MULTI-HOP MODEL FOR ENERGY CONSERVATION IN WIRELESS SENSOR NETWORKS

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ABSTRACT

This paper proposes a new multi-hop model for energy conservation in Wireless Sensor Network. The Base Station chooses the Cluster Heads. For this base station opts the randomized approach. Then, a multi-hop communication is carried out where a downstream cluster head aggregates messages from its cluster members and then forwards it to the upstream cluster head in the respective time slot. The proposed protocol is implemented using Python programming language. Simulation results are compared to BMA-MAC, LDC-MAC and MLDC-MAC protocols. The proposed protocol shows better performance in network lifetime.

Keywords: WSN, multi-hop communication, cluster, energy, network lifetime

I. INTRODUCTION

A Wireless Sensor Network (WSN) is a collection of numerous small autonomous devices that collect information from their surroundings and cooperate with each other to send this information to the Base Station (BS) [1]. Such a device (sensor node) is usually equipped with a sensor, processor, memory unit, transceiver (radio), and a power source (battery). As a sensor node is a standalone device, it solely sustains on its battery. When the energy is exhausted, the node is unable to sense, process, communicate, or even carry out any other basic task. This may also affect the functioning of some nearby nodes as they may be using the services of the concerned node to forward their data towards the BS. Hence, the premature death of one or more nodes may have a serious effect on the network connectivity and network traffic flow.

It has been found out that the radio of a sensor node consumes much more energy as compared to all other components [2-4]. Basically, the function of the radio is to send and receive data. However, a node also spends a significant amount of time scanning the channel for possible incoming signals. This is called idle listening. In this process, the concerned node may overhear packets destined for other nodes. Furthermore, it may have to retransmit packets that are corrupted due to collision. All these factors may lead to the untimely death of a node, which is highly undesirable.

One effective solution to all these problems is to toggle the radio between ON and OFF as and when required. This is commonly known as Duty Cycling in which a node alternates between sleep and wakeup modes to reduce battery consumption [2, 3]. This mechanism however, should not disrupt the normal functioning of the network in any way. A medium access mechanism called Time Division Multiple Access (TDMA) implements duty cycling to conserve energy of sensor nodes. It allocates one or more time slots to each sensor node during which it may transmit/receive packets. At all other times, a node may turn off its radio to save energy. This access scheme ensures that the energy draining factors like overhearing, idle listening and collision are minimized.

Clustering is another mechanism to conserve the energy of sensor nodes in which nodes are grouped into clusters and one node in each cluster is appointed as the cluster head (CH) [1, 5]. The primary function of a CH is to collect data from each member node (MN) and send it to the BS. The BS basically acts as a gateway between the WSN and the outside world. Clustering ensures that all the communications within a cluster are short range communications. Furthermore, a CH performs data aggregation and fusion to decrease the number of packets transmitted to the BS. A good number of Medium Access Control (MAC) protocols implement a TDMA-based medium access scheme along with a cluster-based data collection and forwarding technique. In such protocols,
each CH generates and broadcasts a transmission schedule in its cluster. All the member nodes follow this schedule to send/receive packets. Each member node transmits in the allocated slot and keeps its radio OFF during the slots of other member nodes.

Most of the MAC protocols adopt a de-centralized approach towards CH selection. In other words, a sensor node decides whether it should become a CH in a particular round. Hence, the CHs are randomly distributed in the target area. Some regions may be overcrowded with CHs, while others may not be having a CH at all. Moreover, there are no rules governing the size of clusters. Some clusters may be very big in size as compared to others. This leads to non-uniform distribution of load among the CHs in the network. The proposed model, Energy-Efficient Medium Access Control (EE-MAC), considers the proximity of CHs during the CH selection procedure. It is ensured that no region is overcrowded with CHs. The proposed model also sets up some rules to govern the size of clusters. This ensures that no cluster in the network is too big or too small, leading to a uniform distribution of load among all the CHs.

