GATEWAY BASED STABLE ELECTION
MULTI HOP ROUTING PROTOCOL FOR WIRELESS SENSOR NETWORKS

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ABSTRACT

A gateway based energy efficient multi hop routing protocol for wireless sensor networks (WSNs) is introduced. The main aim of our paper is to design a protocol which minimizes energy consumption. Gateway nodes are deployed in sensing field. These gateway nodes are rechargeable, reduce traffic and also reduce distance for reliable transmission of data. Simulation results show that our proposed gateway based protocol is better in terms of network lifetime, stability period, throughput etc. than traditional protocol like SEP which is single hop.

KEYWORDS


1. INTRODUCTION

A wireless sensor network consists of hundreds and thousands of micro sensors nodes. These are designed to sense data, transmit it to user. The main components of WSN are: Sensor nodes, processor, Base Station (BS). Sensor nodes are basic component of WSNs. These are small in size, portable and light weight; the sensor nodes required sending data to BS. Another component BS is another main component that collects all the data from different nodes.

![Figure 1: A Typical Wireless Sensor Network](image)

Classical approaches like direct Transmission used to send data from sensor nodes directly to BS and in Minimum Transmission Energy (MTE) nodes near BS has higher probability to send data than nodes which are located far away from BS. Therefore, need to introduce concept of clustering. In clustering, number of sensor nodes select a Cluster Head (CH) on the basis of initial
or residual energy, and then cluster the remaining nodes with these heads. Sensor nodes transmit data to CH; the main function of CH is to aggregate data of sensor nodes and transmits it to BS [10]. Sensor networks can be classified as Homogeneous protocols and heterogeneous protocols. Example of Homogeneous protocol is LEACH (Low Energy Adaptive Clustering Hierarchy. It is very basic protocol in which concept of clustering is used. In LEACH, nodes are distributed randomly having same energy. Therefore, need to introduce concept of heterogeneity which increases lifetime of the network by dividing energy on some parameters, here SEP (Stable Election Protocol) is introduced. In SEP, nodes are divided as normal node and advanced node having different energy levels. Now, it becomes easy to choose CH, mainly advanced nodes become CH according to random number when compared with threshold values.

We propose a new gateway based SEP protocol, G-SEP, which increases network lifetime i.e. stability period, throughput and data transmission from nodes to CH as well as to BS. The proposed protocol senses that election probabilities are weighted on initial energy of node relative to that of other nodes in the network. In our proposed protocol, rechargeable gateway nodes are used which are placed at the edge of sensing field and BS is located far away from sensing field.

2. RELATED WORK

In [1], homogeneous clustering based LEACH routing protocol for WSNs is introduced. In LEACH, it uses same energy level for all sensor nodes which are randomly distributed over the sensing field; then CH is chosen and finally transmits data to BS. This technique shows improvement over DT, MTE, but need to be more improved.

In [8], heterogeneous clustering based SEP routing protocol is presented. Here, heterogeneity means different energy levels i.e. normal nodes and advance nodes are considered. The energy of advance nodes is higher than that of normal nodes. Advance nodes have more probability to become CH per iteration. Therefore, increases lifetime as compared to LEACH. However, transmission rate do not show much improvement.

In [10], an extension to SEP is introduced known as Enhanced SEP. In this, three levels of energies are used: normal nodes, intermediate nodes, advance nodes. Energy of advance nodes is highest then intermediate nodes then normal nodes. This protocol reduces distance among CHs and BS which prolongs lifetime of the network and also increases stability period.

In [11], heterogeneity aware hierarchical SEP for WSNs is designed. In HSEP, two energy levels of nodes are used i.e. normal and advanced nodes and even two types of CH are being elected; primary CH and secondary CH. Primary CH is being elected from sensor nodes while secondary is elected from primary CHs i.e. only primary CHs can take part in electing Secondary CH and transmits data to BS. This protocol outperforms DEEC, ESEP, SEP and LEACH.

