data packet, 40% for the SYNCrts and 43% for the CTS and ACK packets. This overhead is further reduced because of transmission of one combined SYNCrts packet instead of two separate packets SYNC & RTS. In the experiment the total number of control packets transmitted and received was also recorded. As expected the total number of control packets in the proposed scheme is lesser than both S-MAC and T-MAC protocols.

These modifications in the control packets contribute to the lower energy consumption in the proposed MAC scheme as compared to S-MAC. The energy consumption of the proposed MAC protocol is however slightly higher than T-MAC protocol in which there is premature termination of listen interval when no event is expected to occur.

(b) Latency Behaviour

The latency behaviour of the three different MAC protocols measured at the destination node is shown in Fig. 5. The latency of the proposed MAC protocol is less than both S-MAC and T-MAC protocol because of adaptive adjustment of the duty cycle based on the network traffic.

When the network traffic load is high, the number of messages in a queue pending at the sensor node increases. This results in the sensor's automatic adjustment to higher duty cycle. So the sensor node listens again during the same sleep interval. Therefore the latency of the proposed MAC is low as sensor node gets one more chance to receive the packets.

When the network traffic is low, the duty cycle is again changed from higher to lower in order for the sensor node to conserve energy. As expected the latency of T-MAC protocol is higher as compared to Proposed MAC and S-MAC protocols. This is because T-MAC trades off latency for energy savings.

Therefore the proposed MAC scheme achieves high energy efficiency under wide range of traffic loads and is able to adjust itself to improve the latency performance when the network traffic load is high.

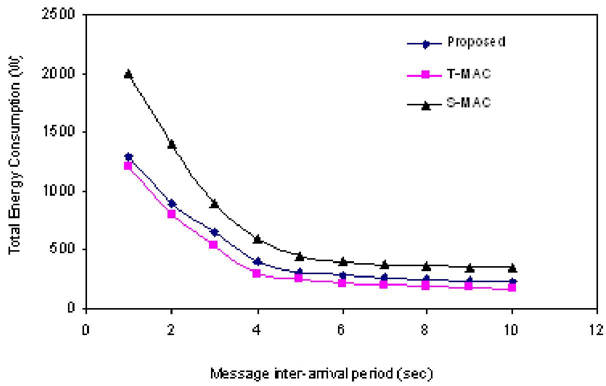

Fig. 4 Aggregate Energy Consumption

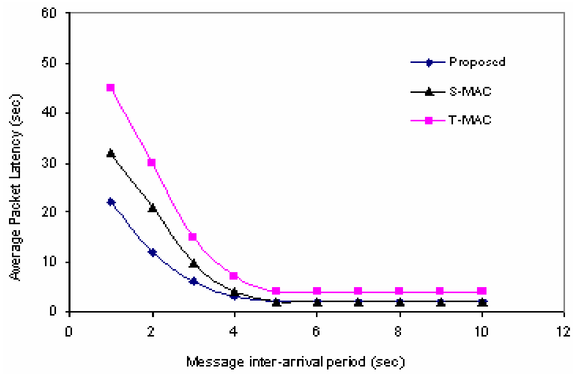

Fig. 5 Latency Behavior

4. Conclusions

In this paper we proposed a Medium Access Control (MAC) scheme for the wireless sensor network. This medium access control scheme is based on the concept of listen/sleep mode cycle like S-MAC. The S-MAC protocol achieves the energy efficiency at the expense of sensor latency and may not be suitable for the delay sensitive medical and defence applications.

The proposed scheme is good for applications where apart from energy efficiency there is need for lower latency. In the proposed scheme the latency is less because of the adaptive adjustment in the sensors duty cycle based on the network traffic conditions. The energy consumption has been reduced because of the reduction in the number and size of the control packets. As part of our future work, we plan to incorporate node mobility.

References

[1] I. Akyildiz, W. Su, Y.Sankarasubramaniam and E. Cayirci, " A Survey on Sensor Networks", IEEE Communication Magazine, Aug. 2002 p.p. 102-114

[2] Wei Ye, J.Heidemann and D. Estrin "An Energy-Efficient MAC Protocol for Wireless Sensor Networks",IEEE INFOCOM,New York, NY, June 2002, Vol.2, p.p. 1567-1576

[3] Tijs van Dam, Koen Langendoen, "An Adaptive Energy Efficient MAC Protocol for Wireless Networks" In Proceedings of the First ACM Conference on Embedded Networked Sensor Systems, Nov 2003.

[4] Changsu Suh, Young-Mi Song,Young-Bae Ko, We Duke Cho "Energy Efficient & delay Optimized MAC for Wireless Sensor Networks" In Proceedings of the Workshop in the Seventh International Conference on Ubiquitous Computing (Ubicomp'05),Sep 2005.

[5] S. Park, A. Savvides and M. B. Srivastava, "SensorSim: A Simulation Framework for Sensor Networks, "Proc. of MSWiM 2000, Boston, MA, August 11, 2000.

[6] Brenner, Pablo "A Technical Tutorial on the IEEE 802.11 Protocol", Breezecom Wireless Communications, July 1996.

[7] The Network Simulator –ns-2, http://www.isi.edu/nsnam/ns/

[8] IEEE Standard 802.11. Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, 1999.

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