The rest of the paper is organized as follows. Section 2 discusses some basic TDMA-based MAC protocols. Section 3 explains the working of the proposed model in detail. Section 4 describes the implementation and results. Finally, Section 5 concludes this paper.

II. LITERATURE SURVEY

Basically, MAC protocols can be divided into two categories: (i) Carrier Sense Multiple Access (CSMA) based MAC protocols and (ii) TDMA based MAC protocols. In CSMA based MAC protocols, each node contends with its neighbors to gain access to the medium. In TDMA based MAC protocols, each node is assigned one or more time slots depending upon a specific scheduling algorithm. These slots are used by sensor nodes to send/receive packets. CSMA based MAC protocols are scalable and maintain a lower delay as compared to TDMA based MAC protocols. However, CSMA based MAC protocols are not energy efficient due to increased idle listening, overhearing and collisions. Some basic TDMA-based MAC protocols for WSNs have been discussed below.

LEACH [6] is a TDMA-based MAC protocol which divides the time into rounds. Each round consists of (i) Setup phase and (ii) Steady-state phase. In the beginning of the setup phase, each sensor node generates a random number (between 0 and 1) and compares it with a threshold. If the random number is less than the threshold, then the node elects itself as a CH. Next, the node broadcasts an advertisement (ADV) packet. This ADV packet is received by all the non-CH nodes lying in its transmission range. A non-CH node sends a join-request (JOIN-REQ) packet to the CH from which it received the strongest signal (ADV packet). In this way, sensor nodes are grouped into clusters. Each CH broadcasts a transmission schedule to allot data slots to its member nodes. A member node may transmit only in its allocated slot and keeps its radio OFF during all other slots. In the steady state phase, a CH collects data from the member nodes and sends it to the BS.

BMA-MAC [7] divides a round into (i) set-up phase and (ii) steady-state phase. In the set-up phase, sensor nodes are grouped into separate clusters as in LEACH. The steady-state phase is composed of k equal-sized sessions/frames. Each frame consists of three parts namely, (i) contention period, (ii) data transmission period, (iii) and idle period. The contention period comprises small time slots called control slots. A CH allocates one control slot to each of its member nodes. A source node (node that has data) sends a control packet to its CH in the allocated control slot. It stays idle during the other control slots. A non-source node is idle for the complete duration of the contention period. Based on the number of control packets received, a CH sets up and broadcasts a transmission schedule in its cluster. Each source node is allocated one data slot. A source node transmits in the allotted data slot and keeps its radio OFF during the other data slots. A non-source node's radio is OFF for the complete duration of the data transmission period. During the idle period, each node turns its radio OFF to save energy. After collecting data from all the source nodes, a CH sends the aggregate data to the BS.

Energy-Efficient MAC protocol [8] divides a round into two phases namely, (i) setup phase, (ii) and steady-state phase. In the setup phase, sensor nodes are grouped into separate clusters. Each session of steady state phase consists of three parts namely, (i) contention period, (ii) data transmission period, (iii) and idle period. In this protocol, source nodes do not send 1-bit control messages to the CH unlike BMA-MAC. Instead, each source node sends the difference data between the measured value and the predefined threshold. This difference value is a 4-bit message. When a node finds that the measured value is equal to or greater than the predefined threshold, it calculates the difference data and sends it to its CH. The CH compares the difference data that is received from

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3342
all the source nodes. If n source nodes have sent the same difference data, then only one of them is allotted a data slot.

In S-TDMA [9], each frame is partitioned into four periods. In the first period, sensor nodes are grouped into separate clusters as in LEACH. The second period is itself divided into three periods namely, (i) $T_{\text{verify}}$ (a period to verify the number of data accumulated by each member node), (ii) $T_{\text{alloc}}$ (a period to allocate time slots to member nodes), and (iii) $T_{\text{req}}$ (a period to transfer data to CH). In the third period, the BS queries each CH about the number of data collected at the CH. Based on this information, each CH may be allotted the required number of slots by the BS. In the fourth period, CHs forward their data towards the BS in the time slots assigned to them. The ordinary nodes go into sleep mode when they are not sending or receiving data. However, the CHs stay awake continuously to interact with the ordinary nodes and the BS.

