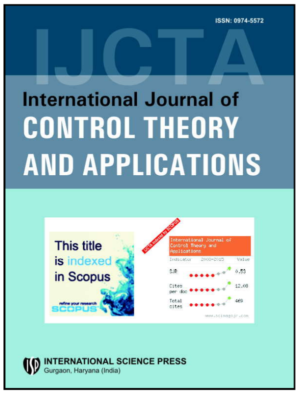

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 13 • 2017

A Low Duty Cycle MAC protocol for energy conservation in Wireless Sensor Networks

Kumar Debasis[1] and M. P. Singh[1]

[1] Department of Computer Science and Engineering NIT Patna, Patna, Bihar, India,
Emails: devkunu@gmail.com , mps@nitp.ac.in

Abstract: A Wireless Sensor Network (WSN), once deployed, may be needed to function for a very long duration without any interruption. But sensor nodes, equipped with small low capacity batteries,may not support the application requirements of the network. TDMA (Time Division Multiple Access) based Low Duty-Cycle MAC (Medium Access Control) protocols for clustered WSNs turn off the radio units of cluster members in all but their own allotted time slots. This also allows the cluster head (CH) to sleep in the slots in which no members are transmitting. But the necessity to broadcast a schedule in each frame drains a significant amount of the CH's energy at the end of each round. This paper proposes a model in which the CH broadcasts the schedule only once in each round, saving a considerable amount of its energy which would have been wasted otherwise. The cluster members are also relieved from listening to the schedule broadcast multiple times in a single round.

Keywords: Mini slot, Data slot, Schedule, Cluster Head, Cluster Member

1. INTRODUCTION

In Wireless Sensor Networks (WSNs), many sensor nodes work in an organized manner and report to the base station on the physical and environment conditions monitored. Each node is basically equipped with a sensor, a processor, a transceiver, a memory unit and a low capacity battery. The transceiver drains the maximum energy as compared to all other units. A sensor node loses considerable amount of energy even when the radio unit is idle (neither transmitting nor receiving). TDMA (Time Division Multiple Access)based MAC (Medium Access Control) protocols for clustered WSNs allow cluster members (CMs) to transmit in their own time slots and sleep (radio unit is turned off) at all other times [1]. This also allows the cluster head (CH) to sleep in the slots wherenone of the CMs are transmitting. However, the CH broadcasts the slot allocation schedule in each frame which may lead to a considerable amount of energy loss for the CH at the end of each round. This paper proposes a model in which the schedule is created based on the order in which nodes join the cluster and is broadcasted only once in each round.

The rest of the paper is organized as follows. Section II gives an overview of the literature survey. Section III defines the problem statement. Section IV explains the proposed model. A comparative analysis is presented in section V. Concluding remarks are given in section VI.

2. LITERATURE SURVEY

Low-Energy Adaptive Clustering Hierarchy(LEACH) protocol proposed by Heinzelman et al. in 2000 implements the traditional TDMA mechanism with clustering [2]. The time is divided into rounds, with each round consisting of a setup phase, a TDMA schedule phase and numerous TDMA frames. In the setup phase the network is divided into clusters, with one cluster head (CH) being appointed in each of them. In the TDMA schedule phase the CH broadcasts a schedule that is to be followed throughout the duration of the round. In the TDMA frames that follow, each cluster member (CM) transmits data only in its allocated time slots. Each round consists of only one TDMA schedule phase and all the TDMA frames are same in length. There drawback of this protocol is that the CH is not aware of the fact that which members will be transmitting in the current frame. Therefore, the CH must be active throughout the frame duration. This leads to a considerable amount of energy loss at the end of each round.

Bit-Map Assisted Medium Access Control (BMA MAC) protocol proposed by Li et al. in 2004 removes the drawback of the LEACH protocol by adding a contention phase (CP) at the starting of each TDMA frame [3]. The CP is divided into mini slots and each source node (node that has data to send) transmits a 1-bit message to the CH only in its allocated mini slot. This message is aimed at informing the CH that the member has some data that it wants to send. CH allocates successive data slots to such members. After all the source nodes have transmitted, the CH can go to sleep, only to wake up in the next frame. The TDMA frames of this protocol are however equal sized just like LEACH, resulting in low channel utility.

