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Energy efficient heterogeneous DEEC protocol for enhancing lifetime in WSNs

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In this paper, we propose a 3-level heterogeneous network model for WSNs to enhance the network lifetime, which is characterized by a single parameter. Depending upon the value of the model parameter, it can describe 1-level, 2-level, and 3-level heterogeneity. Our heterogeneous network model also helps to select cluster heads and their respective cluster members by using weighted election probability and threshold function. We compute the network lifetime by implementing DEEC protocol for our network model. The DEEC implementation for the existing 1-level, 2-level, and 3-level heterogeneous network models are denoted as DEEC-1, DEEC-2, and DEEC-3, respectively, and for our proposed 3-level heterogeneous network model, the DEEC implementations are denoted as hetDEEC-1, hetDEEC-2, and hetDEEC-3, respectively. The network lifetime in DEEC-3 and hetDEEC-3 increases by 154.17% and 182.67%, respectively by increasing the total network energy 100% with respect to the original DEEC.

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1. Introduction

The wireless sensor networks (WSNs) contain hundreds or thousands of sensor nodes equipped with sensing, computing and communication abilities. Each node has the ability to sense the environment for an activity or object and can perform simple computations. A sensor node either communicates among its peers to collect the sensed data or sends (receives) the data to (from) a base station. A base station connects the sensor networks to another network. Designing protocols for sensor networks has to be energy aware in order to prolong the network lifetime, because the replacement of the embedded batteries in sensors is a very difficult process, once these have been installed. The WSNs should utilize their network energy in an efficient way so that they can communicate their sensed observations to the base station. A mobilizer may sometimes be needed to move sensor nodes when required to carry out the assigned tasks [2]. The nodes in wireless networks can be deployed deterministically or randomly. The deterministic deployments are more preferable in applications where the deployment area is physically accessible. The examples include the line in sand for target tracking, city sense for urban monitoring, soil monitoring, etc., where the sensor nodes are placed manually at the selected locations. On the other hand, random deployment of sensor nodes are used when the deployment area is physically inaccessible, e.g., bird observation on Great Duck Island, Mines, etc. In such environments, the sensor nodes are dropped from an aircraft [3–6].

The most important issue in WSNs is related to longevity of the network, which is directly or indirectly influenced by the network.
energy. The efficient utilization of the network energy may be done by organizing the sensors into groups, called clusters. Each cluster has a master node, which is also called the cluster head and several sensor nodes as members of it. The cluster head usually performs the fusion and aggregation. In order to have longer lifetime, the network should have good amount of energy. The network energy can be increased by increasing the number of sensors in the monitoring area. Increasing the number of sensor nodes does increase the network energy, but the cost is quite high because deploying an extra sensor incurs the cost of the sensor, which is ten times more than the cost of the batteries. Therefore, it is more appropriate and economical to increase the network lifetime by deploying some sensors with high battery. The sensor networks with such characteristics, i.e., sensor node with different energy levels are termed as heterogeneous wireless sensor networks [7]. In this paper, we propose a 3-level heterogeneous network model for WSNs to prolonging the network lifetime. Our heterogeneous network model also helps to select cluster heads and their respective cluster members by using weighted election probability and threshold function.

The rest of the paper is organized as follows. Section 2 discusses the literature review. Section 3 discusses the proposed 3-level heterogeneity network model and in Section 4, clustering process of heterogeneous distributed energy efficient clustering protocol for 3-level heterogeneity network model are discussed. In Section 5, experimental results are discussed and finally in Section 6, the paper is concluded.

2. Literature review

The WSNs have attracted several researchers because of their potential applications and related challenges. They have several applications like military applications, environmental applications, health applications, scientific exploration, area monitoring and structural health monitoring, etc. At the same time, they have numerous challenges like simplicity, coverage, connectivity, scalability, robustness, fault-tolerance, security, efficient use of energy, etc. One of the most important challenges is related to the enhancement of network lifetime so that it can observe the monitoring area for long time for the activities of objects. The network lifetime is essentially related to the efficient use of network energy. Accordingly, several approaches have been developed including various protocols. The very first protocol for increasing the lifetime in WSNs was discussed by Heinzelman et al. in 2000, which is known as low energy adaptive clustering hierarchy (LEACH) protocol [8]. It is one of the most accepted protocol based on clustering. In clustering, the sensors are divided into groups, each group is called as cluster. There is a master node in each cluster, called cluster head, that collects the data from its cluster members and sends that data directly or via some intermediate nodes to the base station. All sensors don’t send the data directly to the base station rather they send their data through cluster heads that is why it is called hierarchical protocol.