LEACH-IR [10] is a multi-hop routing protocol in which the cluster formation process is same as LEACH. However, a node becomes CH in the first round only if its residual energy is above the threshold. Each elected CH broadcasts an announcement packet and waits for join-request packets from non-CH nodes. After receiving join-request packets, a CH broadcasts a transmission schedule in its cluster. Each member node communicates with the CH in the allotted slot. The clusters do not change once they are formed. At the beginning of each round (starting from the second round), the energy level of each CH is checked to see if it is above the threshold. If the energy level of a CH is above the threshold, then it retains its role in the current round. If the energy level is less than the threshold, then the CH appoints a member node as the new CH.

In BEST-MAC [11], clusters are formed in the same way as in LEACH. Each round consists of two phases namely, (i) set-up phase, and (ii) steady-state phase. In steady-state phase, each session consists of a Contention Access Period (CAP). During this period, non-CH nodes that could not join the network send join-request packets to their selected CHs. In the CAP, a CH only sends acknowledgment packets to the requesting nodes. In the announcement period, the CH allocates control slots to these newly joined nodes (apart from allocating data slots to existing member nodes). Data slots are allocated on the basis of the knapsack optimization algorithm in which the optimal solution is the maximum number of nodes with the maximum slot utilization. Each source node turns its radio ON during the allocated slot(s) and transmits data to its CH.

In LDC-MAC [12], CHs broadcast transmission schedules in their clusters after the completion of the setup phase. Within a cluster, each member node is allocated one control slot and one data slot. If a member node has data, it sends a control packet in the allocated control slot. The control packet informs the CH that the node has data to transmit. The CH keeps its radio ON during the corresponding data slot to receive data from the node.

In BEE-MAC [13], a source node turns its radio ON at the beginning of the control period. The objective is to analyze control packets received from other source nodes and identify the data slots that are being claimed. This information is then compiled to find out which data slots are still free. The source node can claim one or more of these data slots in its control message to the CH. Unlike LDC-MAC, all the unused slots appear at the end of a frame in BEE-MAC.

All the MAC protocols discussed above adopt a distributed approach towards CH selection. A sensor node itself decides whether it should become a CH in the current round. This results in a completely random distribution of CHs in the network. Hence, some regions may be overcrowded with CHs, while other regions may not have a CH at all. The proposed model prevents any region from being overcrowded with CHs by taking into account the proximity of CHs when they are being selected. Furthermore, the proposed model sets up some rules to govern the size of clusters. This ensures that no cluster in the network is too big or too small. The next section explains the proposed model in detail.

III. MATERIALS AND METHODS

The assumptions of the proposed model are: (i) the network functions as an Event Detection Network, (ii) the target area is composed of equal-sized grids, and (iii) each Sensor Node (SN) can communicate with the Base Station (BS) directly. Figure 1 and Figure 2(a) shows the depiction of network. The algorithmic steps of the proposed model are as follows.

1. At the beginning of a round, each SN sends a HELLO message to the BS.
HELLO \rightarrow SNid + SNre + SNloc

(SNid = SN identifier, SNre = SN residual energy, SNloc = SN location)

1 The BS randomly selects a Cluster Head (CH) in each grid such that the SNre >= Threshold Energy (TE) which is predefined. However, to ensure load balance, if a node is selected as a CH in this round, then it won’t be selected as a CH until all the other nodes in the grid have been selected as CH once.

![Figure 1. Nodes deployed in equal sized grids](image)

1 The BS broadcasts a SELECT message in the target area. The SELECT message contains an information tuple for each CH:

SELECT \rightarrow SNid, SNid

The first SNid represents the identifier (ID) of the CH and the second SNid represents the ID of the upstream CH.

