EEH-MAC: Energy-Efficient Hybrid MAC Protocol in Wireless Sensor Networks

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

Abstract

In wireless sensor networks (WSNs), energy is a very scarce resource and has to be managed wisely in order to extend the life of the sensors. Therefore, to be energy-efficient, this paper is presented as hybrid protocol for MAC layer in Wireless Sensor Networks (WSNs). It combines contention and schedule-based methods. Time slot assignment is designed by semi-distributed manner. A base station is considered as a master only for its one-hop children because nodes are also memory (buffer)-constrained ones in real world. When a base station sends token to its neighboring nodes all the way through the largest-hop nodes and token is sent back to the base station, this may cause the overflow of buffer or the time slot assignment table may be damaged during token is passing through all the nodes. To avoid this problem, time slot assignment is only considered as the two-hop neighbors from each parent.

1. Introduction

The wireless sensor networks (WSNs) are used in a wide range of applications to capture, gather and analyze live environmental data. The wireless sensor network architecture typically consists of a large number of sensor nodes scattered among an area of interest and are networked together collaboratively gather data from the environment and send back to the base station. The sensor nodes [1] communicate one another through the wireless channel to self-organize into multi-hop network and forward the collected data towards the base station. In a wireless sensor network, sensors nodes are low cost, resource-constrained devices and are often deployed randomly [2]. Unlike other wireless networks, it is generally impractical to charge or replace the exhausted battery, which gives way to the primary objective of maximizing node/network lifetime. As a result, energy efficiency is a crucial necessity in a medium access control protocol for wireless sensor networks. The major sources of energy waste in MAC protocol are collision, control packet overhead, idle listening, and overhearing [3].

Due to the contention-based method, there is a significant increase in the probability of collision as every node compete the same medium at the same time and retransmission are required causing energy waste. A good MAC protocol can enable collision avoidance effectively; reduce retransmission of data and save energy. Moreover, the contention-based method causes idle listening (nodes listen to the medium at all time) and overhearing (nodes listen to the message that are not intended to them) which are undesirable sources of energy waste.

On the other hand, although schedule-based method can reduce collision, idle listening and overhearing as all nodes are assigned which time slot is listen/sleep for a certain node, it is difficult to decide how to assign time slot. As all nodes are homogenous (they all have the same level of memory, CPU and power, etc.), it is impossible to select the leader node which has to assign time slot for neighboring nodes. If time slot assignment entirely depends on base station, time slot assignment duration is significantly overdue and time slot reassignment is unfeasible for multi-hop networks like WSNs. Moreover, as a result of schedule-based method, there is a considerable delay as time slot may be dissipate if the owners of time slot do not need to send or receive data although other need to do this.

To overcome the above problems, energy–efficient hybrid MAC protocol (EEH-MAC) is presented in this paper. This protocol is based on contention as well as schedule-based method which are necessary to be assigned time slot. Unlike other wireless or wired networks, it is unattainable which node is responsible for assigning time slot and therefore centralized approach is unsuitable for WSNs. On the other hand, it is also impractical to adopt decentralized (distributed) method causing complexity which is one of the major power-consumers. Therefore, semi-distributed time slot assignment is presented. After time slot assignment is completed, each node knows which time slot is listen period for receiving data. Nodes which have to send the data compete the medium using RTS/CTS.

The remainder of this paper is organized as follows. In Section 2, the former MAC protocols for WSNs are briefly discussed and some problems adapting the MAC protocol is mentioned. Section 3 describes the proposed energy-efficient MAC protocol which reduces not only collision but also overhearing and idle listening. Finally, conclusion and further work are described.

.

2. **Related Work**

Locally managed synchronizations and periodic sleep-listen schedules based on these synchronizations form the basic idea behind the Sensor-MAC (S-MAC) protocol [4]. One of the disadvantages of S-MAC is the broadcast data packets do not use RTS/CTS which increases collision probability. In the proposed system, CSMA/CA protocol is applied during the initialization phase. Therefore, collision is able to be avoided. Moreover, S-MAC is based on contention protocol. The nature of contention-based protocol can be the result of increment in not only collision but also idle listening and overhearing.

Z-MAC [5] 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. In the proposed system, two-hop nodes run semi-distributed algorithm and parent of nodes only help child nodes to get TDMA slot. Therefore early death problem of parent nodes can also be eliminated.

FlexiTP [6] is TDMA-based protocol for WSNs. A token is generated from the base station through the farthest nodes to get TDMA slot. When the token is sent back to the base station, TDMA assignment is successful and data transmission starts. If the token is damaged, the base station may retransmit a new token, causing both energy and time waste. In the proposed system, instead of using token, the message that I (parent or base station) have got the nth time, you (the child node) will get the next one is generated only among two-hop neighbors to get TDMA slot. Therefore, topology changes can be guaranteed and mobility also may be guaranteed.

