An Energy-efficient and Collision-reduced MAC protocol for Wireless Sensor Networks adapting Single Homogenous scheme based on border node handover procedure

Sai Maung Maung Zaw, Aung Htein Maw, Ni Lar Thein
University of Computer Studies, Yangon, Myanmar
saisaimmz@gmail.com, ahmaw73@gmail.com, nilarthein@gmail.com

Abstract

Wireless sensor node is a micro-electric device that can be equipped with constrained power source and it is generally unrealistic to charge or replace the exhausted battery, which gives way to the primary objective of maximizing node/network lifetime. Therefore energy efficiency is one of the most important issues in wireless sensor networks and an important attribute sensor network MAC protocols. Sensor-MAC (SMAC), the widely used protocol may require some nodes to adapt multiple sleep/listen schedules which results in the early death of border nodes and this problem has a significant adverse on the lifetime and connectivity of WSNs. Although this problem can be solved by modifying SMAC with border node handover procedure, some nodes may encounter collision which is one of the major causes of energy waste. This paper presents the modified SMAC adjusting single homogeneous scheme based on border node handover procedure in order to reduce or eliminate collision amongst the border node area. The impact of the novel approach on the network performance is compared with SMAC and the modified SMAC with border node handover procedure through simulation.

1. Introduction

A large variety of applications such as military, security and disaster management has boosted up the interest in sensor networks during the past few years. Research on wireless sensor networks (WSNs) has grown speedily and novel techniques have been developed for the physical, data link (or MAC), and network layers. This popularity is the result of technological advancements in micro-electromechanical systems (MEMS) for sensing, microelectronics for computation and communication, and wireless networking techniques for efficient transmission [1]. A WSN consists of a large number of wireless sensor nodes scattered among an area of interest and are networked together to collaboratively gather data from the environment (or object in the case of monitoring a target). Nodes can be uniformly or non-uniformly distributed depending on the application. The data is taken from the elements sensed and these elements include temperature, light, sound, motion, etc.

Collaborative communication between adjacent nodes is needed because received data from one node is not accurate and must be compared to others, which improves fault tolerance of the system and allows data fusion [2]. Therefore, gathering information or data between adjacent nodes is the responsibility of MAC layer of WSNs. Unlike other wireless networks, it is generally impractical to replace or recharge the exhausted batteries for sensor nodes in WSNs, which is the primary objective of maximizing node or network lifetime, leaving the other performance metrics as secondary objectives. As a consequence of this, energy efficiency is a critical issue in wireless sensor networks because batteries are the only energy source to power the sensor nodes. In a sensor node, there are three activities which are main sources of energy consumption. Those activities are sensing, computation, and radio operations. Out of those three sources, energy loss due to radio operation which is the responsibility of MAC layer in WSNs is the maximum one [3].

The Medium Access Control (MAC) protocol directly controls the communication. As a result, it has important effect on the nodes' energy consumption. The major sources of energy waste in WSN are collision, overhearing, idle listening, and control packet overheads [4, 5].

To reduce this energy waste, Medium Access Control (MAC) protocols for wireless sensor networks have been proposed in recent years. The primary objective of these protocols is to manage energy efficiently. Most of these protocols use either contention based method or scheduled based manner or a hybrid of the two for accessing the shared medium.

The remainder of this paper is organized as follows. In Section 2, the former MAC protocols for WSNs and problem statement of S-MAC are briefly discussed. Section 3 describes the proposed modification of S-MAC which satisfies the early death problem of border nodes which has a negative effect on energy efficiency of wireless sensor networks. In Section 4, we add single homogenous adaptation scheme based on border node handover procedure in order to reduce collision probability due to the previous section. Section 5 discusses the NS-2 Simulation and performance evaluation of the proposed system. Finally section 6 describes the conclusion and some remarks of the proposed system.

2. Related Work

Z-MAC [6] is a hybrid MAC protocol that starts off as CSMA and switches to TDMA if network load increases. Nodes execute a distributed schedule algorithm known as DRAND to get a TDMA slot. When a node has to send data, it listens to all slots to check whether its neighbors need to send data. If the node is the slot owner, it randomly back off for a certain time and attempts to send its data if the medium is idle. The owner of a slot has a higher priority than non owners. The owner may use its slot; otherwise it allows other nodes to use this slot.

