An Energy Efficient Clustering Scheme with Mobile Sink for Heterogeneous Multi-level Wireless Sensor Networks

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Abstract— In this paper an Energy Efficient Clustering Scheme with Mobile Sink (EECSMS) for Heterogeneous Multi-level Wireless Sensor Networks is proposed. In EECSMS, the cluster-heads (CHs) are elected by a probability based on the ratio between residual energy of each node and the average energy of the network, the sink or base station (BS) moves towards each CH by a distance proportional to that CH’s probability. Furthermore, normal nodes select the optimal cluster-head based on the cost function.

Finally, Simulation using MATLAB software shows that our proposed protocol achieves longer lifetime, stability period and more effective messages to BS than LEACH[1], DEEC[2], EDCS[3] in multi-level heterogeneous environments.

Keywords— wireless sensor networks (WSNs); BS movement; cost function, lifetime; multi-level heterogeneous environments.

I. INTRODUCTION

The advancement in the areas of Micro-Electro-Mechanical Systems (MEMS) and wireless communication technologies, have allowed the rapid development of wireless micro-sensors for wireless communications. The WSNs is composed by a large number of micro sensors called nodes communicating with each other through radio links independently and randomly distributed over an area of interest. nodes are powered by battery, which is impossible to get recharged after deployment. As a large part of energy is consumed when communications are established, so it is imperative to develop an energy efficient routing protocol and taking into account the constraints by these sensors (lifetime, Quality of Service etc.).

For this reason Several routing protocols have been designed for wireless sensor networks to satisfy energy utilization and efficiency requirement. Efficiency, scalability and lifetime of wireless sensor network can be enhanced using hierarchical routing. Here, sensors organize themselves into clusters and each cluster has a cluster head [4]. The main role of the cluster head is to provide data communication between sensor nodes and the base station efficiently [5].

In WSN the BS can be either a mobile or a fixed node that connects the sensor network to other types of network such as Internet or satellite where reported data are accessible to the user [6]. However , The use of mobile sinks can potentially provide energy-efficient data collection with well-designed networking protocols for WSNs [7]. When using the mobile sink in practice, the sink nodes can be attached to vehicles, animals or people that can move inside the region of interest. Usually, static sink nodes are not very efficient [8]. Although single hop data collection is feasible in networks deployed in small regions, the multi-hop transmission manner is more commonly used in large sensor areas [9]. Intuitively, mobile sinks gain advantages by mitigating the so-called hot spot problem, balancing energy among sensor nodes, prolonging network lifetime, reducing transmission latency and improving network performance by periodically accessing some isolated nodes into the network.

Extending network lifetime is the most important design issue in WSNs. In this paper we propose an EECSMS for Heterogeneous Multi-level WSNs in which the use of mobile sink permits to minimize CH-to-BS transmission distances, thereby minimizing the energy consumption of the CHs nodes, which constitutes the majority of the energy consumption of the entire network. Hence the network’s lifetime is extended.

The remainder of the paper is structured as follows: Heterogeneous model for wireless sensor network in Section 2. In section 3, describes The EECSMS Protocol, section 4, simulations and results, section 5 discussion . We draw the conclusion in Section 6.

II. HETEROGENEOUS MODEL FOR WSNs

There are three common types of resource heterogeneity in sensor nodes: computational heterogeneity, link heterogeneity and energy heterogeneity [10]. In this paper we just consider the heterogeneous networks with nodes heterogeneous in their initial amount of energy. Assume that there are N sensor nodes, which are all different from each other, uniformly
distributed in an MxM square region. The cluster head(s) formed aggregates the data received from normal nodes belonging to their communication range and transmits them to the next hop cluster head closer to the BS or to the BS depending on the cluster formation and the shortest distance between the cluster head and the BS.

In multi-level heterogeneous WSNs, each node is equipped with a random initial energy over the interval of [E_0, E_0(1+\lambda)]. where E_0 is the lower bound and parameter \lambda is a constant (\lambda > 0) which determines the value of the maximal initial energy. Usually, the heterogeneous network will become homogeneous when \lambda = 0. Mathematically, we can express our network as Set S = \{ s_i | s_i = (x_i, y_i), s_i \in \mathbb{R}^2, i = 1, 2, \cdots, N \}.

Each sensor node s_i is equipped with initial energy E_0 (1 + \lambda_i), which is \lambda_i times more energy than the lower bound E_0.

The total initial energy of the multi-level heterogeneous networks is given by:

\[ E_{\text{total}} = \sum_{i=1}^{N} E_0 (1 + \lambda_i) = E_0 \sum_{i=1}^{N} (1 + \lambda_i) \tag{1} \]

From equation (1), the total initial energy in a heterogeneous WSNs can be treated as \( \sum_{i=1}^{N} (1 + \lambda_i) \) nodes which are equipped with initial energy of E_0 in a homogeneous WSNs.

