Extending the Lifetime of WSNs with Maximum Energy Selection Algorithm (MESA)

Korhan CENGİZ
Electrical-Electronics Engineering Department
Kadir Has University
Istanbul, Turkey
korhan.cengiz@stu.khas.edu.tr

Tamer DAĞ
Computer Engineering Department
Kadir Has University
Istanbul, Turkey
tamer.dag@khas.edu.tr

***Abstract*— The limited battery supply of a sensor node is one of the most important factors that limit the lifetime of the WSNs. As a consequence, increasing the lifetime of WSNs through energy efficient mechanisms has become a challenging research area. Previous studies have shown that instead of implementing direct transmission or multi-hop routing, clustering can significantly improve the total energy dissipation and lifetime of a WSN. The traditional LEACH and LEACH based algorithms have evolved from this idea. In this paper, we propose a fixed clustering routing algorithm for WSNs which selects the node with maximum residual energy for the following rounds according to a threshold level. The Maximum Energy Selection Algorithm (MESA) can improve the lifetime of the network and reduce the energy dissipation significantly. Our studies have shown that when compared with LEACH, and LEACH based algorithms such as ModLEACH and DEEC, MESA gains for the lifetime extension and energy dissipation is very important.**

Keywords—Wireless Sensor Networks; Clustering; Energy-Efficient Routing

I. Introduction

Wireless Sensor Networks (WSN) are able to perform data collection, aggregation and communication from an environment through many distributed individual sensor nodes through radio communications. By sensing the environmental events within their respective ranges, the sensor nodes collect data of interest and communicate the data through the nodes until the data finally reaches to the base-stations (BSs) for final processing. WSNs have become increasingly useful in a variety of critical applications, such as environmental monitoring, smart offices, battlefield surveillance, and transportation traffic monitoring.

According to the participating way of the nodes, routing protocols can be classified into three categories, namely, direct transmission, multi-hop routing and clustering protocols. With direct transmission, each sensor node directly transmits its sensed data to a remote receiver. Thus, the sensor nodes do not require any type of communication amongst themselves. With multi-hop routing, each sensor node transmits its data to the remote receiver through other sensor nodes in the network. With clustering, a cluster head (CH) is responsible for conveying any information obtained by the nodes in its cluster. The CHs may aggregate and compress the data before sending it to the BS. It has been shown that clustering is an efficient and scalable way to organize WSNs although the energy consumption of the CHs is more than the regular sensor nodes.

LEACH (low-energy adaptive clustering hierarchy) [1, 2, 3] is one of the most popular distributed cluster based routing protocols for WSNs. In LEACH, each data transmission round consists of a set-up and steady-state phase. In the set-up phase, some of the nodes in the network elect themselves to be local CHs with a certain probability. As a node is elected to be a CH, it broadcasts an advertisement message which contains the information qualifying for the CH. After the advertisement of the CHs, the remaining nodes join to a cluster by finding the closest CH. In the steady-state phase, cluster members gather data continuously and transmit these data to certain CHs in certain slots. The CHs fuse these data and forward the collected data to the BS. LEACH protocol can provide a significant amount of energy saving when compared to direct transmission or multi-hop routing.

On the other hand, in LEACH, a cluster topology changes at every transmission round due to the randomized cluster formation structure. Selection of new CHs and forming new clusters for every round induce more energy consumption and bring extra network costs. The same problem is also observed in other LEACH based protocols.

In this paper, to overcome this problem, we propose maximum energy selection algorithm (MESA) for WSNs. MESA not only reduces the overall energy dissipation but also increases the network lifetime significantly. MESA uses threshold based CH selection and selection of the node with maximum residual energy approaches together. Instead of changing CHs for every round, MESA uses fixed clustering approach. Section II, describes the details and operation of MESA and its phases.

Our results indicate that significant energy savings can be obtained with MESA. To illustrate the impact of MESA, it is compared with LEACH, ModLEACH and DEEC. While the simulation environment is described in Section III, the performance comparison of MESA with other algorithms is described in Section IV. Our paper concludes with conclusions and the future work described in Section V.

