ABSTRACT

The past few years have witnessed increased interest in the potential use of wireless sensor networks (WSNs) in applications such as environment monitoring, disaster management, healthcare and security surveillance. In a wireless sensor network, an efficient arrangement of network topology is required for energy optimization. Clustering has been proposed as an effective way of organizing sensor networks. Current clustering algorithms usually utilize two techniques, selecting cluster heads with more residual energy and rotating cluster heads periodically, to distribute the energy consumption among nodes in each cluster and extend the network lifetime. In this paper, Heed (a Hybrid Energy Efficient Distributed clustering algorithm), one of the pioneers algorithms for clustering WSN, has been investigated. Three mechanisms to improve the Heed algorithm namely Unequal Heed, Hierarchical Heed and Relay Heed have been proposed. Simulation results have shown that Hierarchical Heed offers around 36% of energy savings for the clustering process and 69% energy savings for the routing process compared to the Heed algorithm.

General Terms
Algorithms, Simulations, Sensor Networks.

Keywords

1. INTRODUCTION

Wireless Sensor Networks consist of large quantity of individual nodes (sensors) that are able to interact with their environment by measuring physical quantities which can be amount of heat, air content, and amount of rainfall among others [1]. Each node in a sensor network is equipped with a wireless communication device, usually a radio transceiver, a small microcontroller, and a battery.

There exists many challenges that still have not been met completely in WSN and these are the real time, power management, security and privacy factors. The energy challenge is considered to be very important because nodes in a WSN run on non-renewable batteries and hence the lifetime of a WSN depends on that [2, 3]. Therefore, one of the solutions put forward by researchers, in WSN, recently is clustering.

Clustering is a technique that can be used to organise sensors in a wireless sensor network (WSN). In clustering, nodes can be partitioned into a number of small groups called clusters. Each cluster has a coordinator, known as a cluster head, and a number of member nodes [4]. These member nodes communicate only to their cluster heads to transmit observed readings.

In this paper three algorithms have been proposed (Hierarchical Heed, Unequal Heed, and Relay Heed) and implemented, all with different features and all geared towards improving network lifetime. Relay Heed which elects another member node in each cluster to help in the routing process, Unequal Heed which forms unequal size clusters, smaller clusters as we move nearer to the base station to prevent early death of nodes that are near to it. Hierarchical Heed extends Original Heed by electing 2nd level cluster heads. Electing 2nd level cluster heads together with data aggregation helps greatly in the routing process as this reduces considerably the amount of relay traffic that 2nd level cluster heads have to do.

Hierarchical Heed consists of two parts. In the first part cluster heads are elected same as in Original Heed. But in the second part, the 2nd level cluster heads are elected based on 2 new energy efficient parameters. The second part has been implemented in such a way that 1st level cluster heads has a high probability of being elected as a cluster if it is rich in residual energy and if it has the lowest number of sensor nodes associated with it.

2. RELATED WORKS

Many clustering algorithms have been proposed for wireless sensor networks in recent years [5, 6, 7, 8]. We review some of the most relevant works in this section.
LEACH [9] is the first clustering protocol proposed for periodical data gathering applications in WSNs. It assumes that sensor nodes communicate with each other by single-hop only, and they can transmit the data to the base station directly. LEACH is a probabilistic clustering technique. It is one of the most studied algorithms and its main objective is to minimise energy consumption. LEACH is a single-hop clustering algorithm whereas M-LEACH is an implementation of LEACH for multi-hop network, where a node is multiple hops from its cluster head. To minimize energy consumption, it ensures that all nodes die, i.e. run out of energy about the same time which extends the network lifetime and leaves very little energy left in the nodes when the network dies. It can also be configured so that nodes dies at about the same time by rotating the role of the cluster head and basing cluster head selection partly on remaining energy.

Two hierarchical routing protocols called TEEN (Threshold-sensitive Energy Efficient sensor Network protocol), and APTEEN (Adaptive Periodic Threshold-sensitive Energy Efficient sensor Network protocol) are proposed in [10] and [11], respectively. These protocols were proposed for time-critical applications. TEEN is designed to be responsive to sudden changes occurring to the environment being monitored. In TEEN, an event driven protocol, responsiveness is important since it is used for time critical application. The sensor network architecture is based on a hierarchical grouping where closer nodes form clusters and this process goes on the second level until the base station (sink) is reached.

