A Balanced Distribution Method of Cluster Head Selection for Clustering in Wireless Sensor Networks

Marzieh Gholami1, Mehdi Golsorkhtabar-amiri 2

1) University College of Rouzbahan, Sari, Iran
2) Department of Computer Engineering, Babol Branch, Islamic Azad University, Babol, Iran
ma12gholami@rouzbahan.ac.ir; golesorkh@baboliau.ac.ir

Received: 2016/06/30; Accepted: 2016/09/05

Abstract

Wireless sensor network includes hundreds or even thousands of sensor nodes, which are devices with low energy and often impossible to be replaced or recharged. For this reason, efficient use of energy is one of the major challenges in these networks. One way for increasing energy efficiency in such networks is clustering. Clustering protocols such as LEACH, TEEN, SEP and DEEC randomly select the cluster heads for the clustering process. This causes the cluster heads to be close together, decreasing the efficiency of protocols. For this reason, we proposed a new approach called EBDCH. In this method, when cluster heads are close together, we distribute them based on the energy situation. The proposed approach runs on the clustering protocols. The simulation results show that with the implementation of the proposed method, throughput is increased and network lifetime is improved compared to protocols LEACH, DEEC, SEP and EEHC respectively at 26%, 28%, 37% and 36%.

Keywords: Wireless Sensor Network; Distribution of Cluster Heads; Clustering; Energy Efficiency; Network Lifetime; EBDCH Approach

1. Introduction

Sensors are devices with low energy and small memories, as well as low processing power. They are capable of forming networks with many nodes which have self-configuration features and no infrastructure. A wireless sensor network (WSN) is a combination of many nodes with many applications used depending on their applications [1]. Wireless sensor network technology includes several advantages such as low costs, scalability, reliability, accuracy, flexibility and ease of deployment that guarantee their use in large-scale environments and for various applications [2].

With the advancement of technology and smarter, cheaper and smaller sensors, millions of wireless sensors have been developed for various applications. Some of these applications are in the military domains, healthcare, surveillance and security. In the military domain, sensor nodes can be used to identify, locate and target tracking. In the field of natural disasters, sensor nodes sense and detect the environment to forecast disasters [2].

Energy efficiency is one of the most important considerations in wireless sensor networks. Each sensor node sends data directly to the base station, but when base
stations are located in places away from the sensor nodes, nodes die faster due to high energy consumption [3]. Resources in wireless sensor networks are limited because in these networks, sensors cannot send data directly to the sink [4].

In recent years, researchers have proved that clustering is an efficient method for increasing the network lifetime and matters of scalability concerning wireless sensor networks. There are two types of nodes in a cluster in the clustering method: cluster heads and cluster members. Members of the cluster periodically collect data from the environment and then send them to the cluster heads. The cluster heads then combine and integrate the data and send them to the base station [5].

There are several routing protocols for efficient use of energy which are generally divided into three categories: hierarchical routing protocols, flat and location-based routing protocols [6]. Hierarchical routing is an efficient method to save energy. Hierarchical routing has been proposed for both homogeneous and heterogeneous wireless sensor networks [7].

LEACH [8] and TEEN [9] are clustering protocols used in homogeneous wireless sensor networks where the primary energies of nodes are the same. DEEC [10], SEP [11] and EEHC [12] are clustering protocols in heterogeneous wireless sensor networks where the primary energies of nodes are different and in fact, there are two or more than two types of sensor nodes in this type of network. In all these protocols, the cluster head is selected firstly after which the clusters are formed. Cluster members send data to the cluster heads and the cluster heads send data to the sink after combining and integrating them.

Since it is possible that selective cluster heads in each protocol are close together, reducing the efficiency of the network, in this paper, we present a new approach, which is the EBDCH that increases energy efficiency, in other words, lifetime and throughput in each mentioned protocol.

In this paper, related works are discussed in Section 2. Section 3 describes the EBDCH approach. The simulation results and comparison of them are shown in Section 4, and conclusions and future directions are shown in Section 5.

