RESEARCH ARTICLE


Sandeep Verma¹*, Neetu Sood¹ and Ajay Kumar Sharma²

¹Electronics and Communication Engineering, Dr BR Ambedkar National Institute of Technology, Jalandhar, India; ²I. K.G. Punjab Technical University, Kapurthala, India

Abstract: Background: The green Information and Communications Technologies (ICTs) have brought a revolution in uplifting the technology efficiently to facilitate the human sector in the best possible way. Green Wireless Sensor Network (WSN) tactically focuses on improving the survival period of deployed nodes (as they have a limited battery) in any target area.

Objectives: To address this concern, the main objective is to improve the routing in WSN. The cluster-based routing helps in acquiring the same with the appropriate Cluster Head (CH) selection. The use of energy heterogeneous nodes that normally comprise of high energy nodes, puts a lot of financial burden on the users as they incur a huge cost, thus becoming a bottleneck for the growth of green WSN. Therefore, another objective of the study is to reduce this cost involved in the network.

Method: A cost-effective routing protocol is proposed that introduces energy-efficient CH selection by incorporating parameters namely, node density, residual energy, the total energy of network and distance factor. Thus, the proposed protocol is termed as Cost-Effective Cluster-based Routing Protocol (CECRP) as it performs remarkably better with only two energy level nodes as compared to state-of-the-art protocols with three levels nodes.

Results and Conclusion: It can be encapsulated from the simulation results that CECRP outperforms state-of-the-protocols on different performance metrics. Furthermore, it is comprehended from the simulation results that CECRP proves to be 33.33% more cost-effective as compared to the competent protocols, hence CECRP favors the green WSN.

Keywords: Cost-Effective; Green WSN; CECRP; Cluster-based routing; Cluster head selection.

1. INTRODUCTION

The Wireless Sensor Networks (WSNs) have shown to be a promising sensing technology but been suffering from the bottleneck of limited energy resources [1, 2]. WSNs comprise numerous spatially distributed sensor nodes, which are basically exploited to monitor the environment for various factors namely, humidity, temperature, vibration, pressure or any detection of moving object [3]. These sensor nodes have the capability to undergo wireless communication with other nodes or sink in single-hop or multi-hop manner [4]. Due to such sensing and wireless communication capabilities, there are numerous applications of WSNs which are only limited to the human imagination. The development in MEMS (Micro-Electro-Mechanical Systems) technology has helped in the production of small-sized and low-cost sensor nodes that can be deployed over large areas for monitoring [5].

Once nodes are deployed in unattended areas, it is infeasible to replace the batteries of these nodes that get depleted due to the wireless communication. Once the battery is dead, it becomes non-operational and it does not collect any data; furthermore, the network suffers from connectivity loss. Therefore, it is essential to design a model for energy-efficient communication within nodes or between nodes and sink [6]. These energy-efficient techniques help in acquiring enhanced network lifetime which is defined as ‘the number of rounds completed till all nodes are dead’ [7].

Large area monitoring inevitably requires multi-hop communication to avoid long haul communication which eventually devours energy of a high magnitude. Cluster-based routing has been promising in dealing with large area networks by facilitating networks with enhanced scalability,
uniform load balancing, reducing the number of data transmissions, etc. [8].

1.1. Heterogeneous WSN

When nodes deployed are of the same configuration, the network is said to be homogeneous, whereas the network deployed with different energy levels of nodes are heterogeneous networks [9]. The heterogeneity in a node can be of different genres namely, sensing, computational, coverage and energy [10]. Many researchers have proposed various heterogeneous routing protocols that have achieved enhanced stability period of the network as compared to homogeneous routing protocols. So, in this work, energy heterogeneity of the nodes is taken into consideration.

A network can be made heterogeneous by incorporating different energy levels of sensor nodes. It starts from the two energy levels (i.e., normal and advanced nodes) wherein advanced nodes carry more stock of energy as compared to normal nodes in a protocol known as Stable Election Protocol (SEP) [11]. The number of energy levels of nodes is further increased to three levels (normal, intermediate and advanced nodes) in EEHC (Energy Efficient Heterogeneous Clustered) scheme [12]. In order to acquire the enhanced stability period, the number of heterogeneous nodes is further enhanced to four levels in BEENISH (Balanced Energy Efficient Network Integrated Super Heterogeneous) protocol [13]. These protocols focus on proposing the energy-efficient method of Cluster Head (CH) selection for energy-efficient routing. It is noteworthy to mention that a CH has the responsibility to collect the data from the cluster nodes and after aggregating the data, it forwards it to the sink. The inclusion of different parameters for CH selection namely, energy and distance has helped in acquiring a better network performance. However, very few techniques have incorporated node density factor that helps in selecting a node to be CH that is surrounded by a greater number of nodes as compared to any other node.