The goal of Sensor-MAC (S-MAC) [4, 7] is to minimize energy usage for prolonging network lifetime of a stationary network. Locally managed synchronizations and periodic sleep-listen schedules based on these synchronizations form the basic idea behind the Sensor-MAC protocol. This protocol S-MAC is robust medium access control (MAC) for wireless sensor networks. Because of significant reduction in energy consumption and its robustness, S-MAC has been applied in many wireless sensor networks (WSNs). Many TinyOS adopted this protocol for a number of platforms as WSN nodes [8].

T-MAC [9] improves S-MAC to reduce energy consumption on idle listening. It introduces an adaptive duty cycle: all messages are transmitted in variable length bursts and the lengths of bursts are dynamically determined. Similar to S-MAC, there are active periods and sleep periods in a time-frame.

In the following section 2.1, the problem statement of S-MAC is discussed and in the next following section 3, the proposed S-MACBH (S-MAC Border node Handover) is discussed and then the problem statement of this protocol is discussed.

2.1. Problem Statement of S-MAC

At the beginning, Nodes exchange their schedules by periodically broadcasting the sync (synchronization) frames. Sync frames allow a node to choose its schedule when it starts. If a node does not hear a valid sync frame from its neighboring node within a pre-determined synchronization period, it arbitrarily chooses its own schedule for itself and starts following its schedule and then broadcasts its own schedule to other neighboring nodes.

After one or more schedule exchanges have been completed across all nodes, some nodes become border nodes that follow two or more (sleep/listen period) schedules between or among virtual clusters. They are likely to listen all the time following schedules and as a result of this, the early death problem of border node will be encountered.

For example, suppose that border node follows four schedules of virtual cluster 1, 2, 3, and 4 as shown in figure 1. As a consequence of this, border nodes listen almost all the time as depicted in figure 2.

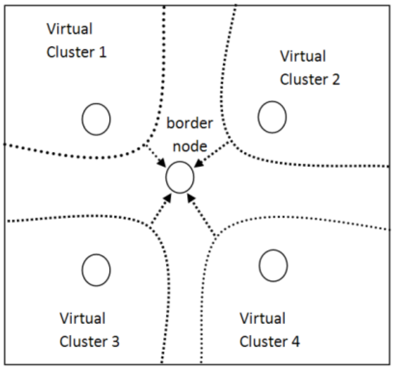

Figure 1. Border Node and Virtual Clusters

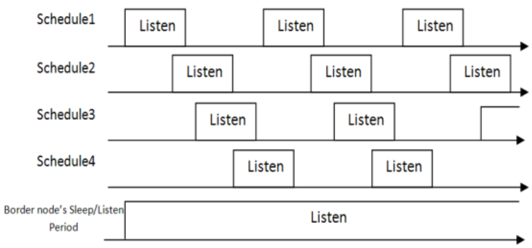

Figure 2. Border Node's schedule adapting four schedules

3. The Proposed S-MACBH (S-MAC Border node Handover)

The previous section proves that WSNs using S-MAC may have a higher proportion of listen period of border nodes which lead to the early death problem of border nodes that are bridges of neighboring nodes in virtual clusters.

In this section, to overcome this problem, the proposed modification of S-MAC protocol is presented. This modification does not change transmission and reception of data frames. This modification starts only after border node has appeared. At the beginning, it broadcasts all neighboring nodes to inform that it is border node and may claim to hand responsibility over one of neighboring nodes according to their residual energy and topology state. The following section describes the detailed procedure of the responsibility of border node handover.

3.1. Procedure Overview

There are two main functions of procedure:

a) Initialization Phase
b) Border node handover Phase

In initialization phase, border node initially broadcasts border node notification to all neighboring nodes to collect them. In border node handover phase, border node firstly sends border node handover message to the intended node and then the intended potential border node accepts that it hands over border node and the previous border node releases one of listen/sleep schedule.

3.2. Initialization Phase

After border node broadcast notification messages, all neighboring nodes send Ack (acknowledge) that they are ready to accept border node handover. Border node performs regular routine as S-MAC until it faces two criteria; the residual energy and multiple schedules (i.e. equal to or larger than the number of 2 ones).

3.3. Border node Handover Phase

As soon as a border node knows that it use certain power (every time 5% energy is used in this paper), it attempts to release one of the schedules. After that, it sends border node handover request to one of the neighboring nodes which has the same schedule it will release.

After the node received the handover request, it accept the request and send Ack back to inform that it hands over responsibility of border node and then former border node release the same schedule. The algorithm for border node is shown in figure 3. The algorithm for neighboring node is also shown in figure 4.

However, during border node handover period, some works may be suspended or collision probability may increase and this problem has an adverse on the lifetime of sensor networks.