In [12], a mobile sink based SEP is introduced. BS is kept mobile at the center trajectory so that nodes can easily transfer data directly to BS or via CH being elected from weighted election probabilities. It out performs SEP and LEACH, but mobility of BS is risky in dropping data and even cost is introduced to manage it.

In [13], gateway nodes are introduced, a gateway node is deployed at the place of BS and BS is moved out of the sensing field. In this research, energy consumption is reduced by dividing field into four regions. Region 1 sends data directly to BS, region 2 communicated directly to gateway node and region 3, 4 uses clustering technique i.e. CHs to transmit data to BS. M-GEAR outperforms well in terms of stability period, throughput and remaining energy than LEACH.
In [17], author proposed a modified energy efficient protocol named as EM-SEP. In the research, author modified CH selection criteria by balancing energy consumption to increase lifetime of the network and also to increase stability period of WSN. Even authors worked on the concept if there is more than one SN available to become CH then it would pick the node having highest energy. Simulation results showed that EM-SEP performs 5% in terms of stability period and 5% in lifetime of network than SEP.

In [19] Zonal-Stable Election Protocol (ZSEP) uses the concept of both direct transmission and clustering. ZSEP divides network field into three zones, zone0, head zone 1, head zone 2, where in zone 0 which is defined around sink that is close to sink are equipped with only normal nodes, and zone 1 and zone 2 are at corners or zone which are at distance from sink are equipped with advanced nodes, as they have more initial energy. Zone 0 nodes uses direct transmission of data to BS but head zone 1 and head zone 2 uses clustering approach (advance nodes) for data transmission to sink. Simulation results showed that there is 1.4 times improvement in stability period as compared to SEP.

In [20] author proposed Energy Consumption Rate based Stable Election Protocol (ECRSEP), in which CHs are elected on the basis of weighted election probabilities of each node according to the energy consumption rate (ECR) of each node. In ECRSEP energy consumption is calculated mathematically as shown in equation 2.1:

$$ECR = \frac{(e_{int} - e_r)}{(r-1)}$$

Where, $e_{int}$ is initial energy, $e_r$ is residual energy of each node and $r$ is current round. In next round CH is selected on the basis of ECR in previous round so, a CH selected in present round have less chances to be selected as CH in next round because of more ECR as compared to other nodes, so a node having high ECR have more chances of becoming cluster head node. Simulation results showed that ECRSEP performs well in terms of stable region, overall lifetime 3 times and 3.3 times respectively as compared to SEP.

In [25] fixed zone clustering protocol (FZCP) in which CH is elected on the basis of ratio of residual energy to its average energy as in DEEC and EDFM. Now, network area is divided into sub regions. As in other protocols like DEEC, SEP random number is generated and compared with threshold value, but in FZCP author introduced concept of cost function which is defined as product of ratio of residual energy to average energy and expected energy consumption to average energy consumption. Simulation settings and results showed 38% improvement in first dead node than SEP and 61% in terms of lifetime of the network than SEP.

3. NETWORK MODEL OF PROPOSED PROTOCOL

3.1 Basic Assumptions:

- We deploy the BS far away from the sensing field. Sensor nodes and the BS are stationary after deployment.
- A gateway node is deployed in the same network field at the edge of the network.
- Gateway nodes are stationary after deployment and rechargeable.
- Each sensor node has distinctive identifier (ID).
- Nodes are uniformly distributed in the network.
3.2 First Order Radio Model:

According to the radio energy dissipation model as illustrated in Figure 2, in order to achieve an acceptable Signal-to-Noise Ratio (SNR) in transmitting an $L$-bit message over a distance $d$, the energy expended by the radio is given by:

$$E_{TX}(l, d) = \begin{cases} \frac{L \cdot E_{elec} + L \cdot \epsilon_{fs}}{\epsilon_{mp}} \cdot d^2, & \text{if } d \leq d_o \\ \frac{L \cdot E_{elec} + L \cdot \epsilon_{mp}}{\epsilon_{mp}} \cdot d^4, & \text{if } d > d_o \end{cases}$$  \hspace{1cm} (1)$$

Where, $E_{elec}$ is the energy dissipated per bit to run the transmitter or the receiver circuit, $\epsilon_{fs}$ and $\epsilon_{mp}$ depends on the transmitter amplifier model, and $d$ is the distance between the sender and the receiver.