2. Related Work

Wireless sensor networks consume more energy to send data than to sense, and energy consumption is one of the main challenges in these networks. When the sensors have power restrictions, the farther nodes consume more energy to send data to the sink, and this shortens the network lifetime [13].

There are many methods for energy efficiency in wireless sensor networks among which clustering is one of the best. When network lifetime decreased, clustering was proposed as a solution for wireless sensor networks. Clustering protocols not only focus on grouping, but also on the election of cluster heads and their periodic changes. The cluster heads can both be selected by nodes and predefined or determined by the network designer. Data aggregation and combination plays an important role in clustering. A sensor node does not send data directly to the sink but rather to the cluster head, and the cluster head aggregates data and discards the additional data and finally sends them to the sink [14].

One of the famous protocols based on clustering is the Low Energy Adaptive Clustering Hierarchy (LEACH) [8] that has advantages such as load balancing, energy efficiency, data aggregating and simplicity. Nodes are organized in the cluster, and each
node becomes the cluster head just once in each round. Time is divided into rounds. Each round consists of two phases: a start-up and a steady phase. The start-up phase contains selection of cluster head and cluster formation. Each node in the start-up phase produces a random number between zero and one for selection of cluster head, where if the randomly generated number was smaller than the threshold value, it becomes the cluster head in the current round. The threshold guarantees that the node which became cluster head in the $1/P$ round, cannot be cluster head in the current round.

$$T(n) = \begin{cases} \frac{p}{1-P\left(\frac{r \mod P}{P}\right)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$ (1)

Where $P$ is the probability of cluster head, $n$ is the number of nodes, $r$ is the number of current round and $G$ is the set of nodes that are not elected as a cluster head in previous rounds.

After selection of the cluster head, each node chooses its own head according to the distance between itself and that head. The CH then collects data from other nodes in the cluster and sends them to the base station directly.

The distributed energy efficient clustering algorithm (DEEC) [10] is a protocol for heterogeneous wireless sensor networks. When starting a grid, nodes have different primary energies. The DEEC protocol uses the primary energy level and the remaining energy of the nodes to select the cluster head. Nodes with higher initial and residual energy have more chances to become cluster heads than those with lower initial and residual energy.

The Stable Election Protocol (SEP) [11] is based on the probability weight that each node has as cluster head based on primary energy. Rotation and probability of selection are directly associated with primary rather than remaining energy of nodes. Advanced nodes are frequently cluster heads and in some of the rounds, the advanced nodes energies can be less than those of normal nodes.

Another clustering protocol is the Energy Efficient Heterogeneous Clustered (EEHC) [12]. The probability of selecting a node for cluster heads is based on the energy remaining. This protocol is similar to the LEACH protocol. The difference, however, is that in this protocol, in addition to the normal nodes, there are also advanced and super nodes. In this protocol, advanced nodes and super nodes die later than normal nodes and thus in the final round, advanced and super nodes are alive.

The Equally Distributed Cluster Heads Technique is implemented on the clustering protocols. When several cluster heads are close together, the performance of the protocol is decreased. This technique places the cluster heads in the network optimally, and this will increase the efficiency of the protocols. This technique effectively improves the performance of clustering protocols with respect to throughput and network lifetime. In this technique, the clusters are made of a balanced approach, and the cluster heads are distributed evenly. Energy consumption is less when the cluster heads are distributed evenly. In this method, when cluster heads were close together, the cluster members and including cluster heads calculate their distance with the rest of the cluster nodes. The node having minimum link cost compared with the other nodes will be selected as the new cluster head, and it initiates the clustering process, and the previous cluster head converts to the normal node [14].

In a real wireless sensor network, in the initial round or the following rounds, the sensor nodes may distribute as heterogeneous, and they are dense in parts of the
network [15]. For this reason, in this paper, we present a new approach, named the EBDCH whereby the cluster heads are distributed based on energy.

3. The Proposed Approach

The proposed approach includes a distribution of cluster head technique. Protocols select the cluster heads randomly to begin the clustering process. It is likely that the cluster heads are close together, and this causes the efficiency of the protocol to decrease. In this paper, we propose a new approach called EBDCH.