1.2. Problem Definition and Objectives

A. Problem Definition: In the quest of acquiring a higher stability period and network lifetime, many researchers follow the approach of increasing the number of energy levels of the nodes in the network [14]. However, the cost factor involved in incorporating these higher energy nodes is overshadowed. The increase in the cost of the nodes tends to exert a huge financial burden on the users working for a particular application for a green WSN [15]. Furthermore, CH selection is another important concern which must be addressed so that the survival period of CH could be improved. Therefore, there is a requirement of energy-efficient CH selection that compensates for the decreased level of energy heterogeneity.

B. Objectives: In consideration of the problem defined above, the following objectives are framed.

a. The primary objective is to reduce the effective cost of the network for employing energy heterogeneity in nodes, while still acquiring the enhanced network performance.

b. Another objective is to select CH by including the essential parameters along with mostly exploited parameters which are residual energy and distance to the sink. It is done to elongate the survival of CH node.

In order to compensate for both the cost factor and energy-efficient CH selection, the following contributions are reported.

1.3. Major Contributions

There are two significant contributions reported in this manuscript that are highlighted as follows.

a) In this work, Cost-effective Cluster-based Routing Protocol (CECRP) is proposed that selects a node with respect to CH on the basis of parameters namely, residual energy, the total energy of the network, ‘distance between the node and the sink’ and node density factor.

b) CECRP is made cost-effective by incorporating the network with only two energy levels of nodes that too with very less stock of initial energy as compared to the competitive protocols namely, DRESEP (Distance-based Residual Energy-efficient Stable Election Protocol) [16], SEECP (Stable Energy Efficient Clustering Protocol) [17] and TERP (Threshold-sensitive Energy-efficient Routing Protocol) [18]. CECRP (proposed work) still outperforms the aforementioned protocols on the benchmark of different performance metrics namely, stability period, network lifetime and network’s remaining energy.

1.4. Novelty Analysis of Proposed Work

In the development of energy-efficient routing techniques in WSN, the various levels of energy heterogeneous nodes are considered for network stability and longevity. However, the attention of the research, towards the increased cost of the network due to the different levels of energy heterogeneous nodes, is still missing.

Therefore, this is the first-ever attempt towards handling the financial burden i.e., increased network cost due to the different levels of energy heterogeneous nodes. Another striking feature of the proposed work is that it not only reduces the financial expenditure occurring due to the various heterogeneous nodes but also uplifts the network performance by the proposed CH selection technique. Hence, the network performance is not compromised with the reduced number of levels of energy heterogeneous nodes.

The rest of the manuscript is organized as follows. Section 2 discusses the related work in the field of heterogeneous WSN and the methods of their CH selection. Section 3 presents the proposed protocol CECRP and the discussions about the set-up and steady-state phase are covered. The simulation results are presented in Section 4 and finally, the conclusion and future scope are discussed in Section 5.

2. RELATED WORK

A plethora of research has reported the advancements made in cluster-based routing techniques. The nodes are as-
assumed to be homogeneous, but due to different morphological and operational factors, the nodes always differ in their initial energy before coming to any operation. Cluster-based routing has helped in abating the number of data transmissions in the network [19]. In this work, the heterogeneous routing protocols focusing on clustering, have been studied [20]. SEP [11] was the first protocol that decided upon the CH selection on the basis of different weighted probabilities. It failed to operate for multi-level heterogeneous networks. DEEC (Design of a distributed Energy-Efficient Clustering) algorithm [21] selected CH by defining the ratio of residual energy to the average energy. It outperformed SEP, however, it suffered from the penalization of advanced nodes which resulted in the frequent selection of advanced nodes as CH. DDEEC (Developed Distributed Energy-Efficient Clustering) [22] worked for the avoidance of penalization of advanced nodes. They introduced the energy threshold for deciding upon the CH selection. Simulation results showed the significant improvement made by DDEEC as compared to DEEC. When the improvement over the stability period was reported at the two levels, EEHC [12] introduced the CH selection at three energy levels. It considered the energy factor but the distance factor was not incorporated that made it inefficient. Furthermore, EEHC still suffered from the penalization effect on the high energy nodes. The number of energy-levels of nodes was increased to four in the case of BEENISH. It again suffered from the penalization of nodes that reduced its performance. The sink mobility was introduced in iBEENISH (Improved BEENISH) [23] that improved the performance of BEENISH protocol and also avoided the penalization effect. However, the increase of energy levels of nodes up to four had exerted a huge financial burden thereby making it highly expensive pertaining to any application.