HEED [12] is a protocol which periodically selects cluster heads according to a hybrid of the node residual energy and a secondary parameter through constant time iterations. It uses the primary parameter, i.e. residual energy, to select an initial set of cluster heads. Unlike previous protocols which require knowledge of the network density or homogeneity of node dispersion in the field, HEED does not make any assumptions about the network, such as, density and size. Every node runs HEED individually. At the end of the process, each node either becomes a cluster head or a child of a cluster head. Below are some important characteristics of HEED:

- HEED is hybrid and clustering is based on two parameters: residual energy of a node is the first parameters in the election of a cluster head and the proximity or node degree.
- HEED is distributed: every node runs the heed algorithm individually.
- HEED is energy-efficient: the algorithm elects cluster heads that are rich in residual energy and re-clustering results in distributing energy consumption.

Unlike most algorithms, Energy Efficient Unequal Clustering Mechanism (EEUC) [13] takes care of a problem in multi hop WSN called the hot spot problem. Previous research has demonstrated that if the communication between a data source (sensor) and a data sink (base station) is multi hop, this allows the network to be more energy efficient than direct transmission because of the characteristics of the wireless channel. However, the hot spot problem arises when using the multi hop forwarding model in inter-cluster communication. When cluster head cooperate with each other to forward their data to the base station, the cluster head closer to the base station have to handle lots of heavy relay traffic and tend to die early. This reduces sensing coverage and causes network partitioning. The node’s competition range decreases as its distances to the base station decreases. The result is that clusters closer to the base station are expected to have smaller cluster sizes, thus they will consume lower energy during the intra-cluster data processing, and can preserve some more energy for the inter-cluster relay traffic. The energy consumed in intra-cluster processing varies proportionally to the number of nodes within the cluster. The EEUC algorithm adopts both the rotation of cluster-heads and choosing CH with more residual energy but uses the novel EEUC mechanism. Table 1 below shows a comparison of the four algorithms presented in this section.

Table 1. Comparisons of clustering algorithms

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Mechanism</th>
<th>Parameters Used</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEACH</td>
<td>Probabilistic clustering technique. Single-hop clustering algorithm. Uses CDMA for communication.</td>
<td>Node uses a random number to elect itself as CH.</td>
<td>All CHs must broadcast an advertisement message to all nodes in its communication radius. All CHs transmit data to the base station using single hop. Large overhead involved to form clusters.</td>
</tr>
</tbody>
</table>
| TEEN & APTEEN | ➔ Hierarchical Protocol  
               ➔ 2nd level CH further aggregates data from 1st level CH | ➔ Makes use of hard and soft threshold | ➔ Overhead and complexity involved in order to form clusters in multiple levels and when implementing threshold based functions. |
| HEED | ➔ Does not make any assumption on network size  
      ➔ Each node runs Heed separately  
      ➔ Allows for re-clustering | ➔ Residual energy of nodes  
      ➔ Node degree | |
| EEUC | ➔ CHs closer to base station have less members associated with them compared to those that are far away | ➔ Uses signal strength to determine appropriate distance to base station | |

3. THE HEED ALGORITHM

Heed is a hybrid algorithm since the clustering process depends on two parameters: residual energy of node and node degree. Heed is a distributed since each node runs the algorithm on its own. Lastly, heed is energy-efficient since it elects cluster heads that contain high level of residual energy and this helps to prolong lifetime of network. Unlike previous protocols which require knowledge of the network density or homogeneity of node dispersion in the field, HEED does not make any assumptions about the network, such as, density and size.

In Heed, clustering is triggered every TCP + TNO seconds to select new cluster heads, where TCP is the time taken for the clustering process and TNO is the time between the end of a TCP interval and the start of the subsequent TCP interval. At each node, the clustering process requires a number of iterations, which we refer to as Niter. Every step takes time tc, which should be long enough to receive messages from any neighbor within the cluster range. We set an initial percentage of clusters heads among all N nodes, Cprob (say 5%), assuming that an optimal percentage cannot be computed a priori. Cprob is only used to limit the initial cluster head announcements, and has no direct impact on the final clusters. Before a node starts executing HEED, it sets its probability of becoming a cluster head, CHprob, as follows:

$$CHprob = Cprob \times \frac{E_{residual}}{E_{max}}$$

where Eresidual is the estimated current residual energy in the node, and Emax is a reference maximum energy (corresponding to a fully charged battery), which is typically identical for all nodes.