**III. THE EECSMS PROTOCOL**

In this section, we present details of our EECSMS protocol. Our proposed protocol implements the same idea of probabilities for CHs selection based on initial, remaining energy level of the nodes and average energy of network as supposed in DEEC[2].

**4.1 Estimating Average Energy of Network**

Let us assume the ideal scenario where all sensor nodes are uniformly distributed and will die at the same time as a result of load balancing. The average energy of the round from [2] is given by:

\[ \overline{E} = \frac{1}{R} E_{\text{total}} \left(1 - \frac{1}{R}\right) \tag{2} \]

where R is the total rounds of the network lifetime. and can be estimated from [2] as:

\[ R = \frac{E_{\text{total}}}{E_{\text{round}}} \tag{3} \]

where \( E_{\text{round}} \) is the energy dissipated in the network during single round. We use the same radio energy dissipation model that was proposed in [1][11].

The total energy dissipated \( E_{\text{round}} \) can be approximated to:

\[ E_{\text{round}} = L \left(2N E_{\text{elec}} + NE_{\text{DA}} + ke_{\text{mp}} d_{\text{toBS}}^4 N_{\text{ts}} d_{\text{toCH}}^2\right) \tag{4} \]

where, 
\( E_{\text{elec}} \) : Energy dissipation to run the radio
\( K \) : Number of clusters.
\( E_{\text{DA}} \) : Data aggregation cost expended in CH.
\( d_{\text{toBS}} \) : Average distance between CH and BS.
\( d_{\text{toCH}} \) : Average distance between cluster members and CH.
\( L \) : Packet size.

Assuming that the nodes are uniformly distributed in an MxM square area \( \mathcal{M} \), we can get [11]:

\[ d_{\text{toBS}} = \int \int \sqrt{x^2 + y^2} \frac{1}{M} \ dM^2 = 0.3825 \mathcal{M} \tag{5} \]

\[ d_{\text{toCH}} = \sqrt{(x^2 + y^2)p(x,y)dxdy} = \frac{M}{\sqrt{2\pi}} \tag{6} \]

We can find the optimum number of cluster \( k_{\text{opt}} \) by setting the derivative of \( E_{\text{round}} \) with respect to \( k \), to zero, we can get:

\[ k_{\text{opt}} = \left(\frac{N}{\sqrt{2\pi}} \right) \sqrt{\frac{2\pi}{k_{\text{emp}}}} \tag{7} \]

The optimal probability of a node to become a cluster head, \( p_{\text{opt}} \), can be calculated as follows:

\[ p_{\text{opt}} = \frac{k_{\text{opt}}}{N} \tag{8} \]

**4.2 Cluster Head Selection**

At start of each round, node \( s_i \) decides whether to become a CH or not based on threshold calculated by the following equation and as supposed in [1][2]:

\[ T(s_i) = \begin{cases} \frac{p_i(s_i)}{1-p_i(s_i)(\text{mod} \ 1/p_i(s_i))} & \text{if } s_i \in G \\ 0 & \text{otherwise,} \end{cases} \tag{9} \]

where, \( G \) is the set of nodes eligible to become CH for round r and \( p_i(s_i) \) is the desired percentage of CH in real scenarios. And \( p_i(s_i) \) can be calculated as follows:

\[ p_i(s_i) = \left(\frac{N N_{\text{tot}}}{(N \sum_{i=1}^{N} \lambda_i)}\right)^{-1} \frac{E_{\text{res}}(i)}{E(r)} \tag{10} \]

where \( E_{\text{res}}(i) \) is the residual energy of node \( s_i \) in \( r \)th round. In each round \( r \), when node \( s_i \) finds whether it is eligible to be a cluster head, it will choose a random number between 0 and 1. If the number is less than the threshold \( T(s_i) \), then node \( s_i \) becomes a cluster head during the current round.

Let \( n_i = 1/p_i \) denote the number of rounds to be a cluster head for the node \( s_i \), and we refer to it as the rotating epoch.

\[ n_i = \left(\frac{N N_{\text{tot}}}{(N \sum_{i=1}^{N} \lambda_i)}\right)^{-1} \frac{E_{\text{res}}(i)}{E(r)} = \left(\frac{1}{E_{\text{res}}(i)} \right)^{-1} \tag{11} \]

from equation (11) the rotating epoch \( n_i \) of each node fluctuates around its reference epoch \( I_i \) based on the residual energy \( E_{\text{res}}(i) \). If \( E_{\text{res}}(i) > E(r) \), we have \( n_i < I_i \) and vice versa. That means the nodes with more energy will have more chances to be the cluster head than the nodes with less energy due to different initial energies and energy dissipated every round in such a heterogeneous environment. Thus the energy of network is well distributed in the evolving process.