II. Maximum Energy Selection Algorithm (MESA)

The proposed MESA algorithm divides the WSN into fixed clusters whose members do not change through the entire lifetime of the WSN. A CH for each cluster is responsible for collecting and delivering the sensed data to the base station.

MESA works in two phases. The first phase is the set-up phase where the clusters are formed, and the second phase is the steady-state phase where data transmission occurs. Different from LEACH and other LEACH based protocols, the set-up phase is not repeated for every round. This is achieved by using fixed clusters, which in turn results in significant energy savings.

Under MESA, the initial CHs are selected randomly and the CHs broadcast an announcement message to inform the other sensor nodes. All the remaining sensor nodes join to their nearest clusters at the initial set-up phase.

The following subsections explain the operation of the set-up and steady-state phases of MESA in detail.

1. Set-Up Phase

With the deployment of the sensors, the MESA algorithm initiates with the set-up phase, as illustrated in Fig. 1. Each deployed sensor node self-elects itself as a CH or a regular node. The CH nodes later form the clusters by broadcasting its identity so that neighbor nodes join its cluster. Then, the schedule for collecting data from cluster member nodes is determined.

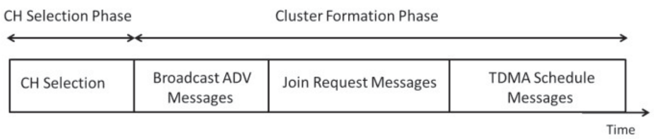

Fig. 1. The Set-Up phase for MESA algorithm.

a. Cluster Head Selection Phase

In MESA, the clusters are formed randomly with the deployment of the sensors where each sensor node makes an autonomous decision without any centralized control.

Suppose that the desired number of clusters for the sensor network is denoted by *nc* (number of clusters) and the number of sensor nodes is *N*. Thus, each node has a $P_{CH} = nc / N$ chance to be elected as a CH.

Each node *i* ($1 \leq i \leq N$) in the network takes a random probability *Pi* to be elected as a CH in the set-up phase.

If $Pi \leq P_{CH}$, then the node *i* elects itself as a CH. Otherwise, that node continues as a regular cluster member. However, a node which is not elected as a CH in the set-up phase has a chance to become a CH in the subsequent rounds. The main objective of MESA is to abuse the energy of a CH node before electing a new CH node with the maximum residual energy. By this way, the number of CH changes and the corresponding overhead is minimized. But, whenever a CH node does not have enough energy to continue, other cluster members can be elected as a CH during the rounds in the steady-state phase.

b. Cluster Formation Phase

Each node which has elected itself as a CH needs to notify the remaining nodes about the selection and later form its cluster for the MESA algorithm.

To distribute the identity of the CHs in the network, each CH node broadcasts an advertisement message (ADV) using a carrier-sense multiple access (CSMA) MAC protocol [1]. The ADV message includes the CH node's ID.

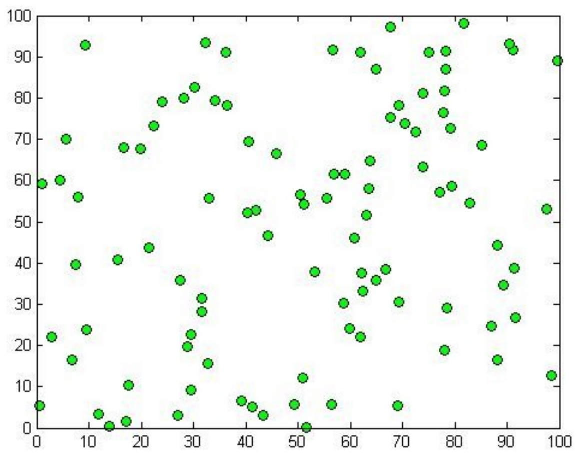

Fig. 2. The randomly deployed sensor nodes in a WSN.

When the ADV messages are broadcasted in the network, each regular node receiving these messages needs to decide to which cluster it belongs by choosing the CH that requires minimum communication energy. A regular node chooses to join the CH with the highest received signal strength by replying back a join-request message to the associated CH using CSMA MAC protocol. The join-request message contains the regular node's ID and the ID of the CH that the node wants to join to. With the join-request messages, the CHs learn about the identity of the members that belong to their clusters. With this information, the CHs prepare a TDMA schedule for members for transmitting their sensed data. The length of this schedule is fixed and it is determined according to the number of nodes in each cluster.