The HEED algorithm is in 3 stages. We have the initialisation stage which consists in discovering neighbors within cluster range. Then the initial cluster head probability CHprob = f(Er/Emax) is calculated.
The main processing stage is as follows:

If v (a node within my communication range) received some cluster head messages, choose one head with min cost

If v does not have a cluster head, elect to become a cluster head with CHprob.

\[ CH\text{prob} = \min(CH\text{prob} \times 2, 1) \]

Repeat until CHprob reaches 1

Finally, if a cluster head is found, a node joins its cluster else it is elected to be a cluster head.

In Heed, tentative cluster heads are randomly selected based on their residual energy. Therefore, Heed cannot guarantee optimal head selection in terms of energy since it uses the secondary parameter to resolve conflicts.

The amount of energy spent for the clustering process depends on the number of iterations. The latter depends on the CH prob formula. In the case of Original Heed, using its defined formula, the clustering process terminates in 6 rounds; hence in order to have more savings in terms of energy, the clustering process must terminate in fewer rounds by using another formula / improved formula for the CH probability.

Clusters formed by Heed are usually equal in size. CH nearer to the base station have to handle both heavy relay traffic (inter cluster traffic) and intra-cluster traffic from their member nodes. Hence to alleviate that work load, clusters formed nearer to the base station should contain fewer number of member nodes compared to those further away thus solving the hot spot problem. By having more than 1 hierarchy among the cluster heads, this will minimise the energy consumption during the routing process. This feature allows for more data aggregation, hence less number of packets to transmit and less load on the network.

4. PROPOSED ENERGY EFFICIENT CLUSTERING ALGORITHM

Three mechanisms are proposed in order to improve the original Heed namely Relay Heed, Unequal Heed and Hierarchical Heed, all use two parameters that allows for increase in network lifetime.

The first parameter is the “residual energy” of nodes which is used to probabilistically select an initial set of cluster heads and the second one is the intra-cluster “communication cost” which is used to break “ties” (A tie in this context means that a node falls within the “range” of more than one cluster head, including the situation when two tentative cluster heads fall within the same range.)

Relay Heed and Unequal Heed all use the same CHprob equation as in Original Heed. Hierarchical Heed (also referred as HHEED) consists of electing 2 levels of CHs. The first level election uses the same CHprob equation as above, whereas the second level election is different from the first one where only the first level CH participate and their CHprob is calculated according to the following equation:

\[ CH\text{prob} = \frac{E_{\text{residual}}}{E_{\text{max}}} \times \left(1 - \frac{\text{ClusterSize}}{\text{NumNodes}}\right) \]

In the 2nd level CH election, the 2nd level CHs have an Unequal topology, where the 2nd level CHs which are near the BS have less members associated with it compared to those that are far away.

The advantage derived from such topology is that it prevents second level cluster heads from dying fast due to heavy relay and intra-cluster traffic. Here, a 1st level CH will join 2nd level CH with highest residual energy.

The main objective of HHEED is that it is more efficient for the relaying of packets to the base station. In this new algorithm, fewer nodes are involved for transmitting packets to the base station compared to Original Heed thus reducing the overall consumption of energy in the network and thus helping in prolonging the network lifetime.

Both HHEED and Unequal Heed form unequal clusters where cluster heads near BS will have less members associated with it compared to those that are far from BS. To achieve this kind of topology, each node decreases its competition radius as it nears the BS hence resulting in an unequal topology.

The competition radius (Rcomp) is a function of a node distance to the base station is given by:

\[ R_{\text{comp}} = \left(1 - c\frac{d_{\text{max}} - d}{d_{\text{max}} - d_{\text{min}}}BS\right)R_{\text{comp}}^{0} \]

Rcomp is the maximum competition radius which is predefined.

dmax and dmin denote the maximum and minimum distance between sensor nodes and the base station.
d(si, BS) is the distance between a node si and the base station.
c is a constant coefficient between 0 and 1.

4.1 Clustering Algorithm Design
In this section the pseudo code of Relay Heed, Unequal Heed and Hierarchical Heed are described.

