An Energy Conserving Cluster-Head Election Scheme for Wireless Sensor Networks

S. Jeba Anandh and E. Baburaj

Department of Computer Science and Engineering, University College of Engineering Nagercoil, Anna University Constituent College, Konam, Nagercoil, Tamil Nadu, India
Department of Computer Science and Engineering, Sun College of Engineering and Technology, Kanyakumari District, Tamil Nadu, India

Abstract: Clustering of wireless sensor nodes has proven to be an efficient method of conserving energy of the overall wireless sensor networks. In this clustered scenario, under diversified conditions, any node can drain its energy abruptly. When the wireless sensor nodes move around with random mobility, it is possible that there can be a sudden upsurge in data traffic in a particular region. The cluster-head node in these regions may be subjected to overloading of data processing. They collect data from their member nodes and forward them to other cluster-heads so that collected data can reach the base station. If cluster-heads lose energy, the data they collected may get lost and the nodes connected to them may get disconnected from the entire network. Therefore placement of cluster-heads should be efficient enough that they should have optimally dense nodes connected to them. We propose a dynamic cluster-head election scheme based on residual energy, distance from base station and distance between candidate cluster-heads and its member nodes. This cluster-head election and subsequent deployment ensures optimal usage of the energy reserve. We analyzed the network behavior in terms of energy efficiency and packet delivery rate. Our results showed that through rotating the cluster-head, the network conserved considerable amount of energy and also ensured data integrity.

Key words: Density • Cluster • Energy • WSN • Distance • Lifetime • Data-delivery

INTRODUCTION

The architecture of a wireless sensor node includes numerous number of sensor nodes equipped with an energy reserve and an antenna to send and receive data. The sensor nodes collect data such as pressure, temperature, humidity from the environment on which they are deployed and forward the collected data to the base station for further processing. Wireless sensor nodes find their applications in medical, military, wildlife and environment monitoring.

Important factors that affect the functioning of the wireless sensor networks are high energy consumption, node disconnection leading to data loss and network security. If efficient methodologies are not employed to overcome these issues, the nodes may die early due to lack of energy. All wireless sensor nodes are fitted with a small energy reserve by which the node should sense, transmit and receive data. Under random deployment of sensor nodes, it is possible that certain nodes may get concentrated to a particular region, where large amount of data processing takes place. This may also lead to network congestion requiring frequent retransmission of data packets. With the above scenario, the nodes drain energy very quickly creating a hot-spot area where nodes get disconnected from the network.

A better architecture that can conserve energy of the whole network is the clustering of nodes under a head node. In this clustered architecture, Sensor nodes (SN) are allowed to form into groups under a leader head node. Cluster-heads have the role of collecting data from its member nodes and forwarding them to other cluster-heads.

Corresponding Author: S. Jeba Anandh, Department of Computer Science and Engineering, University College of Engineering Nagercoil, Anna University Constituent College, Konam, Nagercoil, Tamil Nadu, India.
and subsequently to the base station. To have a good use of the energy reserve, single hop communication pattern is recommended for intra-cluster data transmission whereas multi-hop communication pattern is better for inter-cluster communication. Fig. 1 depicts the intra-cluster and inter-cluster communication pattern in a wireless sensor networks. Base station (BS) coordinates the cluster construction and cluster-head election process. One node in every cluster that is having high energy reserve is elected as the cluster head. But under dynamic conditions such as high mobility of nodes, the head node can be over or under utilized based on node density at a particular region. This uneven node distribution may decrease the life-time of the network.

This proposed work includes a cluster-head election process by employing energy threshold value for the cluster-heads. In-order to avoid frequent re-election of cluster-heads, sensor nodes can be allowed to join, disconnect and rejoin the different cluster-heads based on their mobility, energy reserve of the CH and a distance factor. With this we believe that the energy reserve of the cluster-head can be effectively utilized. When the energy level of cluster-head reaches the threshold level, the base station initiates CH re-election process. The Base station computes a distance factor of other nodes of that region based on their distance towards the base station. It correlates it with the energy reserves of the possible CH contenders. A node with good energy reserve and at an optimal distance accessible to other nodes is then elected as the new cluster head.

**Related Work:** There has been several works done in minimizing the energy required in operating a wireless sensor networks. Authors Jiguo Yua and et. Al. proposed a cluster based non-uniform node distribution [1] in which they addressed imbalanced energy consumption by cluster-heads. Cluster-heads with dense member nodes consume more energy whereas cluster-heads having less number of member nodes have high unused energy reserves. The work by Heinzelman and co-authors detailed a clustering protocol [2] that gathers data periodically using the cluster architecture. At each periodic operation, the current cluster-head is analysed for its energy reserve. If satisfactory amount of energy reserve was not available to continue with the next round of operation, then the authors initiated a cluster-head re-election process. Younis and Fahmy proposed a clustering protocol [3] that effectively increases the network lifetime. The authors in [4] put forward a method of cluster-head election based on the residual energy of nodes and number of rounds the node remains as member node. Here the node with comparatively low residual energy can be selected as CH.