After the reception of the TDMA schedule by the cluster member nodes, the set-up phase is completed and data transmission with the steady-state phase is ready to start. Fig.

2 shows an example of randomly deployed sensor nodes in a WSN and Fig. 3 shows an example illustration of the clusters formed after the MESA set-up phase.

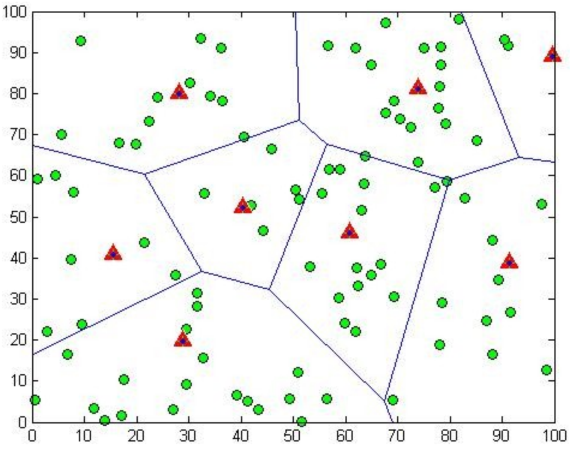

Fig. 3. The cluster formation and CHs after the set-up phase.

2. *Steady-State Phase*

In the steady-state phase, the CHs start to collect the sensed data from their cluster and transfer the gathered data to the BS. While the CHs are collecting sensed data from their associated members, they also collect residual energy level information of the members for each round. This information helps to choose the next CH, when the current CH energy is drained.

During the steady-state phase, the CH should keep its receiver on at all times to receive all the data from the nodes in its cluster and it should decide whether a CH change needs to be made. Once the cluster head receives all the data, it can operate on the data, and then data are transmitted from the CH to the BS.

The steady-state phase of the MESA algorithm repeats itself for the entire lifetime of the WSN and is called as a round. Fig. 4 shows a typical round for the MESA algorithm. A round has two sub phases: data transmission and CH change decision.

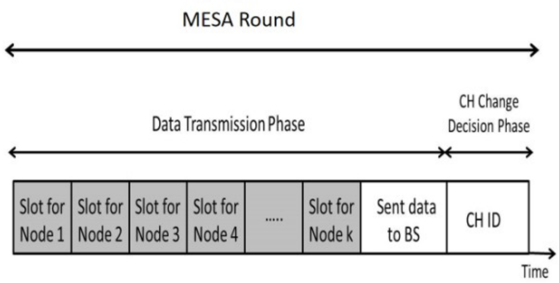

Fig. 4. The MESA Round. Data transfers and changing of CHs if needed occur during the steady-state phase.

a. *Data Transmission Phase*

This phase is divided into slots assigned for each of the cluster members, where the member nodes transmit their data to the CH. The duration for each slot is fixed, thus the time to transmit depends on the number of member nodes in the cluster.

A member can only transmit data during its allocated time interval. Other member nodes sleep until their transmission time begins, thus extra energy savings become possible. By this way, collision among cluster members' data transmission is prevented. If a node's battery is completely drained or if its operation stops, the assigned time slot will remain idle.

When the data collection from the cluster members is completed, the CH transmits the data to the base station.

b. *Cluster Head Change Decision Phase*

The MESA algorithm uses fixed clusters, thus a sensor node which becomes a member of a cluster during the set-up phase stays as a member of the same cluster for the entire lifetime of the sensor network. However, the CH change may occur when the energy level of the current CH falls below a threshold level.

When the data transmission phase of a round is completed, the CH needs to determine whether it will stay as a CH for the next round or appoint a new CH. This decision is made based on a threshold value. The threshold value (ThV) is quite important for MESA because it identifies when the CH needs to be changed. It should be determined very carefully because it determines the survival status of the CHs. If it is determined as a very low value, the battery of the CH may drain and the network connectivity can be broken off. If it is determined as a high value, new CHs will be needed to be chosen for almost every round bringing in network and clustering costs. If the threshold value is selected to be equal to initial energy of a node, the CHs will need to be changed in every cluster for every round and thus, MESA will approximately work similar as LEACH. The impact of the threshold value on the lifetime performance of MESA is investigated in simulation results of this study.