**4.3 BS Movement**

In this section, we consider a simple example in a two-dimensional space to illustrate the BS movement strategy in our approach. In the following example, we consider four CHs and show their initial parameters as shown in Table 1, and initial BS location to be at (50,50).
TABLE I.  EXAMPLE PARAMETER.

<table>
<thead>
<tr>
<th>Cluster Head (CH)</th>
<th>Location</th>
<th>CH Probability (p_i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH1</td>
<td>(10,10)</td>
<td>0.2</td>
</tr>
<tr>
<td>CH2</td>
<td>(40,20)</td>
<td>0.6</td>
</tr>
<tr>
<td>CH3</td>
<td>(50,70)</td>
<td>0.8</td>
</tr>
<tr>
<td>CH4</td>
<td>(80,100)</td>
<td>0.1</td>
</tr>
</tbody>
</table>

First the vectors between a BS and all the CHs must be calculated as shown in Fig.1.

\[ V_1 = (10-50,10-50) = (10-40,10-40) \]
\[ V_2 = (40-50,40-50) = (10-30,40-30) \]
\[ V_3 = (50-50,50-50) = (0,10,0) \]
\[ V_4 = (90-50,100-50) = (30-50,100-50) \]

Next step is to multiply each vector by the corresponding CH’s probability.

\[ V'_1 = V_1 * p_1 = (10-40,10-40) * 0.2 = (8-8,0) \]
\[ V'_2 = V_2 * p_2 = (40-50,40-50) * 0.6 = (24-18,24-18) \]
\[ V'_3 = V_3 * p_3 = (50-50,50-50) * 0.8 = (0,0) \]
\[ V'_4 = V_4 * p_4 = (90-50,100-50) * 0.1 = (3,0) \]

Next we add the resulting vectors to produce a net vector (\( V_n \)) as shown below:

\[
V_n = V'_1 + V'_2 + V'_3 + V'_4 \\
= (-8-8 + 24-18 + 0 + 3, 0 + 0 + 0 + 0) \\
= (-11,5) \\
\]

Finally we can add the net movement vector to the current BS location to obtain the final BS location as shown in Fig. 2.

\[ X_{BS}, Y_{BS} = (50,50) + (-11,5) = (39,45) \]

In general, the BS movement is given by:

\[
X_{BS}', Y_{BS}' = X_{BS} + \sum_{i=1}^{K} (X(CH_i) - X_{BS}) * p_i(CH_i), Y_{BS} + \sum_{i=1}^{K} (Y(CH_i) - Y_{BS}) * p_i(CH_i) >
\]

\[ (12) \]

Where,

\( X_{BS}, Y_{BS} \) : Are the initial coordinate of BS at the start of round.
\( X_{BS}', Y_{BS}' \) : Are the final coordinate of BS in the end of round.
\( K \) : Is the number of cluster heads in the current round.

4.4 Cluster Formation

Once the cluster heads nodes have selected, they must let all non-cluster head nodes in the network know through broadcasting message. Meanwhile, they wait for other non-cluster head nodes to join in. Each non-cluster head node receives invitation message packets from multiple cluster heads for this round in its communication range and computes the distance \( d(i, j) \) between the sender and the receiver based on the received signal strength indicator (RSSI). In order to make normal nodes choose optimal cluster head, we introduce the cost function. This can be shown as:

\[ \text{cost}(i, j, r) = \frac{E_{\text{res}}(r)}{d^2(i,j)} \]

\[ (13) \]

Where, \( \text{cost}(i, j, r) \) is cost value between non-cluster head \( s_i \) and cluster head \( s_j \) in the \( r \)th round, and \( E_{\text{res}}(r) \) is the residual energy of the cluster head \( s_j \) in the \( r \)th round.

From Equation (10), in every round, each normal node selects from their inviting cluster heads one that allows to have a maximum value of the cost function. Which leads to a load balancing in the whole network.

After the cluster head receives all the Join messages, in order to avoid collisions during messages transmission among sensors, a TDMA (time division multiple access), schedule is made up and transmitted to the sensor nodes in its cluster. Which allows the sensor nodes to be turn off if not on duty. This can effectively reduce the energy consumption for sensor nodes and prolong the lifetime of the network. The huge amount of data gathered in the cluster head ought to be fused into a single data message and transmitted to the BS, the process of this round is complete. Afterwards, a new process starts as before round by round until the energy is depleted by each node, which means the network lifetime is completely ended.