In the proposed approach, the cluster heads distribute based on the energy situation. In fact, when some cluster heads are close together, the cluster head with more energy remains in the cluster head situation, and another cluster head which has less energy stays on the candidate status. Then the cluster head with an appropriate delay to the energy situation sends the head message. As a result, the node that has more energy sends the head message, and the node with lower energy, after receiving this message, puts itself in the candidate status and does not send any head messages.

All of the nodes count the joining members to the CH. If the number of nodes that joined the CH was less than threshold region with the low nodes, the candidate node puts itself in the normal situation, but if the number of nodes that joined the CH was more than the threshold region with the higher number of nodes, the candidate node stays on the cluster head situation, and then the rest of the nodes join the adjacent cluster head.

In fact, this approach states that when some cluster heads are close together and the number of nodes in that part of the network is low, only one cluster head node, the one with more energy sends head messages, and/or if the number of nodes in that area is high, the clusters must form a balance. It means that after filling the first cluster capacity, the rest of the nodes must join the adjacent cluster head instead of joining the current cluster head. The threshold value for the number of members of each cluster head in the area with the low and high number of nodes is obtained from formula 2 and 3, respectively:

\[ K_{\text{min}} = \frac{N}{5} \]  

\[ K_{\text{max}} = 1.5 \left( \frac{N}{5} \right) \]

Where \( N \) is the number of nodes, and 5 is the number of optimization clusters in the network [16].

Non-uniform distribution of nodes is shown in Figure 1. In area A, when two cluster heads are close together and there is also only a few number of nodes in the area, between these two CHs, the node with more energy announces itself as the cluster head, and the other cluster head doesn’t send head messages and puts itself in a normal situation. But if the number of nodes in the area of the network is more than the threshold, and the number of cluster head nodes in that area is one, as well as the fact that there is no cluster head around it (area B), the CH selects a node with the highest energy as an auxiliary cluster head among its members. This head should not be near his own and/or other cluster heads, and thus initiates the clustering progress.

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1 Energy Based Distributed of Cluster Heads
3.1 Energy Model

In this section, the energy model is described. Sensor nodes can use the threshold value formula 4 to communicate with other nodes.

\[ d_o = \sqrt{\frac{E_s}{E_{mp}}} \]  

(4)

Where \( E_s \) and \( E_{mp} \) are respectively the energy required to free space and multipath communication.

The energy required to transmit packets with size \( L \) for distance \( d \) according to the formula 5 is:

\[
\begin{align*}
\text{IF} & \quad d \leq d_o \quad \text{then} \quad E_{TX} = (E_{elect} \times L) + (E_s \times L^2 \times d^2) \\
\text{IF} & \quad d > d_o \quad \text{then} \quad E_{TX} = (E_{elect} \times L) + (E_{mp} \times L^4 \times d^4)
\end{align*}
\]

(5)

Where \( E_{elect} = E_{TX} + E_{DA} \). Where \( E_{DA} \) for cluster heads is the energy consumption for data aggregation, and for normal nodes it must be zero. \( E_{elect} \) is the energy used for sending a bit.

The energy required to receive packets with size \( L \) and distance \( d \) according to formula 6 is:

\[ E_{RX} = (E_{rx} \times L) \]

(6)

Where \( E_{rx} \) is the energy used for receiving a bit.

3.2 Algorithm Procedure

The pseudo code for the EBDCH approach is demonstrated in algorithms 1 and 2. In algorithm 1, when two cluster heads are close together and the number of nodes is low in the area of the network, only one cluster head node, the one with more energy, sends head messages.
Algorithm 1

1: \( K_{\text{min}} = (N/5) \);
2: If (CHs Closely Placed)
3:     For \( i = 1 \): (CHs closely Placed)
4:         For \( j = 1 \): (CHs closely Placed)
5:             If \( \text{Sensor}(i).E \geq \text{Sensor}(j) \)
6:                 \text{Sensor}(i).Type = \text{'C'};
7:         End
8:     End
9: End
10: \text{Sensor}(i) \text{ send Head Message and then initiates the clustering process.}
11: If \( \text{Sensor}(i).\text{member} \leq K_{\text{min}} \)
12: Elseif \( \text{Sensor}(i).\text{member} > K_{\text{min}} \)
13: \text{Sensor}(j).Type = \text{'C'};
14: \text{Sensor}(j) \text{ send Head Message and initiates the clustering process.}
15: End