In MESA, for each round, CHs collect residual energy of each cluster member while they are collecting sensed data from the cluster members according to the algorithm which is shown below. The residual energy information is used for CH selection for the following round when the residual energy drops below a threshold level.

```
i=1;    // cluster i
while ( i <= number of clusters)
   // Data transmission phase
   CH(i) collects data and energy level from
members
   CH(i) sends aggregated data to the BS
   //CH change decision phase
   if (Residual Energy of CH(i) < ThV)
     select  the member with max. residual
energy
     mark new member ID to CH ID field
   else
     mark current CH(i) ID to CH ID field
i=i+1
end
```

Fig. 5. Flowchart for a MESA round

III. Simulation Environment And Parameters

Matlab is used as the simulation platform to emulate the MESA, LEACH, ModLEACH and DEEC protocols in order to compare their performances. These algorithms are compared for various performance metrics described in the next section. For the simulations, *100* identical sensor nodes are deployed randomly in a *100 m x 100 m* square area. The simulations are conducted with *100* independent iterations for each algorithm. The base station with coordinates *(150, 50)* is placed outside the sensor deployment area. Table 1 summarizes the parameters used during the simulation study.

TABLE I. Simulation Environment Parameters

Parameters	Values
Network area	100 m x 100 m
Number of nodes	100
Base station coordinates	(150,50)
Initial energy per node	2 J
Data packet size	6400 bits
Control Packet Size	200 bits
Transceiver Energy (E_{elec})	50 nJ/bit
Aggregation Energy per Bit (E_{DA})	5 nJ/bit/signal
Free Space Amplifier Energy (ε_{fs})	10 pJ/bit/m^{2}m^2
Multipath Amplifier Energy (ε_{mp})	0.0013 pJ/bit/m^{4}m^4
Iterations	100

IV. Simulation Results and Comparison of MESA

In this section, the performance comparisons of MESA, LEACH, ModLEACH and DEEC protocols are made for threshold value, lifetime and residual energy. LEACH was briefly discussed in the introduction section. Instead of same amplification energy level usage for all transmissions in LEACH, Modified LEACH (ModLEACH) [4] uses low energy level for intra cluster communications. If a node is selected as a CH, it uses high power amplification level in ModLEACH. Threshold based CH changing mechanism is also proposed in ModLEACH to provide energy efficiency.

In DEEC [5], the CHs are selected by a probability based on the ratio between residual energy of each node and the average energy of the network.

1. Impact of the ThV

Fig. 6 compares the performance of LEACH and MESA for different ThVs by illustrating the number of dead nodes vs. round number. From this figure, it can be observed that, as the ThV increases the network lifetime decreases. A lower ThV also results an earlier first node death as MESA abuses the CHs before selecting a new CH. However, the lifetime gain for any ThV is very significant.

Note that, the lifetime of LEACH for the same network is approximately 3200 rounds and a significant improvement for network lifetime is achieved with MESA.

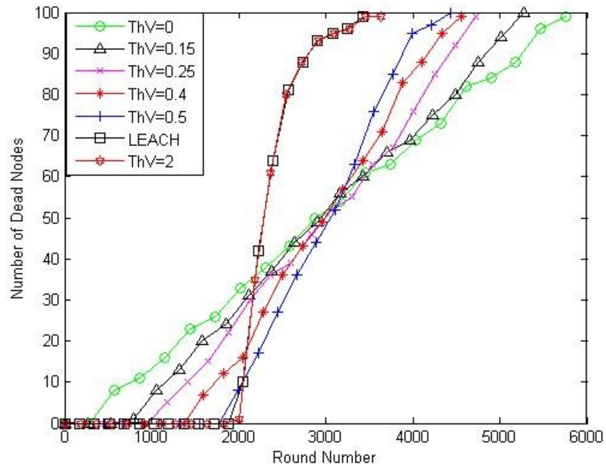

Fig. 6. Number of Dead Nodes according to the different ThVs.

2. System Lifetime

For the rest of the simulations based on the observations made in the previous subsection, the ThV of MESA is chosen as *1/40* of initial energy of a node.