Many researchers have focused on mitigating the hot-spot problem to reduce the energy consumption of sensor nodes [24-26]. Further for uniform energy consumption, Cooperative transmission for the selection of hop device was exploited [26]. In our recently published work [28-30], we proposed cluster based routing technique specifically designed for the harsh environment applications. Some crucial QoS (Quality of Service) aware routing techniques have been reported by some researchers [31-32]. Furthermore, while handling QoS parameters, the delay is investigated as it occurs while data transmission is in progress for multi-hop communication [33-34]. To deal with such a problem for the large area network, researchers opted for a zone concept in WSN [35-36]. Some of the techniques that focused on network longevity with energy-efficient clustering are reported [19] [32][35].

Aforementioned studied protocols are pro-active protocols suitable for attended applications. Whereas, some protocols are developed to work for unattended applications namely, forest fire detection, volcanic eruptions, etc. [36]. TSEP (Threshold-sensitive stable election protocol) [37] worked based on the threshold value i.e., hard threshold and soft threshold, to preserve the energy of nodes. DRESEP [16] selected CH on the basis of not only energy but also the distance factor. It adopted dual-hop communication by incorporating a pre-fixed radius of a circular region defined across the sink that ultimately decides for dual-hop or single hop. The dual-hop communication leads to the energy hole problem. The advancement to DRESEP was made in SEECP [17] that fixed the number of CHs in the network and worked towards acquiring the stability of the network. SEECP fixed the circular radius on the basis of physical geometry. Though the simulations result of SEECP outperformed DRESEP, it still suffered from the energy hole problem. PSEP (Prolong Stable Election Protocol) [38] selected CH on the basis of energy parameter and worked to achieve a higher stability period. The fuzzy-based techniques have been proposed for network longevity and some of the work related to the sensing heterogeneity is also discussed [39, 40].

TERP [18] selected CH on the basis of Boolean Differential Evolution schemes that optimize the CH selection. The protocol is still not energy-efficient as it neither considers the node density factor nor it attempts any effort for the hotspot problem.

2.1. Research Gap

The heterogeneous protocols discussed above have proposed one or the other solutions to efficiently select the CH [41]. None of the protocols have given any consideration to the cost incurred by incorporating heterogeneous nodes of higher energy resources. The inclusion of node density factor will surely lessen the communicating distance of nodes from the other nodes in the cluster. Considering all these important issues, CECRP is proposed that improves the CH selection. After reviewing the configuration of different sensor nodes, it is comprehended that with the increase in energy values of any node, the cost of that particular node is increased significantly. Therefore, a research focus towards the enhanced cost of the network is missing rather researchers have been focusing more on the energy efficiency of the sensor nodes.

3. CECRP

This section discusses the working operation of CECRP by reporting set up and steady-state phase which are discussed as follows.

3.1. Network Assumptions

a) There are few following network assumptions which are taken into consideration for the operation of CECRP. The sensor nodes of two energy levels namely, normal and advanced nodes are deployed in the network and kept stationary along with sink for the entire run of the network. The energy of advanced nodes is more than the normal nodes. These sensor nodes do not have any GPS equipment installed on their devices i.e., these nodes are located unaware.

b) After random deployment of nodes, it is assumed for non-availability of recharging source. So, once a node is dead, it cannot be recharged.

c) As soon as the nodes are deployed, they get connected to each other by the exchange of messages. Sink broadcasts HELLO message in the
network, to which nodes acknowledge by sending their unique IDs. Then those IDs are broadcasted by the sink in the network so as to connect each node with one another.

d) The radio interference, signal attenuation or intervention made by different objects and any damage caused to the nodes under harsh environmental conditions are not taken into consideration.

e) The connection between nodes is symmetrical.

f) The sink is assumed to be enriched with unlimited power supply.

g) The security aspects for the wireless communication by the nodes are beyond the scope of this manuscript.

h) The term ‘green’ is used in the manuscript to emphasize on the energy efficient as well as the cost-effective approach adopted for WSN.