Although this protocol can eliminate the early death problem of border nodes, it still encounters the problem of collision probability. In order to reduce the probability of collision, the following section proposes the adapted Single Homogenous scheme based on border node handover procedure.

Algorithm: the responsibility of border node

BEGIN

1. **IF** maximum number of schedules > 1
2. Broadcast *BorderNodeNotificationMsg* with ID-Schedules

$$\text{Threshold Energy} = \text{Energy} - \left(\frac{\text{Energy}}{100} \times 5\right)$$

3. **IF** Energy == Threshold Energy
4. Send *RequestBorderNodeHandoverMsg* with Released-ID-Schedule and Existing-ID-Schedule

END

Figure 3. The responsibility of border node

Algorithm: the responsibility of neighboring node

BEGIN

1. Receive BorderNodeNotificationMsg
2. **IF** ID-Schedule contains ID-Schedules
3. Send *AcceptBorderNodeNotificationMsg* with its ID-Schedule
4. **IF** Receive *RequestBorderNodeHandoverMsg*
5. Add *Existing-ID-Schedule*
6. Send *AcceptBorderNodeHandoveMsg*

END

Figure 4. The responsibility of neighboring node

4. The Adaptation of Single Homogenous scheme based on S-MACBH

According to the contention-based protocol, there are three types of nodes: ex-border node, border node and common node. In accordance with border node handover procedure, there are two forms of negotiation between nodes in order to handover border node's responsibility. The first type is the communication between border node and ex-border node and the second one is the negotiation between border node and virgin node that has never been the border node. Although second one is satisfactory following border node hand over procedure, the first one may encounter a repetition of being border node and unnecessary operations between nodes and this can cause not only the collision probability but also energy waste of single node.

To overcome the above challenge, the adaptation of single homogenous scheme based on S-MACBH is proposed. The purpose of this scheme is to reduce the repetition of being border node as well as to adjust single global schedule.

First of all, when ex-border node receives the border node notification message, it compares hop count with existing one and decides the appropriate global or homogenous schedule. If the received hop count is less than its own one, it replies the neglect message containing schedule ID with hop count. Then border node compares hop count with existing one and decides the appropriate global or homogenous schedule. The algorithms of the responsibility of border node and ex-border node are depicted in figure 5 and figure 6, respectively.

Algorithm: the responsibility of border node (Modified)

BEGIN

1. **IF** maximum number of schedules > 1
2. BorderNodeFlag = 1;
3. Broadcast **BorderNodeNotificationMsg** with ID-Schedules and HopCount
4. **IF** Energy = = Threshold Energy
5. Send *RequestBorderNodeHandoverMsg* with Released-ID-Schedule and Existing-ID-Schedule

END

Figure 5. The responsibility of border node (modified)

Algorithm: the responsibility of ex-border node or virgin node

```
BEGIN
1.  Receive BorderNodeNotificationMsg
2.  IF BorderNodeFlag = 0
3.  GOTO 13
4.  ELSE IF BorderNodeFlag = 1
5.    IF HopCount = = ReceivedHopCount
6.          Random (schedule, ReceivedSchedule)
7.    ELSE IF HopCount > ReceivedHopCount
8.          Global Schedule = schedule
9.           Send NeglectMsg with HopCout and
             schedule
10.     GOTO END.
11.     ELSE IF HopCount < ReceivedHopCount
12.         Global Schedule = ReceivedSchedule

13.  IF ID-Schedule contains ID-Schedules
14.  Send AcceptBorderNodeNotificationMsg
       with its ID-Schedule

15. IF Receive RequestBorderNodeHand-
        overMsg
16.         Add Existing-ID-Schedule
17.         Send AcceptBorderNodeHandoverMsg

END
```

Figure 6. The responsibility of ex-border node or virgin node

To distinguish the modified version of the protocol presented in this section from the original S-MAC protocol and S-MACBH (S-MAC Border node Handover) [10], we refer to modified version in the rest of the paper by the acronym S-MACBH-SH.

5. Performance Evaluation

The performance evaluation of S-MAC, S-MACBH and S-MACBH-SH is evaluated with Network Simulator version 2 (NS-2) [11], which is one of the most popular network simulators for both wired and wireless networks. It also support for queuing algorithms, routing protocols, multicast protocols and IP protocols. First of all, S-MACBH module for NS-2 was implemented. This module for NS-2 is based on the built-in S-MAC module in NS-2.