IV. SIMULATIONS AND RESULTS

5.1 Simulation Environment

We use the MATLAB simulator to evaluate the performance of our proposed EECSMS algorithm. Simulation parameters
are listed in Table 2, where the number of nodes N=100 sensor nodes are distributed randomly in a square region of 100 × 100 m². For simplicity, we consider that all nodes are either fixed or micro-mobile and the initial position of BS at every round is placed in the center of the network field. With the same network parameters setup, the EECSMS protocol is compared with three different clustering algorithms, namely LEACH, DEEC and EDCS in multi-level heterogeneous WSNs.

The performance metrics used for evaluation of our approach are stability period (the first node dies.), lifetime (the last node dies.) and data packets which are successfully sent to the BS.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes number(N)</td>
<td>100</td>
</tr>
<tr>
<td>Round</td>
<td>5 TDMA</td>
</tr>
<tr>
<td>Node initial energy (E₀)</td>
<td>0.5 joule</td>
</tr>
<tr>
<td>the threshold distance (d₀)</td>
<td>87.7 m</td>
</tr>
<tr>
<td>Packet size (L)</td>
<td>4000 bits</td>
</tr>
<tr>
<td>λ</td>
<td>4</td>
</tr>
<tr>
<td>Network size (M×M)</td>
<td>100 × 100 m²</td>
</tr>
<tr>
<td>E_{elec}</td>
<td>50 nJ/bit</td>
</tr>
<tr>
<td>E_{DA}</td>
<td>5 nJ/bit</td>
</tr>
<tr>
<td>E_{mp}</td>
<td>10 pJ/bit/m²</td>
</tr>
<tr>
<td>E_{mp}</td>
<td>0.0013 pJ/bit/m²</td>
</tr>
</tbody>
</table>

### 5.2 Simulation Results

In this part, N=100, Rounds Number =10000 and λ=4 which means the initial energy of nodes is randomly distributed in interval [E0,5E0], to prevent the affection of random factors, the network is equipped with the same amount of initial energy. Simulation results are illustrated in Fig.3 and Fig.4.

![Fig3. Network lifetime comparison (λ =4, N=100.)](image)

From Fig.3, we can see that the LEACH performances are the poorest as its stability period and lifetime both are very short. This is because it considers that all nodes have the same rotating epoch. DEEC has longer stability period and lifetime than LEACH just because it considers the rotating epoch according to their initial and residual energy. However EDCS and EECSMS have both better performances because, in addition to the advantages of DEEC, they present a load balancing in clusters formation. But the BS movement favors our protocol EECSMS to EDCS and allows it to have a very large stability period and lifetime.

![Fig4. Packets received by the sink node(λ =4, N=100)](image)

Fig.4, shows the number of packets messages received by the sink. As illustrated in the figure above, our protocol EECSMS has a higher number of data received by the sink compared to LEACH, DEEC and EDCS. In the first 380 rounds, the four algorithms have nearly the same packets delivery number. However, after 2504 rounds LEACH stops sending packets, while DEEC, EDCS and EECSMS continue respectively delivering and forwarding data at 10000 rounds a large amount of packets sent to the sink is scored for EECSMS. The summary of Simulation is given in Table 3.

### Table III. Simulation Parameters.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>First Node Dies(FND)</th>
<th>Last Node Dies(LND)</th>
<th>Packets Received (PR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEACH</td>
<td>380</td>
<td>2504</td>
<td>63080000</td>
</tr>
<tr>
<td>DEEC</td>
<td>1243</td>
<td>3096</td>
<td>441972000</td>
</tr>
<tr>
<td>EDCS</td>
<td>1950</td>
<td>3150</td>
<td>586568000</td>
</tr>
<tr>
<td>EECSMS</td>
<td>3717</td>
<td>4988</td>
<td>1045400000</td>
</tr>
</tbody>
</table>

V. DISCUSSION

From the simulation results, our proposed algorithm is seen as an energy efficient routing protocol. In fact, if we consider Table 3, the stability period is increased at nearly 97%, 30%
VI. CONCLUSIONS

In this paper, EECSMS an Energy Efficient Clustering Scheme with Mobile Sink for Heterogeneous Multi-level Wireless Sensor Networks is proposed in which cluster heads selection like that of DEEC protocol and clusters formation like the EDCS protocol. What is new in our algorithm is the use of mobile sink, it adjusts its position according to the priorities of all CH’s. At the beginning of every round, the default sink location is in the center of the field. This strategy minimizes CH-to-BS transmission distances, which allows load balancing and consequently increase the lifetime of the whole network. Simulation results have proved that EECSMS is an energy efficient routing protocol compared to LEACH, DEEC and EDCS in multi-level heterogeneous wireless sensor networks.

REFERENCES