4.1.1 Unequal Heed
I. Initialise
(a) Calculate communication range of node using the formula:
\[ R_{\text{comp}} = \left( 1 - c \frac{d_{\max} - d_{\text{si}, BS}}{d_{\max} - d_{\min}} \right) R_{\text{comp}}^0 \]
(b) For each node within communication range add node id of each neighbour found in an array (Snbr)
(c) Calculate cost of each node based on number of neighbours
(d) For each neighbour found in Snbr array send cost
(e) Calculate cluster head probability based on the formula:
\[ \text{CHprob} \leftarrow \text{max} \left( C_{\text{Prob}} \times \frac{\text{Eresidual}}{E_{\text{Max}}}, p_{\text{min}} \right) \]
(f) Set “Is_Final_CH” attribute to False

II. Repeat
(Repeat)
(a) For each node in Snbr, if node is a Tentative CH or a Final CH, add that node to an array (Sch array)
(b) If Sch is not empty, find node with least cost in the Sch array
   
   \( \text{My\_cluster\_head} \leftarrow \text{least\_cost}(\text{Sch}) \)
   
   If(\( \text{my\_cluster\_head} = \text{nodeid} \))
   
   If(Chprob = 1)
   
   Inform all neighbours(Snbr array) that I am a Final Cluster Head
   
   Is_Final_Ch \leftarrow True
   
   Else
   
   Inform all neighbours that I am a Tentative CH
   
   Else if(Chprob = 1)
   
   Inform all neighbours(Snbr array) that I am a Final Cluster Head
   
   Is_Final_Ch \leftarrow True
   
   Else if(Random(0,1) <= Chprob)
   
   Inform all neighbours that I am a Tentative CH
   
   (c) CHprevious \leftarrow Chprob
   
   (d) Chprob \leftarrow \text{minimum}(\text{Chprob} \times 2, 1)
   
   UNTIL Chprevious = 1
III. Finalise

(a) If(is_final_Ch = False)
    
    If(Sch contains atleast 1 final Ch)
    My_cluster_head ← least_cost(Sch)
    Join_cluster of least_cost node in Sch

(b) Else advertise myself as a final Ch

(c) Else advertise myself as a final Ch

4.1.2 Relay Heed
Relay heed is also a single level clustering algorithm, however, differs from unequal heed in the following way:
In relay heed, the communication range is a constant fixed in the algorithm and is not based on the distance from the base station.
After the election of cluster head ends, the process of choosing a relay among members of a cluster is done as follows:
(a) If node is a Final Cluster Head
(b) Build an array containing nodes that have joined the cluster
(c) If array is not empty
(d) Loop in array to find node with highest residual energy
(e) Assign it role of relay node

4.1.3 Hierarchical Heed
As the name suggests, in hierarchical heed there are more than one level of cluster heads. Election of first level cluster heads uses same parameters like that of Relay Heed without the election of relay node part. After election of first level cluster heads, a topology as shown in fig 1 is formed:

Fig 1: Topology of network after first level election.

In the election of second level cluster heads, only first level cluster heads participate. The topology for the second level clustering formed is that of unequal heed. Note that 2 parameters in hierarchical heed differs from unequal and relay heed in the Initialise part of the algorithm, that is, the cost and the Ch prob.

Fig 2: Topology of network after second level election completed. (Unequal sized clusters, smaller near base station).
I. Initialise for hierarchical heed

(a) Calculate communication range of node using the formula:

\[ R_{\text{comp}} = \left( 1 - c \frac{d_{\text{max}} - d}{d_{\text{max}} - d_{\text{min}}} \right) R_{\text{comp}}^{0} \]

(b) For each node within communication range add node id of each neighbour found in an array (Snbr)

(c) Calculate cost of each node based on residual energy of node

(d) For each neighbour found in Snbr array send cost

(e) Calculate cluster head probability based on the formula:

\[ CH_{\text{prob}} = \left( \frac{E_{\text{residual}}}{E_{\text{max}}} \right) \left( 1 - \frac{\text{ClusterSize}}{\text{NumNodes}} \right) \]

(f) Set “Is_Final_CH” attribute to False

The Repeat-Until and Finalise part remains the same as for unequal heed.

5. SIMULATION STUDY
A custom simulator was developed in Java to test the different topologies, energy spent to do the clustering and routing process. The parameters that were varied were the number of nodes in the network (the clustering and routing process of the different algorithms are run with different number of nodes) and the grid size which is the dimension of network area, e.g. 200m x 200m is varied. This represents the area on which the nodes have been deployed. As output from the simulator, the energy spent for clustering process (represents the total energy spent by the whole network when the clustering process is over) and the energy spent for routing of 1 packet (represents the total energy spent by the whole network when each sensor node sends a packet to the base station) are noted.