An Event Driven TDMA (ED-TDMA) protocol proposed by Gong et al. in 2009 improves BMA by allowing variable length TDMA frames which is based on the count of source nodes [4]. ED-TDMA, just like BMA, divides the time into rounds. Each round consists of a setup phase and a steady phase. In the setup phase the network is divided into clusters. The steady phase consists of manyTDMA frames, each with a size depending on the number of source nodes identified. The number of source nodes may be small enough to introduce frequent schedules and reservations. This will again lead to significant amount of energy loss for the cluster head as well as the cluster members. To avoid such situations ED-TDMA defines the minimum length of a frame that cannot be violated under any circumstances.

An Energy-Efficient MAC protocol proposed by Sazak et al. in 2010 also divides time into rounds, with each round consisting of a setup phase and a steady-state phase [5]. In the setup phase the network is grouped into clusters. Like the BMA protocol, each session of the steady-state phase consists of a contention period. But unlike the BMA protocol, source nodes do not send 1 bit control messages to the cluster head in this period. Instead they send the difference data between the measured values and the predefined threshold. For this purpose,each cluster member is allotted a 4-bit time slot. When a node finds that the measured value is equal to or bigger than the predefined threshold, it calculates the difference data and transmits it to the cluster head during its own 4-bit time slot. The cluster head compares the difference data from all the source nodes. If n source nodes have sent the same difference data, then only one of them is allotted a data slot.

Sensor-Time Division Multiple Access (S-TDMA) protocol proposed by Boulfekhar et al. in 2012 splits time into frames of equal length. Each frame is again partitioned into four periods [6]. In the first period the steps in the setup phase of a LEACH protocol are followed. The entire network is grouped into clusters with one cluster head in each cluster for the management purpose. The second period is itself divided into three periods: T_{verif} (a period to verify the number of data accumulated by each member node), $T_{alloc\ CH/ON}$ (a period to allocate time slots to member nodes) and T_{rcv} (a period to transferdata to cluster head). The cluster head queries each member node and allocates slots to each node depending on the number of data that it has gathered. Each node transmits data only in the slots that it has been allotted. In the third period the base station (BS) queries each cluster head and is informed about the number of data collected at each CH. BS then allocates slots based on this information. In the fourth period the CHs forward their data to the base station in the time slots assigned to them.

3. PROBLEM STATEMENT

In TDMA based MAC protocols for clustered WSNs, cluster heads broadcast the slot allocation schedule in each frame of a round. Due to this the cluster head loses a significant amount of energy at the end of each round.Even the cluster members are burdened with listening to the schedule broadcast multiple times in a single round. A new model that restricts the frequency of the schedule broadcast phase to just one in each round, should save a significant amount of energy of the cluster head as well as the cluster members.

4. PROPOSED MODEL

The proposed model divides time into rounds. Each round contains a setup phase, TDMA schedule phase and several TDMA frames. The cluster formation algorithm resembles the LEACHprotocol. During the setup phase, each node decides whether it should become the CH based on some predefined threshold [2]. The node which elects itself as the CHbroadcasts an advertisement message. Based on the received signal strength each non-CH node decides which cluster it wants to join. The node then informs the same to the CH of the selected cluster. After receiving these messages from all such nodes, the CH broadcasts the schedule for reservation slots (mini slots)and CM transmission slots (data slots).