Fig. 7 shows the number of alive nodes vs. round number of LEACH, ModLEACH, DEEC and MESA. Under MESA, the network lifetime increases from *3237* rounds to approximately *5500* rounds, a *57%* improvement compared to LEACH and approximately 50% improvement compared to ModLEACH. Although, node deaths start earlier under MESA, since the CHs are abused, the rate of the number of dead node increases is significantly less and this yields to a longer lifetime.

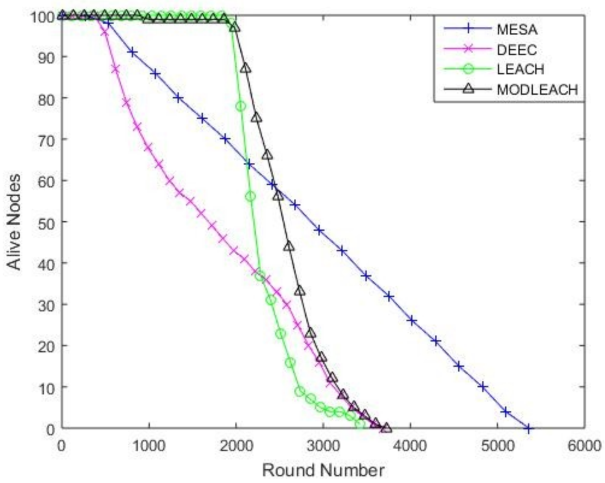

Fig. 7. Round Number vs Alive Nodes.

One major difference between other protocols and MESA can also be observed from Fig. 7. Immediately following the first node death under LEACH and LEACH based protocols, the remaining node deaths will happen swiftly. But with MESA, node deaths are scattered evenly for the network lifetime.

3. *The Residual Energy*

Fig. 8 illustrates the total residual energy of the WSN for other protocols and MESA for a selected $ThV = 0.05\ J$. With fixed clustering, full utilization of the CHs and selecting the sensor node with maximum residual energy, it can be observed that MESA provides a significant energy savings when compared to LEACH, DEEC and ModLEACH. When the network lifetime ends under other protocols, MESA still maintains approximately *15%* of its total initial energy.

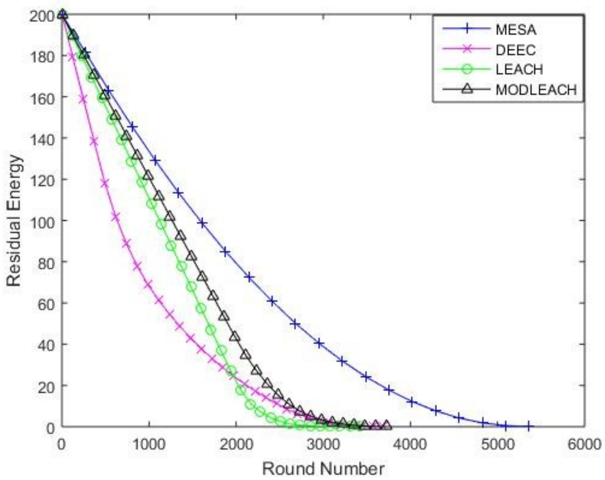

Fig. 8. Comparison of Total Residual Energy

When the figures are examined carefully it is clearly obtained that MESA outperforms other algorithms in terms of residual energy, number of alive nodes and lifetime. MESA provides significant energy savings. It also gives opportunity for load balancing in the network.

V. Conclusions And Future Work

Enabling energy-efficiency [6, 7, 8], prolonging lifetime and promoting greening solutions [9] for WSNs has become an essential research area. By using fixed number of clusters and reducing the number of CH changes, MESA minimizes the cluster formation overhead. When compared with LEACH and other protocols significant improvements are obtained in terms of energy usage and network lifetime. MESA extends the lifetime of the WSN, while reducing the energy usage.

In MESA, it has been observed that clusters that are farthest from the base station is prone to consume more energy due to the distance factor. To improve the MESA algorithm, a smart CH selection mechanism can be used at the set-up phase of the algorithm. Also, putting certain percentage of the nodes in each cluster into sleep mode can prolong the lifetime of the MESA algorithm.

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