3. The Proposed System

The proposed MAC protocol for WSNs consists of three main parts: initialization phase, TDMA assignment phase and data gathering phase as shown in figure 1. Initialization phase includes collecting nodes with the help of base station by means of CSMA/CA which is one of the contention-based protocols. In TDMA assignment phase, time slots are assigned in the way of simple semi-distributed manner. In data gathering phase, parent nodes synchronize all the neighboring nodes and sender nodes attempt to get the time slot of sender nodes.

3.1. Initialization Phase

In this phase, base station initially broadcasts message to collect the neighboring child nodes and then child nodes attempt to collect their own child nodes and sends back information to base station.

3.1.1. Base Station Broadcast Phase

Base station broadcasts synchronization frame to all neighbor nodes. BS knows that it has children by overhearing the broadcast message of his potential children. Base station waits the ACK and information from his neighbors until all neighboring nodes collect their children. In figure 2(a), a scenario for broadcasting message from a base station to nodes is illustrated.

3.1.2. The Function of Child Nodes

As soon as the neighbors of BS have known that they are the children of BS, they prepare for broadcast message to search their children according to random backoff time to avoid collision. When the neighboring nodes receive the broadcast message, they accept the parent of them which has the smallest hop count. The neighboring nodes also save other parents broadcast messages which have larger hop counts than the parent node for the backup purpose. After that, they try to send ACK message to their parents using CSMA/CA as depicted in Figure 2(b).

.

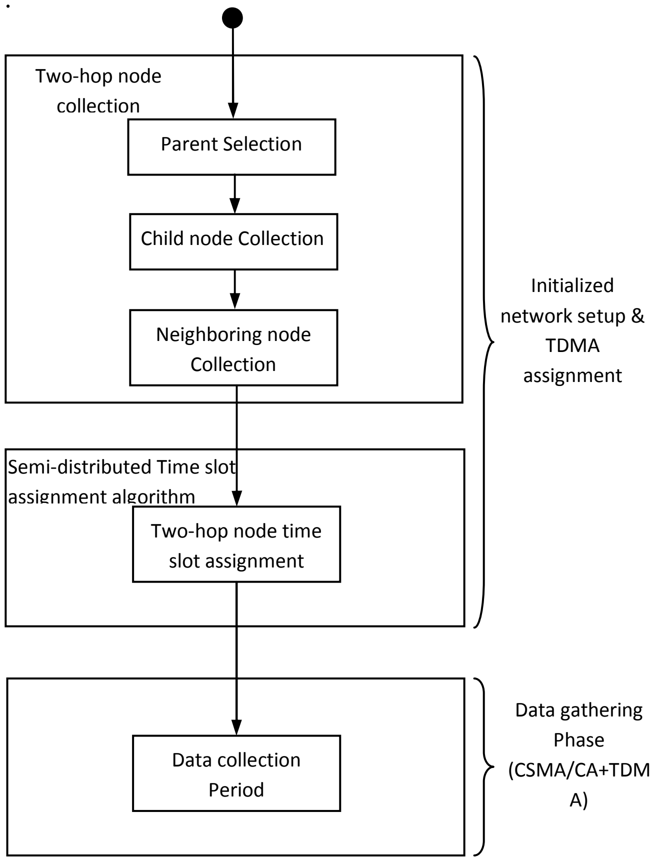

Figure 1. Overall Phases of the Proposed System

After collecting all neighboring child nodes' information, each parent node try to send (confirmation message) ACK message to Base Station using CSMA/CA as shown in Figure 2(c).

After that, BS sends each child node to get TDMA assignment in accordance with the priority (The node that has the largest number of child nodes wins the first priority). As soon as the node has received the TDMA assignment from BS, it sends "Do-Priority-Assignment" to their children by means of random calculation that sorts each node to avoid collision.

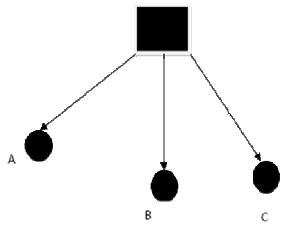

Figure 2(a). Broadcast message from BS to nodes

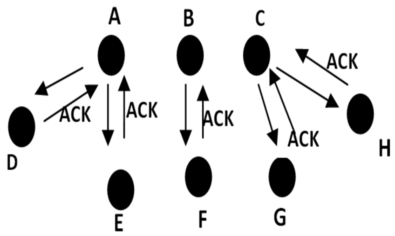

Figure 2(b). The negotiation of nodes

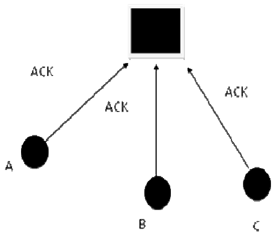

Figure 2(c). ACK message from nodes to BS

3.2. TDMA Assignment Phase

It is critical to assign TDMA slot for each node because all nodes are not only homogenous devices but also resource-constrained ones. Therefore, it is appropriate to assign TDMA slot as not only distributed manner but also simple way. The proposed system puts forward simple semi-distributed TDMA algorithm as the following example as shown in Figure 3, 4 and Table 1.