In LEACH, the cluster heads may not be dispersed uniformly in the entire region as they are selected randomly. Another problem in LEACH is that the number of cluster head nodes is not fixed due to stochastic selection. These problems have been addressed in LEACH-C and fixed LEACH [9], by dispersing the cluster heads all over the network so that it can produce better performance. In LEACH-C, the base station (BS) organizes the nodes and controls the network. In each round of LEACH-C, a node needs to send its residual energy and location information to BS. Based on the received information, the BS can uniformly distribute the cluster heads throughout the topology and adjusts the size of each cluster. The BS also adjusts the probability of selecting the cluster heads according to the nodes’ residual energy because the BS carries out energy intensive tasks like cluster formation and cluster head selection. In fixed-LEACH, the number of cluster head is fixed. The sensor nodes choose their nearest node as cluster head where the number of supported nodes may be different for each cluster head. This leads to the uneven energy dissipation among the nodes. The LEACH has been modified by Lindsey and Raghavendra [10] and named as power efficient gathering in sensor information systems (PEGASIS) protocol. The PAGASIS protocol is nearly optimal in terms of energy cost for data gathering applications. The key idea in PEGASIS is to form a chain among the sensor nodes so that each node receives from and transmit to a closest neighbour node. The gathered data moves from node to node, gets fused, and, eventually, a designated node transmits it to the base station (BS). The nodes take turns in transmitting to the BS so that the average energy spent by each node per round is reduced. It, however, due to excessive delay, is not suitable for large networks. Manjeshwar et al. discuss the threshold sensitive energy efficient sensor network (TEEN) protocol [11] based on hierarchical clustering. In this protocol, a cluster head broadcasts two thresholds to the nodes, which are called as hard and soft thresholds for sensed attributes. The hard threshold is the minimum possible value of an attribute to trigger a sensor node to switch on its transmitter and transmit to the cluster head. Thus, the hard threshold allows the nodes to transmit only when the sensed attribute is in the range of interest; thus reducing the number of transmissions significantly. The soft threshold further reduces the number of transmissions if there is a little or no change in the value of the sensed attribute. The TEEN is however not good for applications where the periodic reports are generated because some users may not get any data at all if the thresholds are not reached. The TEEN protocol has been extended in [12] and the resultant protocol is known as adaptive threshold sensitive energy efficient sensor network (APTEEN) protocol. This protocol is meant for capturing periodic data collections and time-critical events. It allows users to set threshold values and a count time interval. The main drawbacks of the APTEEN protocol are overhead and complexity of forming the clusters. Younis et al. discuss hybrid energy efficient distributed (HEED) clustering protocol [13], an extension of the LEACH protocol, which uses two parameters for selecting the cluster heads. The primary parameter for cluster heads selection is the residual energy and the secondary parameter as degree of the node. The degree of a node and the number of nodes in its range, help in distributing the load among cluster heads for load balancing. It has low overhead in terms of processing cycles and message exchanged. This protocol does not assume any distribution of the nodes or location awareness.

For past few years, the WSNs have mainly focused on technologies based on the homogeneous WSNs in which all nodes have same system resources. Recently, the heterogeneous wireless sensor networks are becoming more and more popular. The researches [14,15] show that heterogeneous nodes can prolong the network lifetime and improve the network reliability without significantly increasing the cost. The heterogeneous nodes are more capable of providing data filtering, fusion and transport; but they are more expensive than the homogeneous nodes. A heterogeneous node may possess one or more types of heterogeneous resources, e.g., enhanced energy capacity or communication capability. Compared with the normal nodes, they may be configured with more powerful microprocessor or more memory or both. They may also communicate with the base station via high-bandwidth and long-distance network. The deployment of heterogeneous nodes increases the network energy and hence the network lifetime. There have been some works that discuss heterogeneous network models. Smaragdakis et al. discuss stable election protocol (SEP) [16], an extension of LEACH, that uses heterogeneity. It is the very first protocol, which talks about heterogeneity. In this protocol, a
node becomes cluster head on the basis of weighted election probability, which uses a function of the remaining energy of the nodes to ensure uniform usage of node energy. The underlying network of the SEP considers two levels of heterogeneity, consisting two types of nodes, known as normal and advanced nodes. The energy of the advanced node is higher than the normal nodes and their number is less than that of the normal nodes due to the increased cost factor. Let $N$ be number of sensor nodes deployed in a monitoring area. Suppose, $E_0$ is the initial energy of a normal node and $m$ is the fraction of the advanced nodes, which has $\alpha$ times more energy than a normal node. Then there are $m \cdot N$ advanced nodes equipped with initial energy of $E_0 \cdot (1 + \alpha)$, and $1 - m \cdot N$ are normal nodes. This network model provides longer lifetime due to the increased network energy brought by more powerful nodes. The total energy of the 2-level heterogeneous network model [16], denoted by $E_{\text{total}}$, is given by