The proposal by Li and Wen states that energy optimization [5] of the network using a single level of clustering. Sourabh Jain et al in their work [6] suggested a routing algorithm based on the placement of cluster-heads in the network. Sunil Srinivas and Martin Haenggi proposed a uniform distribution of nodes by which cluster-heads will have equal load. The work in [7, 8] by Saro and Heinzelman states an effective cluster-head election technique by which the energy-hole can be prevented. Here when a cluster-head’s energy reserve goes below a threshold level, a new cluster head with higher energy level is elected. In a decentralized [9] cluster based network, a square type of sensing field is assumed. An expected distance between the base station and individual was computed and based on that density of nodes in a particular sensing area was computed.

The authors in [10] suggests cluster head election technique based on distance and residual energy. This technique uses different election strategies for nearer and farther nodes. The suggest partitioning of nodes based on distance. Kim and et al. optimized the number of clusters [11] required for data collection. Neighboring smaller clusters are converged into single clusters to
effectively use unused energy reserve of the cluster-heads. Similarly larger clusters are allowed to disintegrate into optimal sized clusters to save the cluster-heads from dying. Authors in [12] are of the view that the network lifetime depends on nodes that consume more energy than others. They recommend the cluster radius should be fixed so that all nodes consume energy equivalently.

The proposal in [13] ensures minimum power cost during data transmission and protects nodes with relatively low energy reserve. The authors in [14] utilized the mobility of sink node for data collection. This technique allows sink to move towards unreachable nodes for collecting data. They found the data request flooding problem where redundant data request packets circulate the network causing high energy consumption affecting network life-time. Mariam and et al. [15] rank the nodes based on energy levels, distance between nodes and distance of nodes from base station. This rank forms the basis for electing new cluster-heads. This algorithm feeds future possible cluster-heads in advance thereby addresses the coverage problem.

The authors in [16] addressed the issue of mobile cluster-heads. They proposed methods of electing new cluster-heads when current cluster-heads move out of range. The authors [17] discussed the various cluster-head election techniques, their advantages and drawbacks. Afrashteh Mehr in [18] specified an imperialistic cluster-head election scheme in which cluster-heads were elected from sub-clusters by initiating a competition among them.

**Cluster-Head Election:** This work proposes a new cluster-head election technique called Dynamic CH Election (DCHE) based on residual energy and a distance metric. The distance metric is computed by relating the inter-node distances with base station distance. In this architecture, the nodes are distributed sparsely so that the sensing field is optimally dense. A circular region of sensing is considered in which the density of nodes at different levels are computed. Here we generate circular rings of regions in which density of individual sectors are computed. By comparing the density of different sectors, we made decisions on electing the number of cluster-heads required for different sectors. With this method we ensure that the nodes will always have good number of cluster-heads to join and accumulate their data. We analyzed our technique with other existing methods such as Leach and Equal CH Election (ECHE) for energy consumption and packet delivery rate.

**Inter-Node Distance Computation:** This inter-node distance is based on the density of the nodes in a particular region. Here a group of nodes that are in range with each other are taken into consideration. First step is to compute the received signal strength of the transmitting node. The power of the signal P can be computer using equation 1.

\[
P = \frac{V_{rms}^2}{I}
\]  

where \(V\) is the rms voltage of the received signal and \(I\) is the antenna impedance.

Therefore received signal strength can be computed in decibels as in equation 2.

\[
RSSI = 10\log_{10} \left( \frac{P}{0.001V} \right) \text{dbm}
\]

Path loss can be computed from RSSI to be the difference of the initial signal strength and received signal strength. Using path loss, the inter-node distance can be calculated as described in equation 3.

\[
d = \frac{10^\left(-10\log_{10}(\text{RSSI})/\gamma\right)_{dB}}{10^n}
\]

where \(pl\) is the path loss, \(d\) is the reference distance, \(\lambda\) is the signal wavelength and \(n\) is the signal decay component.

**Node Distance from Base Station:** As the base station has the capacity to reach all the nodes, it issues beacon signal to all the nodes requesting for their residual energy. Nodes at one-hop distance respond immediately to the BS. The Base station computes distance of these nodes using RSSI discussed in the previous section. But base station should use a different strategy to approximate the distance of nodes which are at multi-hop distances. The base station constructs a graph with edges representing the connection between intermediate nodes.

Farther nodes inform the base station with the inter-node distance of nodes along the path of the graph. Then base station approximates the total distance of a node from itself. This process is described in Fig. 2.