In algorithm 2, when the number of nodes in the area of the network is high and the number of the cluster head is low, the current CH selects a node with the highest energy level as the auxiliary cluster head among its members which is not near its own and/or other cluster heads, and then initiates the clustering process.

Algorithm 2

1: \( K_{\text{max}} = 1.5(N/5) \);
2: If (CHs NotClosely Placed)
3: \( \text{Sensor(CHs NotClosely Placed)} \text{ send Head Message and initiates the clustering process.} \)
4: End
5: IF \( \text{Sensor(current CH). Member} > k_{\text{max}} \)
6: \( \text{tempMaxEng}=0; \)
7: \( \text{helpidCH}=0; \)
8: For \( i = 1: N \)
9:     If \( (\text{Sensor}(i).\text{Type} = 'N' && \text{Sensor}(i).\text{idCH} = \text{'current CH.id'}) \)
10: \( \text{dist1}: \text{sqrt} ((\text{Sensor}(i).X - \text{sensor(current CH).X}) ^ 2 + (\text{Sensor}(i).Y - \text{Sensor(current CH).Y}) ^ 2); \)
11: \( \text{dist2}: \text{sqrt} ((\text{Sensor}(i).X - \text{sensor(other CH).X}) ^ 2 + (\text{Sensor}(i).Y - \text{Sensor(other CH).Y}) ^ 2); \)
12:     If \( \text{Sensor}(i).E > \text{tempMaxEng} \)
13:         If \( (\text{dist1} > 12 && \text{dist2} > 12) \)
14:             \( \text{tempMaxEng} = \text{Sensor}(i).E; \)
15:             \( \text{helpidCH}=i; \)
16: End
17: End
18: \text{Sensor(helpidCH).Type = 'C'};
19: Sensor(helpidCH) send Head_Message and initiates the clustering process.
20: End

4. Simulation and Evaluation

Clustering protocols and the suggested approach are implemented by the simulator MATLAB. The proposed method was the compared with the DECH technique that was implemented on the clustering protocols. The simulation results show that the proposed method is better compared with the DECH technique and the clustering protocols. The simulation environment is considered as 100 * 100, and the total number of sensor nodes in the network is 100. In this model, the network hypotheses are: (i) Sensor nodes are distributed non-uniformly in the network; (ii) All of the sensor nodes and base stations are fixed; (iii) Cluster heads perform data aggregation; (iv) Base station power is unlimited.

Simulation parameters are shown in Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sink position</td>
<td>50×50</td>
</tr>
<tr>
<td>Number of Nodes</td>
<td>100</td>
</tr>
<tr>
<td>Ef</td>
<td>10×10-12 J</td>
</tr>
<tr>
<td>Emp</td>
<td>0.0013×10-12 J</td>
</tr>
<tr>
<td>EDA</td>
<td>5×10 -9 J</td>
</tr>
<tr>
<td>Initial energy</td>
<td>0.02 J</td>
</tr>
<tr>
<td>Packet length</td>
<td>2000 bits</td>
</tr>
<tr>
<td>CtrlPacket length</td>
<td>100 bits</td>
</tr>
<tr>
<td>Probability of CHs</td>
<td>0.1</td>
</tr>
<tr>
<td>Maximum rounds</td>
<td>500</td>
</tr>
</tbody>
</table>

4.1 Performance Measurements

The performance metrics used for clustering protocols using the EBDCH method are: (i) Network Lifetime: the time interval from the start of the operation until the last node dies; (ii) The number of alive nodes: The nodes that still have not lost all their energy; (iii) Throughput: The number of data that has been sent from all of the network nodes to the base station; (iv) The average energy of nodes in each round.