At $d=d_o$,

$$d_o = \frac{\epsilon_{fs}}{\epsilon_{mp}}$$  \hspace{1cm} (2)$$

We assume S1 sensors which are deployed randomly in a field to monitor environment. We represent $i^{th}$ sensor by $S_1$ and consequent sensor node set $S_1 = S_{1_1}, S_{1_2}, ..., S_{1_n}$.

Number of gateway nodes is deployed at the edge of the sensing field. The number of gateway nodes is chosen approximately according to sensor field area and formation of CHs. Its value is approx. 16. The major advantage of gateway nodes is they are rechargeable and it also reduces distance for transmission.
3.3 SEP (Stable Election Protocol)

In SEP protocol a percentage of population of sensor nodes is equipped with additional energy resources, this is a source of heterogeneity. The nodes are randomly distributed over the field and BS is located far away from sensing field. The advance nodes have higher probability to become CH than that of normal nodes. CH is being elected on the weighted probabilities of initial energy. Fractions of nodes ‘m’ are equipped with additional energy factor ‘α’. Now, suppose $E_0$ is initial energy of system, energy of advance node is $E_0 (1+α)$, then total initial energy is

$$n \times (1 - m) \times E_0 + n \times m \times E_0 \times (1 + α) = n \times E_0 (1 + am)$$

Total energy is increased by $(1 + am)$ times. Now, to optimize stable region, new epoch is $\frac{1}{P_{opt}}. (1 + am)$ because system has increased by $am$.

Probability for normal nodes to become cluster heads once every $\frac{1}{P_{opt}}. (1 + am)$ round per epoch.

Probability for advance nodes to become cluster heads exactly $1+α$ times every $\frac{1}{P_{opt}}. (1 + am)$ round per epoch.

To prolong the stable region there is need the constraint of maintaining well balanced energy consumption, which can be done by defining weighted election probability which is given in equation 4
\[ W = \frac{\text{Initial Energy of each Node}}{\text{Initial Energy of Normal Node}} \]  

(4)

For normal nodes weighted probability is-

\[ p_{nrm} = \frac{p_{opt}}{1+m\times\alpha} \]  

(5)

For advanced nodes weighted probability is-

\[ p_{adv} = \frac{p_{opt}}{1+m\times\alpha} \times (1 + \alpha) \]  

(6)

As advanced nodes have \( \alpha \) time more initial energy they must have to be cluster head \( \alpha \) times more than normal nodes, which are ensured by these equations. There are different threshold values for normal and advanced nodes which are given below:

Threshold function for normal nodes-

\[ T(n_{nrm}) = \begin{cases} 
\frac{p_{nrm}}{1-p_{nrm}} r \times \text{mod} \left( \frac{1}{p_{nrm}} \right), & \text{if } n \in g' \\
0, & \text{otherwise}
\end{cases} \]  

(7)

Where \( r \) is current round, \( g' \) is set of normal nodes that have not been cluster head in last \( \frac{1}{p_{nrm}} \) rounds.

Threshold function for advanced nodes-

\[ T(n_{adv}) = \begin{cases} 
\frac{p_{adv}}{1-p_{adv}} r \times \text{mod} \left( \frac{1}{p_{adv}} \right), & \text{if } n \in g'' \\
0, & \text{otherwise}
\end{cases} \]  

(8)

Where \( r \) is current round, \( g'' \) is set of advance nodes that have not been cluster head in last \( \frac{1}{p_{adv}} \) rounds.