Base station also estimates the deviation of a node from its antenna position. This is required to determine the availability of other candidate cluster-heads in the neighborhood. Through an angle of deviation, the BS estimates the position of nodes that will opt to become cluster-heads. The position estimation of nodes by BS is illustrated in Fig. 3.
Algorithm for Cluster-Head Election: In our proposed method, a node is elected as CH based on its residual energy, its inter-node distance measure and its distance from base station. With these measures computed in the previous sections, we now state the following algorithm for cluster-head selection.

Step 1: BS initiates the process by sending beacon signals to all the sensor nodes.
Step 2: All the nodes receiving the beacon respond to the BS request by sending their residual energy level R.
Step 3: BS selects certain candidate nodes (K) based on higher residual energy and intimates them of being included in the future cluster-head list. These nodes sends acknowledgement.
Step 4: Next BS again sends beacon signals to this list of nodes to get their inter-node distance of one-hop nodes (IN) and node-BS distance (NB).
Step 5: These Candidate cluster-heads compute inter-neighbor node or one-hop node distance that provides a measure of the density of the nodes in their vicinity.
Step 6: NB is computed through a graph of intermediate nodes. The intermediate nodes compute distance of next hop node using step 5.
Step 7: BS computes the inter-candidate cluster-head distance using NB.
Step 8: If in a particular region the inter-node distance (IN) is low, the BS elects more cluster-heads whose NB is also low in that region.
Step 9: If IN is high BS elects fewer cluster-heads whose NB is also high.

Step 10: Iterate for the entire sensing region and elect cluster-heads from K.

This proposed algorithm not only takes into account residual energy, it includes inter-node distance and base station distance. This implies BS elects cluster-heads by considering the density of member nodes and also the density of candidate cluster-heads.

**Energy Consumption:** Energy has been the important constraint in the prolonging the life-time of the wireless sensor networks. Energy conservation by every single node enhances the network productivity considerably. Hence network architecture should be designed such that every node should occupy a reliable position in the network where it can expend only minimal energy. Clustering architecture was found to conserve more energy than other type of network architectures. In this proposed method, we elect cluster-heads based on factors such as residual energy and a distance factor comprising inter-node distance and BS-node distance. This enables our system to elect and place cluster-heads at appropriate positions where it can expend minimum energy in collecting and forwarding data. A candidate list of cluster-head can further aid in electing cluster-heads even when the current cluster-head drains energy quickly. Hence this proposed system is designed to conserve energy considerably through efficient cluster-head selection, thereby prolongs the life-time of the wsn network.

**Energy Consumption Model:** In wireless sensor networks, the total energy can be calculated for one-hop distance nodes and using this energy, total energy for multi-hop nodes in different rings of the network can be computed. Under this scenario, for one hop distance nodes, the energy required for transmission of bits of length n to a distance d is;

\[
E_{tx}(n, d) = E_{txelec}(n) + E_{transp}(n, d)
\]  
(5)

\[
E_{tx}(n, d) = \begin{cases} 
1 \times E_{elec} + 1 \times E_{trans} d^2, & d < d_0 \\
1 \times E_{elec} + 1 \times E_{trans} d^4, & d \geq d_0
\end{cases}
\]  
(6)

where \(E_{elec}\) is the energy dissipated for a single bit of data in the transceiver. The terms \(E_{elec}\) and \(E_{trans}\) refer to the energy dissipation for a single bit of the transmitting amplifier. \(d_0\) is the threshold distance for changing the amplification models. \(d_0\) can be calculated to be.

Similarly, energy required for receiving bits of length n can be expressed as;

\[
E_{re} = n \times E_{elec}
\]  
(7)

For multi-hop transmission, the number of hops can be incorporated into the above computation to find the total energy dissipation.

**Data Delivery:** In many wsn network architectures, algorithms were designed with the prime aim of conserving energy compromising data delivery. When hot-spots arise in the network or when nodes move out of range, the packets in transmission may get lost. In certain cases, the packet delivery rate may alarmingly go down so that it requires frequent retransmission of packets. This can further drain the energy of the node that is retransmitting.

In our proposed scheme, we efficiently place cluster-heads around optimal number of nodes so that there is no chance for any hot-spot to arise. The nodes going out-of-range is also minimized in this strategy as cluster-heads are elected based on node density of that region. The delivery rate is defined as the ratio of the number of packets received at a node or cluster-head to the number of packets send to it from other nodes or cluster-heads.

**Performance Analysis:** We analyzed this network for energy consumption and data delivery rate with the following initial conditions for the network parameters. Table 1 enumerated below specified the various network parameters used in this system.