The following radio model is used in the simulation:
A sensor spends E\text{elec} = 50\text{nJ/bit} to run the transmitter or receiver circuitry and E\text{a} = 100\text{pJ/bit/m}^2 \text{ for the transmitter amplifier.} \text{ To transmit a k-size packet over a distance of d using the above radio model, the amount of energy consumed for transmission } ETX, \text{ is:}

\[ ETX = (E_{\text{elec}} \times k) + (E_{\text{a}} \times k \times d^2) \]

And the amount of energy ERX spent to receive a k-bit size message is:

\[ ERX = (E_{\text{elec}} \times k) \]

E\text{elec} refers to the bit energy consumption to run the transmitter or receiver circuitry.
E\text{amp} refers to the energy required by the sensor’s transmitter amplifier in order to transfer messages reliably.

<table>
<thead>
<tr>
<th>Table 2. List of simulation parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constant</strong></td>
</tr>
<tr>
<td>------------</td>
</tr>
<tr>
<td>Initial Energy of nodes</td>
</tr>
<tr>
<td>Broadcast size packet</td>
</tr>
<tr>
<td>Routing size packet</td>
</tr>
</tbody>
</table>
5.1 Energy consumption for clustering

In this simulation the dimension of grid is kept constant and the number of nodes is varied. The values in the table 3 and the graph in fig 3 show the energy consumed in millijoules for clustering a WSN of size 500m x 500m. The graph above shows that, hierarchical heed consumes less energy compared to the other two algorithms.

Grid Size: 500m x 500m

Output Description: Measure energy dissipated for clustering the network.

Table 3. Energy spent in cluster formation vs. Number of sensor – Grid Size 500x500

<table>
<thead>
<tr>
<th>Num of Sensors</th>
<th>Hierarchical Heed</th>
<th>Original Heed</th>
<th>Unequal Heed</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>33.31</td>
<td>53.29</td>
<td>56.30</td>
</tr>
<tr>
<td>1000</td>
<td>62.36</td>
<td>97.19</td>
<td>92.68</td>
</tr>
<tr>
<td>1500</td>
<td>101.07</td>
<td>137.36</td>
<td>137.55</td>
</tr>
<tr>
<td>2000</td>
<td>148.07</td>
<td>184.52</td>
<td>185.61</td>
</tr>
<tr>
<td>2500</td>
<td>201.06</td>
<td>241.95</td>
<td>245.58</td>
</tr>
<tr>
<td>3000</td>
<td>262.26</td>
<td>308.49</td>
<td>307.43</td>
</tr>
<tr>
<td>3500</td>
<td>338.63</td>
<td>383.56</td>
<td>390.36</td>
</tr>
<tr>
<td>4000</td>
<td>425.22</td>
<td>476.39</td>
<td>473.67</td>
</tr>
</tbody>
</table>

5.2 Energy consumption to route 1 packet with grid size 500x500

In this simulation the dimension of grid is kept constant and the number of nodes is varied. The energy dissipated for routing 1 packet to the base station is measured. The table 4 and the graph in fig 4 show the energy consumed to route 1 packet from a cluster head till the base station is reached. Hierarchical heed still consumes the least amount of energy for a grid size of 500m x 500m.
Grid Size: 500m x 500m

<table>
<thead>
<tr>
<th>Num of Sensors</th>
<th>Original Heed</th>
<th>Relay Heed</th>
<th>Unequal Heed</th>
<th>Hierarchical Heed</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>6.24</td>
<td>6.24</td>
<td>2.96</td>
<td>1.78</td>
</tr>
<tr>
<td>1000</td>
<td>7.32</td>
<td>8.36</td>
<td>4.96</td>
<td>2.74</td>
</tr>
<tr>
<td>1500</td>
<td>8.78</td>
<td>9.20</td>
<td>7.05</td>
<td>3.29</td>
</tr>
<tr>
<td>2000</td>
<td>10.32</td>
<td>10.53</td>
<td>9.35</td>
<td>3.96</td>
</tr>
</tbody>
</table>

Output Description: Measure energy dissipated for routing 1 packet to the base station.