4. **OUR PROPOSED PROTOCOL**

In this section, we present detail of our gateway based protocol. The function of CHs is to aggregate data of sensor nodes and sends it to the base station. In order to improve network lifetime, we make use of gateway nodes which are deployed at the edge of the sensor field. The numbers of gateway nodes are selected on the approximation basis of formation of number of CHs so that each CH can send data to nearest located gateway node. It reduces time consumption. The main function of gateway nodes is to collect data from CHs, aggregate it and sends to the BS. The gateway nodes are rechargeable so cost is minimized. Another advantage is in case if one of gateway node is damaged then it can be overcome by another nearest located gateway node. Gateway nodes reduces traffic problems as having multiple numbers of gateway nodes so, distance is also reduced. Sensor nodes which are very closer to gateway nodes can transmit data directly to gateway node if it is free i.e. not receiving data from CH. The whole process is divided into three phases: one is to sense data according to requirements; second is election of CH on the basis of weighted election probabilities of initial energies and comparing threshold values with random generated number, usually advance nodes take part in this; third is to transmit data from
CH to nearest located gateway node by calculating minimum distance to increase stability period of the network. These gateway nodes aggregate data and transmit it to BS. Equations for gateway based SEP are:

For gateway based, normal nodes weighted probability is-

\[
P_{\text{norm}} = \frac{p_{\text{opt}}}{1 + m_1 \times \alpha_1}
\] (9)

For gateway based, advanced nodes weighted probability is-

\[
P_{\text{adv}} = \frac{p_{\text{opt}}}{1 + m_1 \times \alpha_1} \times (1 + \alpha_1)
\] (10)

5. SIMULATION RESULTS

5.1 Simulation Settings

We simulated our proposed protocol using MATLAB. Consider a WSN with nodes randomly distributed in 100*100 fields. We compare our proposed protocol with existing SEP protocol.

Table 1: Radio Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Of Nodes</td>
<td>n 100</td>
</tr>
<tr>
<td>Initial Energy</td>
<td>(E_0) 0.5 [J]</td>
</tr>
<tr>
<td>Packets Sent</td>
<td>Message Size 4000 [bits]</td>
</tr>
<tr>
<td>Transmitter and Receiver Energy</td>
<td>(E_{\text{elec}}) 50 [nJ/bit]</td>
</tr>
<tr>
<td>Dissipation Energy</td>
<td>(E_{\text{DA}}) 5 [nJ/bit/signal]</td>
</tr>
<tr>
<td>Free Space Energy</td>
<td>(\epsilon_{fs}) 10 [pJ/bit/m²]</td>
</tr>
<tr>
<td>Multipath Propagation Energy</td>
<td>(\epsilon_{mp}) 0.0013 [pJ/bit/m²]</td>
</tr>
<tr>
<td>Number of Rounds</td>
<td>No. of Iterations 2000</td>
</tr>
<tr>
<td>Fraction of Advance Nodes for SEP</td>
<td>m 0.3</td>
</tr>
<tr>
<td>Fraction of Extra Energy for SEP</td>
<td>(\alpha) 3.5</td>
</tr>
<tr>
<td>Fraction of Advance Nodes for Proposed SEP</td>
<td>m1 0.4</td>
</tr>
<tr>
<td>Fraction of Extra Energy for Proposed Gateway SEP</td>
<td>(\alpha_1) 3</td>
</tr>
</tbody>
</table>
5.2 Stability period (FND)

It is the time interval from the start of the network operation until the death of the first node. This is also referred as “stable region” as shown in Figure 4. This figure depicts that First dead node of proposed protocol is at 1381 round and for SEP is 1318 i.e. stability period is increased of our proposed protocol.

![Figure 4: First Dead Node](image)

5.3 Number of Half dead nodes per iteration

It is measure the total number of nodes and that of each type that has expended half of their energy as shown in figure 5. This figure shows that in our gateway based protocol at round 700, 57 nodes are half dead, than they remain constant till round 1700 and at 2000 they are fully dead; and in SEP there are 70, half dead nodes at round 700. Therefore, number of dead nodes decreases in our proposed protocol.