We analyzed our proposed Dynamic CH Election (DCHE) system with other clustering protocols such as Leach and Equal sized Cluster Head Election (ECHE) for energy consumption and data delivery rate. As this proposed system (D-UCR) addressed the hot-spot or energy-hole problem and also distributed nodes in high dense region to different cluster-heads, our results yielded with less energy consumption compared to other two schemes. In Table 2, we listed the average energy consumption values for the above mentioned schemes.

With the analyzing of the number of packets delivered against the number of packets sent to a node or cluster-head, we summarized the average data delivery rate achieved in the three schemes in Table 3.
Table 1: Listing of Network Parameters with Initial Values

<table>
<thead>
<tr>
<th>Network Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sensing Area</td>
<td>Circular</td>
</tr>
<tr>
<td>2. Total number of nodes</td>
<td>100-1000</td>
</tr>
<tr>
<td>3. Radius of region</td>
<td>500m</td>
</tr>
<tr>
<td>4. Energy of node</td>
<td>5 KJ</td>
</tr>
<tr>
<td>5. Mobility</td>
<td>limited</td>
</tr>
<tr>
<td>6. Density of nodes</td>
<td>Varying</td>
</tr>
</tbody>
</table>

Table 2: Average Energy Consumption by Clustering Protocols

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.9094</td>
<td>0.8695</td>
<td>0.9287</td>
</tr>
<tr>
<td>200</td>
<td>1.6762</td>
<td>0.8451</td>
<td>0.9561</td>
</tr>
<tr>
<td>300</td>
<td>1.9438</td>
<td>0.8431</td>
<td>1.1653</td>
</tr>
<tr>
<td>400</td>
<td>2.2129</td>
<td>1.07731</td>
<td>1.2563</td>
</tr>
<tr>
<td>500</td>
<td>2.2535</td>
<td>1.186329</td>
<td>1.3842</td>
</tr>
</tbody>
</table>

Table 3: Average Data Delivery rate by Clustering Protocols

<table>
<thead>
<tr>
<th>Nodes</th>
<th>Avg. Data Delivery Rate in Leach</th>
<th>Avg. Data Delivery Rate in ECHE</th>
<th>Avg. Data Delivery Rate in DCHE</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0.82</td>
<td>0.91</td>
<td>0.96</td>
</tr>
<tr>
<td>400</td>
<td>0.78</td>
<td>0.85</td>
<td>0.92</td>
</tr>
<tr>
<td>600</td>
<td>0.754</td>
<td>0.834</td>
<td>0.93</td>
</tr>
<tr>
<td>800</td>
<td>0.72</td>
<td>0.8</td>
<td>0.89</td>
</tr>
<tr>
<td>1000</td>
<td>0.66</td>
<td>0.78</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Fig. 4: Comparison of Energy consumption in Leach and DCHE

These findings on energy consumption from Table 2 were plotted in an x-graph representation to visualize the protocol performance. It is clearly visible that even though Leach and ECHE are energy efficient, DCHE consumes lesser energy than the other two protocols. Fig. 4 represents the comparison of energy consumption by Leach and DCHE, whereas Fig. 5 visualizes the energy consumption by ECHE and DCHE. Fig. 6 represents energy comparison between Leach and ECHE. The analysis provided above demonstrates that the proposed cluster-head selection scheme consumes far lesser energy than other protocols.

Using Table 3, different data delivery rate graphs were plotted for our proposed DCHE and other two protocols ECHE and leach. Fig. 7 compares the average delivery rate of leach and DCHE. Fig. 8 depicts the comparison of average delivery rate of ECHE and DCHE and Fig. 9 compares ECHE and Leach.
Fig. 5: Comparison of Energy consumption in ECHE and DCHE

Fig. 6: Comparison of Energy consumption in ECHE and Leach

Fig. 7: Comparison of average delivery rate of Leach and DCHE
The results analyzed in the above sections reveal that the proposed cluster-head selection methodology outperforms other protocols both in terms of energy conservation and data delivery rate.

**CONCLUSION**

As energy is the major resource constraint in ad-hoc networks such as WSN, efficient algorithms to reduce the power consumption are required to enhance the life-time of the network. Even though clustered architecture conserves more energy than other protocols, improper cluster-head placement would result in heavy energy drain. In this work, a new cluster-head election and placement scheme was proposed in that we used residual energy and a distance metric was used for selecting cluster-heads from a candidate list. Using this scheme, we efficiently placed cluster-heads based on density of nodes as well as proper distances between cluster-heads and inter-nodes. From the performance analysis, it was evident that this scheme completely avoids abrupt energy consumption that may lead to hot-spots. This scheme
also enjoys high data delivery rate over other existing protocols. A future direction on this scheme can be to provide high mobility to the selected cluster-heads in which frequent disconnection happens.

REFERENCES