$$E_{\text{total}} = N \cdot E_0 \cdot (1 + \alpha \cdot m)$$  \hspace{1cm} (1)$$

The network energy is increased by a factor of $1 + \alpha m$. Each normal node becomes a cluster head once in every $\frac{1}{\alpha m + 1}$ rounds; each advanced node becomes a cluster head exactly $(1 + \alpha)$ times in every $\frac{1}{\alpha m + 1}$ rounds; and the average number of cluster heads per round is equal to $N \cdot p_{\text{opt}}$. Here $p_{\text{opt}}$ is a pre-determined percentage of cluster heads (e.g., $p_{\text{opt}} = 0.05$, $p_{\text{opt}}$ is $5\%$ of the total number of nodes are selected as cluster heads initially). Thus, an advanced node becomes cluster head $(1 + \alpha)$ times more at the end of each round than the normal node. The average number of cluster heads that are advanced nodes per round is equal to $N + m \cdot p_{\text{opt}}$. Thus, the average total number of cluster heads per round is given by

$$N \cdot (1 - m) \cdot p_{\text{opt}} + m \cdot N \cdot p_{\text{opt}} = N \cdot p_{\text{opt}}$$  \hspace{1cm} (2)$$

Li et al. discuss the distributed energy efficient clustering protocol (DEEC) [17] protocol by considering 2-level and multilevel heterogeneous WSNs. The 2-level heterogeneity model is exactly same as discussed in [16]. In multilevel heterogeneous network model, the energy of each sensor node is randomly allocated from a given energy interval. The total energy of the network with multilevel heterogeneity [17], denoted by $E_{\text{total}}$, is given by

$$E_{\text{total}} = \sum_{i=1}^{N} E_0 \cdot (1 + \alpha_i) = E_0 \cdot (N + \sum_{i=1}^{N} \alpha_i)$$  \hspace{1cm} (3)$$

In multilevel heterogeneity, the energy of a sensor node is randomly allocated from the given energy interval $[E_0, E_0 \cdot (1 + \alpha_{\text{max}})]$, where $E_0$ is lower bound of energy interval and $\alpha_{\text{max}}$ determines upper bound of the energy interval. Initially, the ith node is equipped with initial energy of $E_0 \cdot (1 + \alpha_i)$, which is $\alpha_i$ times more energy than the lower bound $E_0$ of the energy interval. In this network, all nodes are having different levels of energy due to random allocation. This multilevel heterogeneous network model is hardly of any use because each node has different energy level and designing sensor nodes of large number energy levels may not be practically feasible. Mao et al. discuss an effective data gathering algorithm (EDGA) for heterogeneous WSNs [14]. It considers three levels of heterogeneity by introducing three types of nodes: normal, advanced, and super nodes. The energy of an advanced node is higher than a normal node and the energy of a super node is higher than an advanced node. The total energy for 3-level heterogeneous network model [14], denoted by $E_{\text{total}}$, is given by

$$E_{\text{total}} = N \cdot E_0 \cdot (1 + m + (\alpha \cdot (1 - m_0) + m_0 + \beta))$$  \hspace{1cm} (4)$$

where $m$ fraction of $N$ as advanced nodes and $m_0$ fraction of the advanced nodes as super nodes. $E_0$ is initial energy of a normal node. The energies of the advanced and super nodes are, respectively, $\alpha$ and $\beta$ times more than that of a normal node. Thus the energies of each super and advanced nodes are $E_0 \cdot (1 + \beta)$ and $E_0 \cdot (1 + \alpha)$, respectively. The weighted election probability of each node is used in cluster heads selection so that the heterogeneous energy capacities are efficiently utilized.