![Figure 5: Number of Half Dead Node](image)
5.4 Number of dead (total, Normal and advanced) nodes per iteration:

This instantaneous measure the total number of nodes and that of each type that has expended all of their energy as shown in figures 6, 7, 8.

Figure 6 depicts total number of dead nodes it is 57 in case of proposed protocol and 70 in SEP.

Figure 7 depicts those Number of Normal dead nodes: all the normal nodes are dead in both the cases.

Figure 8 depicts those Number of Advance dead nodes: there is no advance node dies.

Figure 6: Number of Dead Nodes
5.5 Number of alive (total, Normal and advanced) nodes per iteration:

The total number of nodes and that of each type that has not yet expended all of their energy as showed below in figure 9, 10, 11.

Figure 9 depicts number of alive nodes it is 43 in our proposed protocol and 30 in case of SEP.

Figure 10 shows number of Normal alive nodes at round 2000 no normal node is alive, all are dead.

Figure 11 shows number of advance alive nodes; at round 2000 all advance nodes are alive it is 40 in our proposed protocol and 30 in SEP.
5.6 Data Packets to Cluster Heads:

The result for amount of data transmitted by nodes to their respective cluster heads is shown in figure 12. Figure depicts rate of data transmitted to CH in our Gateway based protocol is much higher as compared to SEP as shown in figure at round 2000, 35% of data is transmitted while traditionally only 20% is sent.
Figure 12: Number of packets sent to CH

5.7 Data Packets to Base Station:

The result for amount of data transmitted by cluster heads to base station is shown in figure 13. Figure depicts rate of data transmitted to BS in our Gateway based protocol is much higher as compared to SEP as shown in figure at round 2000, 22% of data is transmitted while traditionally only 12% is sent.

Figure 13: Number of packets sent to BS
5.8 SEP Throughput:

It is defined as total rate of data sent over the network i.e. it is rate of data sent from sensor nodes to their CHs and CHs to BS. Throughput of G-SEP and Sep is shown in figure 14 which depicts that throughput of Proposed protocol is much higher than that of SEP.

![Throughput of SEP](image)

Figure 14: Throughput of SEP

<table>
<thead>
<tr>
<th>Operation</th>
<th>SEP</th>
<th>Proposed Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Node Dies</td>
<td>1318</td>
<td>1381</td>
</tr>
<tr>
<td>Number of Dead Nodes</td>
<td>70</td>
<td>57</td>
</tr>
<tr>
<td>Number of Normal dead nodes</td>
<td>70</td>
<td>57</td>
</tr>
<tr>
<td>Number of Advanced dead nodes</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Number of Alive Nodes</td>
<td>30</td>
<td>43</td>
</tr>
<tr>
<td>Number of Normal alive nodes</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Number of Advanced alive nodes</td>
<td>30</td>
<td>40</td>
</tr>
</tbody>
</table>
6. CONCLUSION AND FUTURE SCOPE

A gateway based network model in order to minimize energy consumption of sensor network is designed. In this research, numbers of gateway nodes are located at the edge of sensing field area. The base station is located away from the sensing field. This technique encourages better transmission of data which further increases lifetime of the network. Simulation results are computed in MATLAB and check for the efficiency of our proposed protocol. Simulation results show that our proposed protocol performs well in term of stability period, network lifetime, packets sent to BS and CHs, throughput than existing Stable election Protocol. This proposed protocol can be extended by considering residual energy in formation of CHs or can also be extended by considering intermediate nodes having energy less than advance nodes but more than normal nodes.

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REFERENCES


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Harminder Kaur is working as an Assistant Professor in India’s one of most reputed Institute Guru Nanak Dev Engineering College Ludhiana, located in Punjab. She had completed her M.Tech. in communication systems in 2010 and having 3.5 years of teaching experience. She has published around 10 research papers in international and national conferences.