When the data transmission is carried out in the network, as a matter of fact when nodes are switched on for operation, the energy consumption takes place by following the radio energy model.

3.2. Radio Energy Model

In this paper, the fundamental radio energy consumption model is used for both the protocols as shown in Fig. (1). It decides for the amount of depletion of energy for all the nodes that communicate in the network. As can be seen in Fig. (1), the transmit and receive electronics are used that are held responsible for the switching on and off the circuit of transmitter and receiver.

The energy consumed while the network is in operation is demonstrated by the set of eq. (1-5). The computational energy is considered to be negligible. So, while formulating the energy model, the energy depleted during communication is taken into consideration.

The eq. (1-2) describe the consumption of energy by the node while pursuing data transmission at a different value of distance. The energy consumed in the transmission of f-bit data at the distance d is represented by $E_{tx}(f, d)$ and given as follows.

$$E_{tx}(f, d) = f \times E_{elec} + f \times E_{amp} \times d^2 \text{ for } d \leq d_o$$

(1)

The term $d$ used in the above equations represents the distance between the source and destination nodes or between nodes and sink. $E_{elec}$ represents the energy consumed for switching on and off the transmitter and receiver circuitry. The threshold distance is represented by ‘$d_o$’ and is expressed as in eq. (3).

$$d_o = \frac{E_{elec}}{\sqrt{E_{amp}}}$$

(3)

The characteristics of transmitter amplifiers are given by $E_{efs}$ and $E_{amp}$ where $E_{efs}$ is for free space energy model (power loss $d'$) and $E_{amp}$ accounts for the energy consumed for multi-path energy model (power loss $d''$).

The energy consumed while receiving the data per bit is given by eq. (4).

$$E_{rx}(f) = f \times E_{elec}$$

(4)

The CH which performs the data aggregation consumes energy as given by the eq. (5).

$$E_{dx}(f) = m \times f \times E_{da}$$

(5)

The amount of energy used for free space model is given by $E_{efs}$ and the energy consumed in the reception of f-bit data is represented by $E_{rx}$. $E_{da}$ is the energy consumed in data aggregation of 1-bit data. Moreover, $E_{dx}(f)$ is the energy expenditure during data aggregation of received f-bit data of m number of data packets.

3.3. Operation of CECRP

The network of CECRP is operated in a similar way to any clustering protocol under two phases namely, set up and steady-state phase.

3.3.1 Set up phrase

The set-up phase includes network formation and CH selection which is discussed as below.

3.3.1.1. Network Formation in CECRP

The total number of advanced and normal nodes is given by a set of equations (6-13). In these equations, the proportion of a number of advanced nodes is represented by $m$ fraction of total number of nodes which is denoted by $n$. The
The total number of advanced and normal nodes is represented by \( N_{ADV} \) and \( N_{NRM} \) respectively.

\[
N_{ADV} = n \times m \quad (6)
\]

\[
N_{NRM} = n \times (1 - m) \quad (7)
\]

The advanced nodes are \( \alpha \) times higher in energy as compared to normal nodes as shown in eq. (8). \( E_{ADV} \) and \( E_{NRM} \) represent the energy of all advanced and normal nodes, respectively.

The total energy of the network is given by \( E_T \) which is computed in eq. (12). The step-wise computation of the energy of the network is done as follows.

\[
E_{ADV} = E_0 \times (1 + \alpha) \times n \times m \quad (8)
\]

\[
E_{NRM} = E_0 \times (1 - m) \times n \quad (9)
\]

\[
E_T = E_{ADV} + E_{NRM} \quad (10)
\]

\[
E_T = E_0 \times (1 + \alpha) \times n \times m + E_0 \times (1 - m) \times n \quad (11)
\]

\[
E_T = n \times E_0 \times (1 + m \times \alpha) \quad (12)
\]

The notations \( \alpha \) and \( m \) are the energy and number fractions of advanced nodes, respectively. The energy of normal nodes given by \( E_0 \), \( E_T \) is computed in eq. (8-12), as it is to be incorporated in the threshold formula for CH selection. These equations give the laconic description of the heterogeneous structure of proposed protocols.