![Figure 2(a). A depiction of network](image)
Note: For each CH, the upstream CH lies in the grid above it in the same column. If a CH lies in the upper most row, then the second value in the tuple will represent the ID of the BS

1. Each selected CH broadcasts an Advertisement (ADV) message in the target area.

2. A non-CH sends a JOIN-REQ message to the CH from which the strongest ADV signal has been received.

Note: The non-CH node has already recorded the IDs of all the CHs (in a LIST) in the decreasing order of the ADV message signal strength.

1. Similarly, a CH also receives a JOIN-REQ message from its downstream CH (if any). In our example, CH-2 receives a JOIN-REQ message from CH-1.

2. After receiving JOIN-REQ messages, a CH broadcasts an Acknowledgement (ACK) message that contains the ID of the downstream CH and the IDs of all the non-CH nodes whose requests were accepted.

3. The important thing to note here is that JOIN-REQ messages from all the non-CH nodes may not be accepted. The decision is based on whether the number of requests is <= the total number of requests that can be accepted.

If so, then all the requests are accepted. Otherwise, the extra requests are rejected. Requests are usually accepted in the FIFO order. The motive behind this approach is not to load any CH with too much traffic compared to other CHs in the network.

1. A rejected non-CH node sends a JOIN-REQ message to the next CH in its LIST and waits for the ACK message. If no ACK message is received, it means that the cluster has reached its maximum size. If an ACK is received but the request of this non-CH node has not been accepted, it means that the CH has accepted one or more new requests (but not this one.) The non-CH continues its attempt until it is included in a cluster.

2. After cluster formation, each CH broadcasts a transmission schedule to allocate time slots (in a time frame) to its cluster members.

3. However, a CH broadcasts a transmission schedule only after its downstream CH has broadcasted a transmission schedule.

![Figure 2(b). Data packet transmission schedule](image-url)

1. In the example shown above in Figure 2(b), CH-A first broadcasts a transmission schedule in which it allocates slot 1 (the first slot in the time frame) to cluster member 33 (33 is the ID of the cluster member),
slot 2 to cluster member 4 and so on. After the broadcast by CH-A, CH-B broadcasts a transmission schedule to allocate time slots to its cluster members. The transmission schedule also contains the time slot allocated to CH-A in which CH-B can receive the aggregate packet from CH-A. In this example, slot 6 is used for this purpose. After the broadcast by CH-B, CH-C broadcasts a transmission schedule to allocate time slots to its cluster members. Time slot 7 is allocated to CH-B so that CH-B can send the aggregate packet to CH-C. Time slot 8 can be used by CH-C to transmit the aggregate packet to the BS using CSMA.

Note: Frames are equal-sized. Frame length can be decided by the BS after it receives HELLO messages from the sensor nodes. This is because with the decrease in the number of nodes (caused by node deaths) the frame length may also be decreased. The BS includes the frame information (e.g., frame length, time slot lengths etc.) in the SELECT message or sends a separate message regarding this.

1 A source node (cluster member that has data) transmits data in its own slot and keeps its radio OFF in all other slots. If a cluster member has no data, it keeps its radio OFF in its own slot also. Similarly, if CH-B does not receive any data from its cluster members or CH-A, then it keeps the radio OFF in slot 7.

2 To reduce idle listening, a CH turns its radio ON for a very short duration at the beginning of each slot. This period is called the Verification (VER) Period. If the CH doesn’t hear from the cluster member or the downstream CH during this period, then the CH turns its radio OFF. Otherwise, the CH keeps the radio ON till the end of the slot.