Kumar discusses two distributed protocols namely, single-hop energy-efficient clustering protocol (S-EECP) and multi-hop energy-efficient clustering protocol (M-EECP) [18]. In S-EECP, the cluster heads are elected by a weighted probability based on the ratio between residual energy of each node and average energy of the network. He observed that in single-hop communication where data packets are directly transmitted to the BS without any relay nodes, the nodes located far away from the BS have higher energy consumption because of long range transmission, and these nodes may die out first. This problem is solved in M-EECP by using multi-hop communication to the BS. M-EECP uses a greedy approach to solve the single source shortest problem to find the shortest path from each cluster head to the BS. Farouk et al. discuss a stable and energy-efficient clustering (SEEC) protocol and extend it to multi-level SEEC [19]. It depends on network structure that is divided into clusters. Each cluster has a powerful advanced node and some normal nodes deployed randomly in this cluster. In the multi-level architectures, more powerful super nodes are assigned to cover distant sensing areas. Each type of nodes has its role in the sensing, aggregation or transmission to the base station. Chand et al. discuss a heterogeneous HEED protocol for WSNs [20,21]. It considers three parameters, i.e., residual energy, node density, and distance. It applies fuzzy logic to determine the cluster heads. In this protocol data may be lost if cluster heads are not able to communicate with each other. Singh et al. discuss an energy-efficient protocol using fuzzy logic for heterogeneous WSNs [22] and is an extension of [20]. It considers four parameters, i.e., residual energy, node density, distance, and distance between the base station and the sensor. It applies fuzzy logic to determine the cluster heads. In this protocol data may be lost if cluster heads are not able to communicate with each other. Paper [23], discusses a multilevel heterogeneous network model for WSNs. It describes result up to seven level of heterogeneity. Furthermore, it also considers four parameters for fuzzy clustering as residual energy, node density, distance, and distance between the base station and the sensor. Xiao et al. discuss a cell-clustered algorithm for energy efficiency (CC-HEED), an extension of [13]. The inner cluster regions of the network are divided into several cell-shaped areas, in which cell nodes are brought out to assemble the data in each cell area by considering power consumption model. The concentric clustering scheme (CCS) is used to reduce the energy consumption loopholes in PEGASIS. The main idea of CCS is to consider the location of the BS to enhance its performance and to prolong the lifetime of the network [24]. Singh et al. discuss a novel energy efficient clustering protocol (NEECP) for increasing the network lifetime in WSNs [25]. This technique selects the cluster heads in an effective way with an adjustable sensing range and performs data aggregation using chaining approach. It also avoids transmission of redundant data by using a redundancy check function for improving the network lifetime. It is implemented by considering the data with aggregation and without aggregation. We use DEEC protocol to estimate the network lifetime for our proposed network models. In the next section, we will discuss proposed 3-level heterogeneous networks model.

3. Proposed 3-level heterogeneity network model

In this section, we discuss our proposed 3-level heterogeneous network model. The basic assumptions made for the network in our model are as follows:

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This model describes a wireless sensor network that consists of three types of sensor nodes based on their energy levels. The nodes having more energy are supposed to be costlier than those having less energy. Because of the high cost, the nodes having maximum energy are assumed to be minimum in numbers. The nodes having a minimum energy level are the cheapest ones and hence they can be deployed abundantly. We assume that the WSN has N number of nodes out of which Θ * N nodes have minimum energy, where 0 < Θ < 1. We may call them as the normal nodes and the energy of a node of these types is denoted as E0. The Θ² * N nodes have more energy than the normal nodes. We may call these nodes as the advanced nodes and denote the energy of such a node by E1. The remaining (N – (Θ * N + Θ² * N) nodes have maximum energy, denoting the energy of a node by E2. These nodes may be called as super nodes. Thus, we have the inequalities for the number of nodes and their energy levels as given below.

\[ \Theta * N > \Theta^2 * N > (N - (\Theta * N + \Theta^2 * N)) \] and, \[ E_0 < E_1 < E_2 \] (5)

Eq. (5), indicates the low energy nodes or normal nodes are higher than the other types of nodes. It reduces the network cost because the nodes having less energy are supposed to be cheapest than those having more energy. Thus, the nodes having minimum energy are assumed to be maximum in numbers.