3.3.1.2. CH Selection in CECRP

The CH selection in DRESEP protocol followed the same criteria as in NEAP [42] protocol but it added distance parameter to its threshold formula. The values of the probabilities and threshold for each type of nodes are discussed as follows.

\[
P_N = \frac{p}{(1 + m \times \alpha)} \quad (13)
\]

\[
P_A = \frac{p(1 + \alpha)}{(1 + m \times \alpha)} \quad (14)
\]

The notations used in above eq. (13-14) are defined as follows. \( P_N \) and \( P_A \) represent the probabilities for normal and advanced nodes, respectively.

\( P \) is the optimum probability of a node to become CH in the network that ultimately helps in constructing the optimal number of clusters in the network. The threshold values for normal and advanced nodes are computed in equations (15-16), respectively. The rest of the terms are the same as defined in the above subsection.

In eq. (15-16), the notations \( D_{avg} \) and \( D_{NS} \) are used to define the average Euclidean distance of all the nodes from the sink and distance of a node from the sink, respectively.

\( N_{DNSTY} \) is the node density of a node computed by discovering the node which is at the least distance from the other nodes. \( E_{RES} \) is the residual energy of the node which is updated after every round and \( E_T \) is the total energy of the node which is computed from the eq. (12). The current number of rounds is represented by \( r \).

3.3.2. Steady-state phase

This phase follows the same procedure as of DRESEP by following the dual-hop communication. The radius is fixed at 30 m distance from the sink. The main focus of this manuscript is the energy-efficient selection of CH that could improve the network performance. So, the steady-state phase is the same as that of DRESEP protocol.

3.4. Methodology of CECRP

The whole operational methodology for CECRP is shown in Fig. (2). The steps considered for the methodology of CECRP are discussed below.

a. In the set up phase, the heterogeneous nodes are deployed with two energy levels in a network where the sink is located in the middle of the network.

b. The probability for each type of nodes i.e., normal or advanced nodes is determined by using eq. (13-14).

c. Simultaneously a random number is generated for each node going through the selection race of CH. The threshold value (T.V.) for the particular is computed by using one of eq. (15-16). Thereafter, T.V. is compared with a random number (R.N.), if the R.N. value is found to be less than the T.V., a node is said to be cluster member node else it is declared as CH.

d. In steady-state phase, cluster member nodes send data to the sink and for the selected CH, distance (denoted by \( D \)) is calculated from the sink. If \( D \) is less than Radius denoted by \( R \), CH sends data to the sink directly, else it is forwarded to the nearest CHs inside the region.

\[
T(N_N) = \left\{ \frac{P_N}{1 - P_N \times \text{remod}(\frac{1}{P_N})} \times \frac{D_{avg}}{D_{NS}} \times N_{DNSTY} \times \frac{E_{RES}}{E_T} \right\} \quad (15)
\]

\[
T(A_N) = \left\{ \frac{P_A}{1 - P_A \times \text{remod}(\frac{1}{P_A})} \times \frac{D_{avg}}{D_{NS}} \times N_{DNSTY} \times \frac{E_{RES}}{E_T} \right\} \quad (16)
\]

e. Energy (denoted by \( E \)) is checked for each \( i^{th} \) node, where \( i \) ranges from 1 to \( N \) (total number of nodes i.e., 100). If the energy of the \( i^{th} \) node becomes zero, that node is said to be dead (denoted by \( D_N(i) \)). If \( D_N(i) \) is equal to \( N \) then the whole network is said to be dead and the network stops functioning. Otherwise, the \( D_N(i) \) is incremented to 1 and the next node is considered for the whole process of threshold computation.