4.2 Comparing the Proposed Approach with LEACH- DECH and LEACH

Figure 2 shows the comparison of the LEACH protocol and its variants. Graph A, shows that the LEACH protocol and the EBCDH approach perform equal up to round 55, but the last node in the LEACH protocol dies in round 146, while the last node in LEACH-EBDCH dies in round 198. The simulation results show that the performance of the EBDCH method is better than that of the LEACH protocol and its variants.

Graph B shows the number of alive nodes in each round for the LEACH protocol and its variants. The simulation results show that in the proposed method all nodes are alive so far 100 and as a result it has better performance.

Graph c shows the average energy of nodes in each round. Graph d shows that in LEACH-EBDCH more data is send to the base station.
4.3 Comparing the proposed approach with DEEC-DECH and DEEC

Figure 3 shows the comparison between the DEEC protocol and its variants. Graph A shows that the DEEC protocol and EBDCH approach perform equally up to round 36, but the performance of the EBDCH method is better than those of other methods and the performance of DEEC-DECH is higher than that of the DEEC protocol.

Graph B shows the number of living nodes in each round. Graph C shows the average energy of nodes in each round for the DEEC protocol and its variants. The simulation results show that energy consumption of nodes in the EBDCH method is lower, and, in other words, the nodes in this method lose their energy later than in other methods. Graph D shows that the throughput of the EBDCH method is better than those of the DEEC and DEEC-DECH, and the number of packets to be sent to the sink is also more.
4.4 Comparing the Proposed Approach with SEP-DECH and SEP

Figure 4 shows the comparison between the SEP protocol and its variants. Graph A shows that the EBDCH method and SEP protocol run equally to round 66 but the death of the first node in SEP-DECH occurs in early rounds. The simulation results show that the Performance of the SEP-EBDCH method is better than that of the SEP-DECH, and the SEP-DECH method has better performance compared to the SEP protocol.

Graph B shows the number of living nodes in each round for the SEP protocol and its variants. The simulation results show that the number of living nodes in the EBDCH method is more.

Graph C shows the average energy of nodes in each round for the SEP protocol and its variants. Graph D shows that in the EBDCH approach more data will be sent to the base station than SEP and SEP-DECH protocol.

4.5 Comparing the Proposed Approach with EEHC-DECH and EEHC

Figure 5 shows the comparison between the EEHC protocol and its variants. As shown in graph A, the EEHC protocol and EBDCH method runs equally to round 68. Death of the last node in the EEHC protocol occurs in round 313 and in EEHC-DECH it occurs in round 452, but in the EBDCH approach it occurs in round 485. The simulation results show that the Performance of the EEHC-EBDCH method is better than that of the EEHC protocol and its variants.

Graph B shows the number of living nodes in each round. The simulation results show that the number of living nodes in the EBDCH approach is more than that of the EEHC and EEHC-DECH protocols.

Graph C shows the average energy of the nodes in each round. As it is shown in graph C, the energy of the nodes is stored by implementing the proposed method. Graph D shows the number of packets sent to the sink. The simulation results show that in the EBDCH approach more packets will be sent to the sink.
5. Conclusion and Future Work

Clustering is an efficient method for increasing network lifetime. In this article, we proposed a new approach called the EBDCH, which was implemented on the clustering protocols. When the cluster heads were close together, the efficiency of the network, in other words, the network lifetime, decreased. In the proposed approach, the cluster heads were distributed based on energy when they were close together. The simulation results show that with the implementation of the proposed method, throughput increases, and network lifetime, compared to protocols LEACH, DEEC, SEP and EEHC improved by 26%, 28%, 37% and 36% respectively, and compared with the protocols LEACH-DECH, DEEC-DECH, SEP-DECH and EEHC-DECH improved by 1%, 7, 26% and 7% respectively. As a result, the performance of the proposed approach, in other words, lifespan and throughput, is better than those of the DECH method and the clustering protocols.

Future work: In this paper, the cluster heads were selected initially after which it was decided that cluster heads send head messages. However, in other studies, approaches could be implemented through which the cluster heads are not close together during the election process.

References