3 A new round begins after n frames, and the whole process is repeated.

IV. RESULTS AND DISCUSSION

The protocols, LDC-MAC[12], MLDC-MAC[14], BMA-MAC[13] and proposed MAC are simulated using the Python Programming Language. In all the simulations, the First Order Radio Model [7] is used to calculate the energy consumption in sensor nodes. Table 1 shows the parameters that are used in the simulations. For the first and second simulation, a 100 × 100 m² area is considered that is equally partitioned into 16 grids while 100 or 200 nodes are deployed respectively. For the third and fourth simulation, the area is 100 × 100 m², and the same number of nodes are deployed but the area is partitioned equally into 25 grids. For the fifth and sixth simulation, the area is halved to 50 × 50 m². The desired percentage of CHs is set to 25% in both cases. The proposed MAC is also simulated in 100 × 100 m² area partitioned into 16 equal sized grids. The BS is assumed to be located outside the deployment area but very close to it. Figure. 3 shows the graph that is generated after the first simulation. Table 2 shows when the first node and the last node of each protocol dies in the first simulation. Similarly, Figure. 4 shows the graph that is generated after the second simulation and Table 3 shows when the first node and the last node of each protocol dies in the second simulation.

Table 1: Simulation Parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployment area</td>
<td>50 × 50 m², 100 × 100 m²</td>
</tr>
<tr>
<td>Initial energy of node</td>
<td>5 Joules</td>
</tr>
<tr>
<td>Eelec (Energy spent in running the transmitter or receiver circuitry)</td>
<td>50 nJ/bit</td>
</tr>
<tr>
<td>Eidle (energy spent in idle mode)</td>
<td>40 nJ/bit</td>
</tr>
<tr>
<td>camp (Energy spent in running the transmit amplifier)</td>
<td>100 pJ/bit/ m²</td>
</tr>
<tr>
<td>Threshold energy</td>
<td>0.1 Joules</td>
</tr>
</tbody>
</table>
There are various definitions for Network lifetime. It can be defined as the time before the first node in the network is dead or some nodes are dead. In this paper the network lifetime is assumed as the time before the first node in the network is dead. From Figure 3, it is observed that proposed MAC significant improvement in the network lifetime compared to BMA-MAC, in the first simulation (the round number in which the first node dies is 434 in BMA-MAC and 2743 in proposed MAC).

![Figure 3](image3.jpg)

**Figure 3:** Number of Dead Nodes vs Number of Rounds when 100 nodes are deployed in a 100 × 100 m² area, partitioned into 16 grids with 25% as the desired percentage of CHs.

![Figure 4](image4.jpg)

**Figure 4:** Number of Dead Nodes vs Number of rounds when 200 nodes are deployed in a 100 × 100 m² area, partitioned into 16 grids with 25% as the desired percentage of CHs.

For the third simulation, a 100 × 100 m² area is considered and 100 nodes are deployed. For the fourth simulation, the 200 nodes are deployed in a 100 × 100 m² area. The desired percentage of CHs is set to 25% in www.turkjphysiotherrehabil.org
both cases. Figure 5 shows the graph that is generated after the third simulation. Table 4 shows when the first node and the last node of each protocol dies in the third simulation. Similarly, Figure 6 shows the graph that is generated after the fourth simulation and Table 5 shows when the first node and the last node of each protocol dies in the fourth simulation.

Table 3: Round number in which the first and the last node of each protocol dies when 200 nodes are deployed in a 100 × 100 m² area, partitioned into 16 grids with 25% as the desired percentage of CHs.

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Round number in which first node dies</th>
<th>Round number in which last node dies</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMA-MAC</td>
<td>343</td>
<td>421</td>
</tr>
<tr>
<td>LDC-MAC</td>
<td>619</td>
<td>832</td>
</tr>
<tr>
<td>MLDC-MAC</td>
<td>1236</td>
<td>1761</td>
</tr>
<tr>
<td>proposed MAC</td>
<td>2779</td>
<td>3275</td>
</tr>
</tbody>
</table>

In the second simulation, from Figure 4 proposed MAC increases the network lifetime by approximately 3.6 times compared to MLDC-MAC. Thus, proposed MAC performs relatively better.