3. RESULTS AND DISCUSSION

In this section, the simulation analysis of CECRP is discussed. The simulation is done using MATLAB software version 2015a [43]. The simulation parameters for simulation of CECRP are kept same as that of TERP. However, the energy of normal and advanced nodes is assigned as 0.5 Joule and 1 Joule, respectively. The normal and advanced nodes are 80 and 20 in number, respectively.
3.1. Simulation Assumptions

There are some assumptions that are considered while performing the simulation analysis.

a. The parameters considered for the simulation analysis are given in Table 1.

b. While implementing the proposed routing technique in the simulation tool, the physical obstruction to the message signal is not considered.

c. It is assumed that the mathematical model of the proposed work is easy to implement in MATLAB Software.

d. The ideal scenario for implementation is taken into consideration. The physical medium through which the signal is sent is assumed to be free from any constraint of the physical medium.

e. The number of iterations occurring in the proposed work is considered to be the number of rounds getting covered by the proposed technique.
f. Signal attenuation due to the scattering and reflection is not considered in this work while simulation.

3.2. Simulation Analysis

The simulation analysis presents the simulation results acquired for the different performance metrics. These are explained as follows.

a) Stability Period: The stability period is the number of rounds covered until any node is depleted of its energy or it is dead. The simulation results show that the stability period for CECRP is 7552 rounds as compared to 5063, 4610 and 3877 rounds of TERP, SEECP and DRESEP protocols, respectively as shown in Fig. (3). CECRP improves the stability period of TERP, SEECP and DRESEP by 49.14%, 63.8% and 94.76%, respectively.

The reason for such improvement is the addition of node proximity factor that reduces the distance among the CHs and the cluster member nodes. That ultimately reduces the energy consumption caused due to data transmission to CHs from the far located cluster member nodes. Furthermore, the

<table>
<thead>
<tr>
<th>Table 1. Simulation parameters.</th>
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<tr>
<td><strong>Network Parameters</strong></td>
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<tr>
<td>Network Area Size</td>
</tr>
<tr>
<td>Number of Nodes ($N$)</td>
</tr>
<tr>
<td>Initial energy of nodes (in Joules) ($E_{in}$)</td>
</tr>
<tr>
<td>Energy heterogeneity Node Type</td>
</tr>
<tr>
<td>Energy fraction of advanced nodes ($\alpha$)</td>
</tr>
<tr>
<td>Number of advanced nodes fraction ($m$)</td>
</tr>
<tr>
<td>Energy required for running transmitter and receiver ($E_{elec}$)</td>
</tr>
<tr>
<td>Threshold distance ($d_a$)</td>
</tr>
<tr>
<td>Amplification energy required for smaller distance $d \leq d_a$ ($E_{efs}$)</td>
</tr>
<tr>
<td>Amplification energy required for larger distance $d &gt; d_a$ ($E_{emr}$)</td>
</tr>
<tr>
<td>Energy consumption incurred while data aggregation ($E_{da}$)</td>
</tr>
</tbody>
</table>

Fig. (3). Performance comparison of CECRP against other protocols. (A higher resolution / colour version of this figure is available in the electronic copy of the article).
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Factors of residual energy, distance to the sink and total energy, help in the selection of the appropriate node for the role of CH. The inclusion of all these factors not only reduces the effective distance of the CH nodes from the cluster member nodes, consequently, the survival period of every node is elongated.

b) Network Lifetime: The number of rounds completed till all nodes are depleted of their energy is termed as network lifetime. The network lifetime of CECRP is found to be 18,294 rounds whereas the network lifetime of TERP, SEECP and DRSEP protocols for 19,169, 4,620 and 16,749 rounds, is respectively as observed from Figs. (3 and 4).

As the energy is preserved for all types of nodes, the nodes are able to sustain for a longer period thereby enhancing network lifetime. It is to be noted that the network lifetime of CECRP is very competitive to TERP but slightly lower. It is due to the load balancing in the network that reduces the instability period and thereby reduces the network lifetime with some rounds. However, the loss of information is very insignificant in the last stages of network operation. In other protocols, for example in TERP, the network reliability is compromised with the increased instability period. Therefore, it is always in the interest of the researchers that they must exploit their techniques in a way that they have reduced instability period so that once the whole network is dead, the new network could be deployed in the same field area.

c) Network’s remaining energy: It is very interesting to note down the fact that the initial energy of the network is kept at 105 Joules but in case of other comparative protocols, it is 140 Joules as shown in Fig. (5). Even though the network energy of CECRP is very less initially, still it is able to cover a competitive number of rounds as compared to other protocols. It is due to energy-efficient CH selection proposed in the network. The reason behind the lower value of initial energy in the proposed protocol is the reduced number of energy heterogeneous nodes. In comparison to the TERP and other protocols, only level-two energy heterogeneous nodes are considered that account for the less energy as compared to the competent protocols. When the proposed work considers the involvement of crucial factors for CH selection, the effective energy of the nodes is preserved. The effective distance of the CH nodes from their respective cluster members is reduced comprehensively which ultimately reduces the energy consumption of the network.