Grid Size: 400m x 400m

<table>
<thead>
<tr>
<th>Num of Sensors</th>
<th>Original Heed</th>
<th>Relay Heed</th>
<th>Unequal Heed</th>
<th>Hierarchical Heed</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>9.27</td>
<td>9.34</td>
<td>4.01</td>
<td>2.63</td>
</tr>
<tr>
<td>1000</td>
<td>10.92</td>
<td>12.39</td>
<td>7.39</td>
<td>3.40</td>
</tr>
<tr>
<td>1500</td>
<td>14.51</td>
<td>15.48</td>
<td>10.40</td>
<td>4.42</td>
</tr>
<tr>
<td>2000</td>
<td>15.16</td>
<td>16.54</td>
<td>13.38</td>
<td>5.23</td>
</tr>
</tbody>
</table>

Table 4. Energy spent to route 1 packet vs. Number of Nodes (Grid size: 500x500)

5.3 Energy consumption to route 1 packet with grid size 400x400

In this simulation the dimension of grid is kept constant and the number of nodes is varied. The table 5 and graph in fig 5 show the energy consumed to route 1 packet from a cluster head till the base station is reached. Hierarchical heed consumes the least amount of energy for a grid size of 400m x 400m.

Grid Size: 400m x 400m

Output Description: Measure energy dissipated for routing 1 packet to the base station.

Table 5. Energy spent to route 1 packet vs. Number of Nodes (Grid size: 400 x 400)

Fig 5. Energy spent for grid size 400x400
6. INTERPRETATION OF RESULTS

Figure 3 shows that hierarchical heed spends the least energy relative to the other algorithms to cluster the network. The graph in fig 3 is labeled “energy spent for 2 clustering rounds” because since hierarchical heed involves 2 level of clustering, therefore 2 election process, it could not be compared to single level clustering algorithm like original and unequal heed. Therefore, these 2 algorithms were run twice and the results are shown in figure 3. From the graph of figure 3, it is clearly shown that hierarchical heed outperforms any other variants of heed.

Figure 4 consists of routing a packet to the base station. Each sensing node transmits to its cluster-head, which aggregates the data and forwards it to the next hop until the base station is reached. Since this paper is primarily about a clustering algorithm, the simulation study of the routing part serves only to prove how a particular topology formed by a specific clustering algorithm is more energy efficient.

In figure 5, it is clear that hierarchical heed again outperforms the other 3 algorithm by a significant saving in energy spent to route a packet from each node till the base station. To conclude, hierarchical heed saves energy both at the clustering level process and while performing routing.

7. CONCLUSION

The objective of this paper was to design a new energy efficient clustering algorithm for wireless sensor network. Hierarchical Heed extends Original Heed by electing 2nd level cluster heads. Electing 2nd level cluster heads together with data aggregation helps greatly in the routing process as this reduces considerably the amount of relay traffic that 2nd level cluster heads have to do.

Hierarchical Heed consists of two parts. In the first part cluster heads are elected same as in Original Heed. But in the second part, the 2nd level cluster heads are elected based on 2 new energy efficient parameters. The second part has been implemented in such a way that 1st level cluster heads has a high probability of being elected as a cluster if it is rich in residual energy and if it has the lowest number of sensor nodes associated with it. This condition has been possible to implement using the following formula:

\[
CH_{prob} = \left( \frac{E_{residual}}{E_{max}} \times \left( 1 - \frac{\text{ClusterSize}}{\text{NumNodes}} \right) \right)
\]

The use of the above parameter has helped to reduce the number of rounds during the clustering process from approximately 6 to 2, hence resulting in a reduction of energy consumption.

Moreover, the 2nd level cluster heads in Hierarchical Heed are elected in an unequal way, i.e. 2nd cluster heads that are near the base station will have less 1st level cluster head associated with it compared to the 2nd level cluster heads that are far away from the base station. The advantage of this kind of topology is that 2nd level cluster heads that are near the base station normally have a lot of relay traffic to do, hence, reducing their number of 1st level cluster head members will help them carry out their assigned tasks for a longer period. This feature was implemented using the following formula:

\[
R_{comp} = \left( 1 - c \frac{d_{max} - d_{BS}}{d_{max} - d_{min}} \right) R_{comp}^0
\]

From the simulation study, it has been noted that there is about 36 % of energy saving for Hierarchical Heed compared to Original Heed during the clustering process. During the routing process, Hierarchical Heed shows about 69 % energy savings compared to Original Heed. From these results, we can clearly deduce that Hierarchical Heed is much better than Original Heed and it also has extra features from Unequal Heed that will help to prolong the lifetime of the network by preventing 2nd level cluster heads that are near the base station from dying too early.

8. REFERENCES