We have simulated wireless sensor networks with regular topology and randomly generated topology in a network area (simulation area) of 300 x 300 m. For manually deployed topologies, the distance between each node is 50 meter respect with x and y coordinates. In our simulations, at the beginning, all nodes have the same fixed amount of energy. We compare S-MACBH-SH to existing SMAC and S-MACBH in terms of the average lifespan of the nodes.

5.1. Simulation Parameters

There are S-MAC/S-MACBH/S-MACBH-SH parameters, as shown in Table 1.

Table 1. Simulation parameters

	Simulation Parameters	Default Values
S-MAC/S-MACBH/S-MACBH-SH	SMAC-DUTY-CYCLE	10
	SMAC-MAX-NUM-NEIGBHORS	20
	SMAC-MAX-NUM-SCHEDULES	10
	Channel bandwidth	19.2 Kbps
	Transmission range	60M
	Transmit power	60mW
	Receive power	50mW
	Idle power	50mW
	Sleep power	0.001W
	Transition power (sleep to idle)	0.1W
	Transition time (sleep to idle)	5ms
	Node initial energy	54,000J

As show in Table 1, listen time of every node is 10% period and maximum number of neighboring nodes and maximum number of schedules that each node can adapt are up to 20 and 10 respectively. These values are defined in smac.h (in ns2 module). The simulations are carried out based on IEEE 802.11 and AODV protocol. For network topologies, the following topologies are used in this simulations; nodes deployed on a straight line, nodes deployed on a matrix, and randomly generated topology.

5.2. Simulation Results

This section reports the results of simulation to examine whether the energy efficiency and lifetime of the network of S-MACBH-SH is improved.

5.2.1. Lifetime of Network

In the simplest network topology study, different wireless nodes (10 nodes and 15 nodes) are manually deployed on straight line and a matrix respectively. The manual deployed simulation of different nodes on straight line and matrix in ns-2 are shown in figure 7 and figure 8.

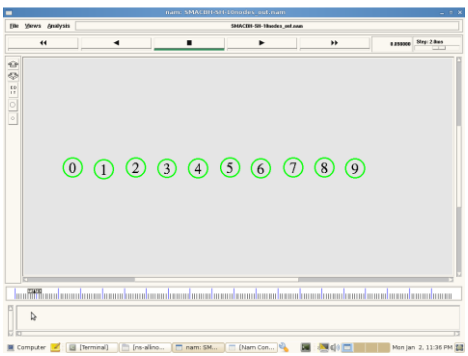

Figure 7. The manual deployment of 10 nodes on straight line

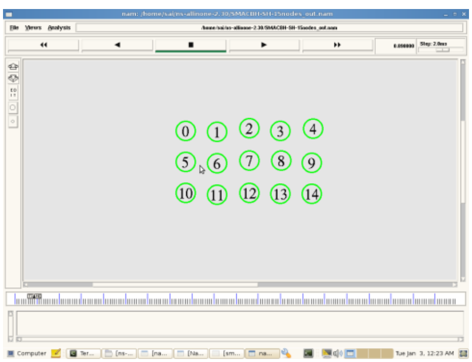

Figure 8. The manual deployment of 15 nodes on matrix

Table 2 shows the result of the simulations of manual deployment of different nodes. Average lifetime of nodes of S-MACBH-SH is compared with the existing protocol, S-MAC, and S-MACBH-SH.

Table 2. Performance in simplest network topologies

No. of Nodes	MAC Protocol	Average lifetime of nodes(sec)
10	S-MAC	5418
10	S-MACBH	6925
10	S-MACBH-SH	6845
15	S-MAC	3671
15	S-MACBH	5541
15	S-MACBH-SH	5648

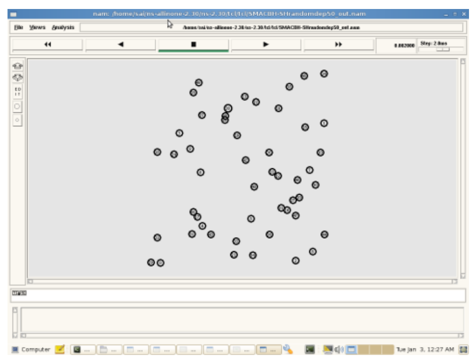

Figure 9. The randomly deployed simulation of 50 nodes

For the randomly deployed network topology, 50 nodes and 100 nodes are randomly deployed as illustrated in figure 9 and figure 10 respectively. Table 3 shows the result of the random deployment of nodes.