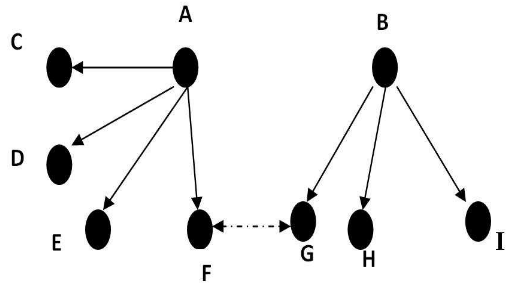

Figure 3. Example of TDMA Slot Assignment

Suppose that random calculation of node A sorts as C, D, F, and E and those of node B H, G, and I respectively. C first catches the TDMA time slot 0 and sends it get slot 0. After that, A catches slot 1 and send it to D. Node D obtains time 2 and A gets time 3 again and F holds time slot 4 and Node A and E get time slot 5 and 6 respectively. After that, A sends back BS the information that it has won time 1, 3 and 5. And then, BS gets time slot 6 and sends to its child node B.

As far as node B is concerned, node B first wins time 0 and 2 respectively. When node G attempts to get time slot, it gets the next time of Node F because it overheard node F's time slot. So, it gets time slot 5. Node B again gets time 0 and node I wins time 1.

Table 1. An example of semi-distributed TDMA Assignment Table

0	1	2	3	4	5	6	7
C	A	D	A	F	A	E	reserved
B	H	B			G	BS	reserved
B	I						reserved

To become a trade-off, slot 7 is not assigned and other time slots may be empty. Within each time slot, each node communicates one another using CSMA/CA like S-MAC. The owner of time slot is the most priority and other nodes that need to communicate wait the Carrier Sense that it is indicated that the medium is free or not. Time slot assignment algorithm is presented as exposed in Figure 4.

```
1.  Begin
2.    Timeslot = Timeslot+1
3.   If (Timeslot E Timeslot set)
4.          Exit
5.   Else
6.      Begin
7.       If (Timeslot E Timeslot set of Neighbor nodes)
8.          Timeslot = Timeslot+1
9.           goto 3.
10.  Else
11.     Timeslot set = Timeslot U Timeslot set
12.     End
13. End
```

Figure 4. Time slot assignment Algorithm

3.2. Data Gathering Phase

After the TDMA assignment is completed partially or totally, all nodes send data according to the time slot assignment.

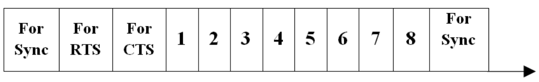

Figure 5. Data transmission/reception state

As shown in figure 5, in synchronization slot, parent node may send synchronization message that contains relative time (timer) to all neighboring nodes according to base station timer in order to inform the synchronization. After that, in RTS/CTS phase, nodes that have to send data request RTS to nodes which have time slot to receive (listen). Nodes that have received CTS win the time slot of the receiver node and other nodes that do not receive CTS will wait the next cycle until the synchronization slot. As this manner, receiver nodes need to listen only in their own slot and sender nodes also wake up in the time slot they win.

4. Conclusion

The proposed system is expected to be reduction in collision free as well as idle listening and overhearing. As a consequence of this, it is expected to be more energy-efficient than any other protocol. After the TDMA assignment has been completed, all nodes wait the only listen state of each time slot and can sleep if the medium is free.

As further work, this system will be implemented and tested the results compared with existing protocols using NS-2[7] which is the most popular simulator developed for wired and wireless networks simulation.

References

[1] I. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, "*Wireless sensor networks: A survey*" , Computer Networks 38 (4), 2002.

[2] L. Chaari and L.Kamoun, "*Wireless sensors networks MAC protocols analysis*", Journal of Telecommunications, Volume 2, Issue 1, April 2010.

[3] K. Sohraby, D. Minoli, T. Znati, " *Wireless Sensor Networks: Technology, Protocols, and Applications*",

Wiley-Interscience, A John Wiley & Sons, Inc., Publication, 2007.

[4] 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.

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

[6] W. L. Lee, M. Datta and R. Cardell-Oliver, "*FlexiTP: A flexible-schedule-based TDMA protocol for fault-tolerant and energy-efficient wireless sensor networks*", IEEE transactions on parallel and distributed systems, vol. 19, no. 6; June 2008.

[7] The network simulator ns-2, http://www.isi.edu/nsnam/ns/