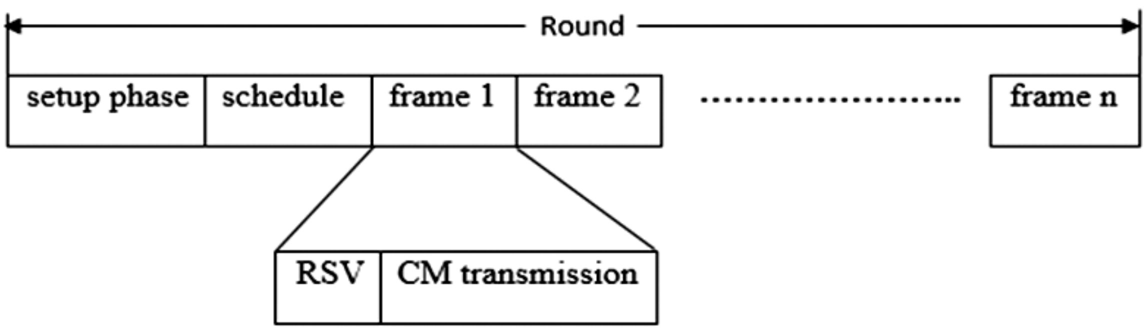

Figure 1: Arrangement of a roundinthe proposed model

Reservation (RSV) period consists of mini slots in which source nodes (nodes that have data to transmit) send 1 bit control messages to CH to reserve data slots in CM transmission period. The CM transmission period consists of data slots in which the source nodes can send their data to the CH. Only one mini slot and one data slot is allotted to each CM by the CH in the TDMA schedule phase. The first node that joins the cluster is allotted the first mini slot and the first data slot, the second node that joins the cluster is allotted the second mini slot and the second data slot and so on. This schedule is followedthroughout the duration of theround.The TDMA schedule phase is followed by several equal sized TDMA frames. Each frame consists of a RSV period and a CM transmission period as shown in figure 1.Within a frame, each source node can send a control packet and a data packet only in its allotted mini slot and data slot respectively. Except for its own data slot a source node is asleep in all other data slots. After the RSV period is over, the CH knows which member nodes will be transmitting data in the current frame. Therefore, the CH stays awake in those data slots and sleeps in the rest of the data slots.

Let us suppose that there are five CMs A, B, C, D and E in a cluster. A joined the cluster first, and was therefore allotted mini slot 1 and data slot 1. B joined second, and was allotted mini slot 2 and data slot 2.Similarly, the rest of the cluster members are allotted mini slots and data slots based on the order in which they joined the cluster. A and C have some data to send to the CH. Therefore, they send 1 bit control messages to the CH in their respective mini slots. CH now knows that A and C have data to send. Therefore, CH stays awake in data slots 1 and 3 and is asleep in all other data slots. CMs B, D and E are asleep during the complete duration of the frame. Figure 2 explains the complete scenario in detail.

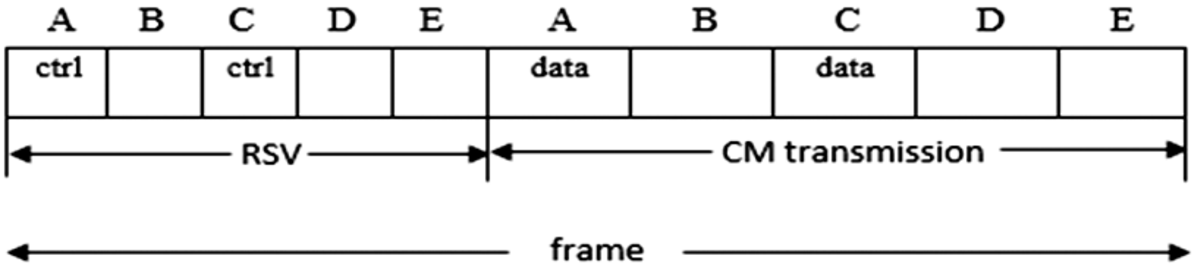

Figure 2: Frame structure of theproposed model

As in Adaptive Periodic Threshold-sensitive Energy Efficient Sensor Network Protocol (APTEEN)proposed by Manjeshwar et al. in 2002, the CH broadcasts some parameters like hard threshold (H_T), soft threshold (S_T) and count time (T_C) during the setup phase [7]. If the sensed value goes beyond the H_T, the member node should inform the cluster head. S_T is the small change in the sensed value that drives the member node to inform the cluster head. T_C is the maximum allowable duration between two succeeding reports sent by the member node, beyond which, it reports the sensed value to the CH.

5. COMPARATIVE ANALYSIS

A comparative analysis with the BMA MAC protocol [3] shows roughly how much energy can be saved if we restrict the frequency of the schedule phase to just one in each round.