Figure 5: Number of Dead Nodes vs Number of rounds when 100 nodes are deployed in a 100 × 100 m² area, partitioned into 25 grids with 25% as the desired percentage of CHs.
Figure 6: Number of Dead Nodes vs Number of rounds when 200 nodes are deployed in a $100 \times 100 \text{ m}^2$ area, partitioned into 25 grids with 25% as the desired percentage of CHs.

Table 5: Round number in which the first and the last node of each protocol dies when 200 nodes are deployed in a $100 \times 100 \text{ m}^2$ area, partitioned into 25 grids with 25% as the desired percentage of CHs.

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Round number in which first node dies</th>
<th>Round number in which last node dies</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMA-MAC</td>
<td>474</td>
<td>523</td>
</tr>
<tr>
<td>LDC-MAC</td>
<td>638</td>
<td>728</td>
</tr>
<tr>
<td>MLDC-MAC</td>
<td>1282</td>
<td>1827</td>
</tr>
<tr>
<td>proposed MAC</td>
<td>2560</td>
<td>2954</td>
</tr>
</tbody>
</table>

Figure 7: Number of Dead Nodes vs Number of rounds when 100 nodes are deployed in a $50 \times 50 \text{ m}^2$ area, partitioned into 25 grids with 25% as the desired percentage of CHs.
Table 6: Round number in which the first and the last node of each protocol dies when 100 nodes are deployed in a 50 × 50 m² area, partitioned into 25 grids with 25% as the desired percentage of CHs.

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Round number in which first node dies</th>
<th>Round number in which last node dies</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMA-MAC</td>
<td>510</td>
<td>800</td>
</tr>
<tr>
<td>LDC-MAC</td>
<td>715</td>
<td>1484</td>
</tr>
<tr>
<td>MLDC-MAC</td>
<td>1869</td>
<td>2242</td>
</tr>
<tr>
<td>proposed MAC</td>
<td>3121</td>
<td>3345</td>
</tr>
</tbody>
</table>

Figure 8: Number of Dead Nodes vs Number of rounds when 200 nodes are deployed in a 50 × 50 m² area, partitioned into 25 grids with 25% as the desired percentage of CHs.

Table 7: Round number in which the first and the last node of each protocol dies when 200 nodes are deployed in a 50 × 50 m² area, partitioned into 25 grids with 25% as the desired percentage of CHs.

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Round number in which first node dies</th>
<th>Round number in which last node dies</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMA-MAC</td>
<td>463</td>
<td>510</td>
</tr>
<tr>
<td>LDC-MAC</td>
<td>682</td>
<td>771</td>
</tr>
<tr>
<td>MLDC-MAC</td>
<td>1903</td>
<td>2120</td>
</tr>
<tr>
<td>proposed MAC</td>
<td>3132</td>
<td>3266</td>
</tr>
</tbody>
</table>

From Table 6 and Table 7 it is observed that proposed MAC shows improvement in the network lifetime compared to BMA-MAC and approximately 4.5 times compared to LDC-MAC in the fifth simulation. In the sixth simulation, proposed MAC increases the network lifetime by 1.64 times compared to MLDC-MAC. So, the proposed MAC performs relatively better in the presence of dense nodes (is increased from 100 to 200) keeping the number of CHs constant as shown in Figure 7 and Figure 8.
V. CONCLUSION

Proposed MAC has a randomized approach towards CH election, unlike BMA-MAC, LDC-MAC and MLDC-MAC. In the beginning, the BS is only involved in sending messages. The randomized approach adopted by the BS, ensures that the CHs are evenly distributed throughout the network. Proposed MAC establishes multi-hop paths between CHs and the BS. This removes the need of long-range communications that are unavoidable in BMA-MAC. Each CH broadcasts transmission schedule after its downstream CH has broadcasted its transmission schedule and each CH also allot one slot for its downstream CH to transmit the accumulated data in that particular time slot. Thus, the energy is saved in communication. The simulation results show that proposed MAC extends the network lifetime compared to BMA-MAC, LDC-MAC and MLDC-MAC.

References