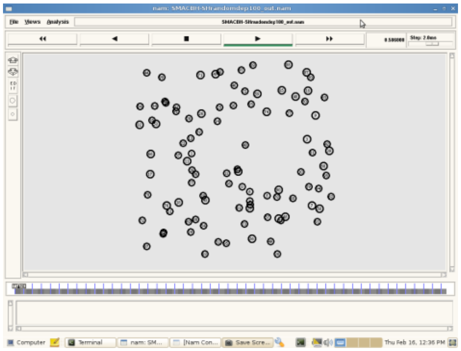

Figure 10. The randomly deployed simulation of 100 nodes

Table 3. Performance in randomly deployed network topology

No. of Nodes	MAC Protocol	Average lifetime of nodes(sec)
50	S-MAC	2137
50	S-MACBH	3914
50	S-MACBH-SH	4653
100	S-MAC	1215
100	S-MACBH	1450
100	S-MACBH-SH	1650

Figure 10 shows the result of the average lifetime of different network topologies (10 nodes, 15 nodes and randomly deployed 50 nodes).

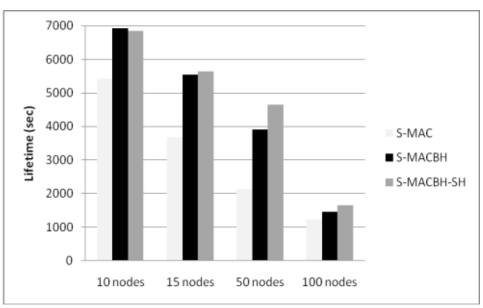

Figure 10. Average lifetime

The simulation result above indicates that the modification S-MACBH-SH can prolong network lifetime compared with original protocol S-MAC and S-MACBH. In 10 nodes simulation, Average lifetime of S-MACBH-SH is lesser than those of S-MACBH. However, in 15 nodes and 50 nodes simulations, S-MACBH-SH can make longer network lifetime than the other two protocols.

6. Conclusion

This paper proposes the modification version of S-MAC based on border node handover procedure, which is more energy efficient than S-MAC, the original protocol. Moreover, this protocol not only eliminates the early death problem border node but also reduces collision due to border node handover procedure adjusting single homogenous scheme. This reduction supports energy efficiency, which is the primary objective of WSNs.

7. References

[1] Shorey R, Ananda A, Chan MC, Ooi WT. "Mobile, wireless, and sensor networks: technology, applications, and future directions", Hoboken, New Jersey: John Wiley & Sons, Inc.; 2006.

[2] Stankovic JA, Abdelzaher TF, Lu C, Sha L, Hou JC, "Real-time communication and coordination in embedded sensor networks", In: Proceedings of the IEEE,vol. 91, no. 7; July 2003.

[3] I. Demirkol, C. Ersoy, and F. Alagoz, "MAC Protocols for Wireless Sensor Networks: A Survey", IEEE Communication Magazine, Vol. 44, Issue 4, April 2006.

[4] W.Yee, J. Heidemann and D. Estrin, "An energy efficient MAC protocol for sensor networks," in INFOCOMM 2002, Twenty-first Annual joint conference of the IEEE computer and Communication Socities proceedings, IEEE, vol.3, June 2002

[5] T. van Dam, K. Langendoen, "An Adaptive Energy Efficient MAC Protocol for Wireless Networks", in Proceedings of the First ACM Conference on Embedded Networked Sensor Systems , November 2003.

[6] I. Rhee, A. Warrier, M. Aia and J. Min, "Z-MAC: A hybrid MAC for wireless sensor networks", ACM international conference on embeded networked sensor systems; November 2005

[7] W. Ye, J. Heidemann, and D. Estrin, "Medium Access Control with coordinated adaptive sleeping for wireless sensor networks" , IEEE/ACM transactions on networking, vol. 12, no. 3, June 2004
[8] P. Levis, S. Madden, D.G. Joe Polastre, R. Szewczyk, A. Woo, E. Brewer and D. Culler, " The emergence of networking attractions and techniques in TinyOS", Proceedings of the First USENIX/ACM symposium, 2004
[9] T. Dam, K. Langendoen" An Adaptive Energy-Effi cient MAC Protocol for Wireless Sensor Networks" Proc. of the fi rst ACM Conf. on Embedded Networked Sensor Systems (SenSys), New York: ACM press,2003
[10] Sai Maung Maung Zaw, Aung Htein Maw and Ni Lar Thein, "Energy Efficient Mechanism for Wireless Sensor Network MAC Protocol using Border Nodes Handover Procedure", The 15th International Computer Science and Engineering Conference 2011, September, 2011
[11]The network simulator ns-2, http://www.isi.edu/nsnam/ns/