BMA MAC protocol uses Rockwell's WINS sensor node for simulation which has the following properties:

- Energy consumed in transmitting 1 bit = 6600 nJ
- Energy consumed in receiving 1 bit = 3300 nJ

The following assumptions were taken in BMA MAC protocol to carry out the simulation:

- Data packet size = 250 bytes
- Control packet size = 18 bytes

To show the extra energy consumption in BMA MAC due to the schedule phase that is introduced in each frame of a round, we take the following assumptions:

- Number of frames in one round = 20
- Number of cluster members in a cluster = 10

In BMA MAC protocol, each cluster head broadcasts a control packet (schedule) in each frame of a round. Considering all the above information we arrive at the following conclusions:

- Power consumption of the CH in each frame due to the schedule phase = $18 \times 8 \times 6600 = 950400$ nJ
- Power consumption of all the CMs in each frame due to the schedule phase = $10 \times 18 \times 8 \times 3300 = 4752000$ nJ
- Total power consumption of the CH and the CMs in each frame due to the schedule phase = 950400 nJ + 4752000 nJ = 5702400 nJ
- Total power consumption in each round due to the schedule phases introduced in each frame = $5702400 \times 20 = 114048000$ nJ

In the proposed model, we consider only one schedule phase in the entire round. Therefore, the energy saved in our model as compared to BMA MAC protocol is:

- 114048000 nJ – 5702400 nJ = 108345600 nJ (approximate value)

The power consumption figures will vary with different sensor nodes, packet lengths, cluster sizes and frame formats. But confining the occurrence of the schedule phase to just one in each round will certainly lead to considerable energy savings for the cluster head as well as the cluster members.

6. CONCLUSION

This paper proposes a model in which the slot allocation schedule is created based on the order in which nodes join the cluster. The schedule is broadcasted soon after the setup phase is over. A schedule once broadcasted, is followed for the entire duration of the round. As the schedule is broadcasted only once in each round, a considerable amount of energy of the cluster head and the cluster members is saved at the end of each round. The three parameters broadcasted by the cluster head during the setup phase,cause the member nodes to report to the cluster head when they see any drastic changes in the values of their sensed attributes, and when the duration between two consecutive reports crosses a certain limit.

REFERENCES

[1] Khan, Junaid Ahmed, Hassaan Khaliq Qureshi, and Adnan Iqbal. "Energy management in wireless sensor networks: a survey." *Computers & Electrical Engineering*, vol. 41, pp. 159–176, Jan. 2014.

[2] Heinzelman, Wendi Rabiner, AnanthaChandrakasan, and Hari Balakrishnan. "Energy-efficient communication protocol for wireless microsensor networks." *System sciences, 2000. Proceedings of the 33rd annual Hawaii international conference on*. IEEE, 2000.

[3] Li, Jing, and Georgios Y. Lazarou. "A bit-map-assisted energy-efficient MAC scheme for wireless sensor networks." *Proceedings of the 3rd international symposium on Information processing in sensor networks*. ACM, 2004.

[4] Gong, Haigang, et al. "An event driven TDMA protocol for wireless sensor networks." *Communications and Mobile Computing, 2009. CMC'09. WRI International Conference on*. Vol. 2. IEEE, 2009.

[5] Sazak, Nukhet, et al. "An energy efficient MAC protocol for cluster based event driven WSN applications." *Software, Telecommunications and Computer Networks (SoftCOM), 2010 International Conference on*. IEEE, 2010.

[6] Boulfekhar, Samra, LouizaBouallouche, and Mohamed Benmohammed. "S-TDMA: A new MAC protocol for wireless sensor networks." *Distributed Simulation and Real Time Applications (DS-RT), 2012 IEEE/ACM 16th International Symposium on*. IEEE, 2012.

[7] Manjeshwar, Arati, and Dharma P. Agrawal. "APTEEN: A Hybrid Protocol for Efficient Routing and Comprehensive Information Retrieval in Wireless Sensor Networks." *Ipdps*. Vol. 2. 2002.