d) Cost-effective HWSN: It is one of the essential metrics that is predominantly targeted in this work. It is to be noted that for CECRP, the total energy of the network is taken as 105 Joules, whereas the total energy of TERP and other protocols is taken as 140 Joules. The aggregated performance of CECRP is given in Table 2. The energy consumed by CECRP is 33.33% less than the competitive protocols. Consequently, it reduces the cost of the network by 33.33%. As the network performance is achieved by the CECRP in terms of stability period and network lifetime, therefore, it can be comprehended that CECRP is one of the most cost-effective heterogeneous protocols as compared to TERP, SEECP and...
With such a gigantic reduction in the cost factor, this method is expected to relax the financial burden on the users and will help them to enhance the scalability of the network for the given application.

e) Aggregated improvement by CECRP: The performance of the protocol CECRP against other protocols is shown in Table 3.

Table 2. Aggregated percentage improvement by CECRP.

<table>
<thead>
<tr>
<th>Protocols</th>
<th>Stability Period (%)</th>
<th>Cost saving (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TERP</td>
<td>49.14</td>
<td>33.33</td>
</tr>
<tr>
<td>SEECP</td>
<td>63.18</td>
<td></td>
</tr>
<tr>
<td>DRESEP</td>
<td>94.76</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Overall improvement of CECRP against other protocols.

<table>
<thead>
<tr>
<th>P.M.</th>
<th>DRESEP</th>
<th>SEECP</th>
<th>TERP</th>
<th>CECRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>FND</td>
<td>3877</td>
<td>4610</td>
<td>5063</td>
<td>7552</td>
</tr>
<tr>
<td>HND</td>
<td>7836</td>
<td>4615</td>
<td>8503</td>
<td>12132</td>
</tr>
<tr>
<td>LND</td>
<td>16749</td>
<td>4620</td>
<td>19169</td>
<td>18295</td>
</tr>
</tbody>
</table>

FND, HND, LND, P.M. are abbreviated for First Node Dead, Half Node Dead, Last Node Dead and Performance Metrics, respectively.

It is evident from Table 3 that the protocol CECRP has outperformed the other protocols in terms of FND and HND as it covers 2489 and 3629 more rounds as compared to TERP. However, the LND is 874 rounds less as compared to TERP. It is one of the added advantages to the network pertaining to applications where the instability period should be as minimum as possible. As given in Table 3, the instability period (Instability Period=FND-LND) of the CECRP is found to be 10743 rounds, whereas in case of TERP, it is 14106 rounds. In the applications such as forest fire detection and military applications, it is imperative to have the least instability period. Therefore, the CECRP outperforms the other protocols in terms of the above discussed performance metrics.

CONCLUSION

Green WSN has been promising in assigning different roles to nodes for data dissemination according to their energy stocks. A node with a high value of energy costs more than that of low value and due to the same reason, more levels of energy heterogeneous nodes to be deployed make the entire network quite expensive. To resolve this concern, in this paper, CECRP is proposed that renders a cost-effective network. It incorporates energy-efficient CH selection with only two levels of energy heterogeneous nodes deployed in the network. The point worth noting is that these deployed nodes incur less cost due to their low value of energy stock, still outperforming TERP, SEECP and DRESEP protocols. The parameter of node proximity helps in lessening the distance of cluster member nodes from the CH that consequently helps in energy preservation of nodes, eventually enhanc-
ing the stability period and network lifetime. It is observed through the simulation that CECPR improves stability period by 49.14%, 63.8% and 94.76% as compared to TERP, SEECP and DRESEP protocols, respectively.

In future, the work can be extended to two modules; in first, the mobility of sink will be introduced to acquire high throughput, thereby reducing the delay caused in data delivery. In the second phase, the proposed work can be extended for the data transmission scenario with multiple data sinks around each periphery of the network. Quality of service parameters (QoS) can be analyzed for thorough investigation of the proposed work.

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