The total network, energy, \( T_{energy} \), is given by

\[ T_{energy} = \Theta * N * E_0 + \Theta^2 * N * E_1 + (1 - \Theta - \Theta^2) * N * E_2 \] (6)

We will show that this model (6) can describe 1-level, 2-level, and 3-level heterogeneity depending on the value of Θ, which is the model parameter. The bounds of Θ are 0 and 1 initially. When Θ = 0, we have only one term in (6) as the first two terms in (6) become zero. For Θ = 0, \( T_{energy} \) in (6) contains super nodes only, which signifies 1-level heterogeneity. We may also call it as homogeneous network because the network contains only a single type of nodes. In this case, a node in the network has E2 energy. We impose suitable constraints so that the model contains normal nodes rather the super nodes in case of 1-level heterogeneity. This can be obtained by defining the following relation:

\[ \Theta = \frac{E_2 - E_0}{n \cdot [E_1, E_2]} \] (7)

where \( n \) is a positive integer greater than 1 and \( f \) is a function of \( E_1 \) and \( E_2 \). In a very simple form, we can have \( f \) either \((E_2 + E_1)\) or \((E_2 - E_1)\). The value of \( \Theta \) in (7) should be in the consonant with the constraint: \( E_0 < E_1 < E_2 \).

We will now show that this model can describe 2-level heterogeneity, i.e., the network contains only two types of nodes. For this, we find the value of \( \Theta \), which is given by the solution of the following equation:

\[ 1 - \Theta - \Theta^2 = 0 \] (8)

Eq. (8) is not an arbitrary; it basically diminishes the third term in (6), thus making the model of 2-level heterogeneous. Using (8), the model (6) contains two types of nodes: normal and advanced nodes. Eq. (8) has two solutions: \((\sqrt{5} - 1)/2\) and \((\sqrt{5} + 1)/2\). Since Θ is upper-bounded by 1 and \((\sqrt{5} + 1)/2 > 1\), the valid solution of (8) is \((\sqrt{5} - 1)/2\)

For 3-level heterogeneity, we need to determine the range of \( \Theta \). The upper bound of its range is \((\sqrt{5} - 1)/2\). Let the lower bound of \( \Theta \) be \( \Theta_l \) that is to be determined. The range of \( \Theta \) for 3-level heterogeneity is \( \Theta_l < \Theta < (\sqrt{5} - 1)/2 \).

Taking \( f \) as \((E_2 - E_1)\) and \( \Theta \) from (7), we have

\[ \Theta_l < \frac{E_2 - E_0}{n \cdot (E_2 - E_1)} < \frac{(\sqrt{5} - 1)/2}{\sqrt{5}} \] (9)

Let \( E_1 = z_1 + E_0 \) and \( E_2 = z_2 + E_1 \). From (9), we have

\[ \Theta_l < \frac{E_2 - E_0}{n \cdot (E_2 - E_1)} < \frac{(\sqrt{5} - 1)/2}{\sqrt{5}} \]

It can be written as

\[ z_2 < \frac{1}{n \cdot \Theta_l - 1} \quad \text{or} \quad z_2 \geq \frac{1}{1 - n \cdot \Theta_l} \] (10)

Since L.H.S. of inequality (10) is negative, we should have

\[ 1 - n \cdot \Theta_l < 0 \]

This gives

\[ \frac{1}{n} < \Theta_l \] (11)

Relation (9) can be written as

\[ (E_2 - E_0) \leq \frac{n \cdot ((\sqrt{5} - 1)/2)}{2} \cdot (E_2 - E_1) \] (12)

This inequality may be written as

\[ n \cdot ((\sqrt{5} - 1)/2) \cdot E_1 - 2 \cdot E_0 \leq n \cdot ((\sqrt{5} - 1)/2) - 2 \cdot E_2 \] (13)

This model gives number of type-1, type-2, and type-3 nodes. For the validation, we calculate the sum of all type of sensor nodes is equal to the total number of sensor nodes in the networks. In this way, we have shown that the energy model (6) can describe 1-level, 2-level and 3-level heterogeneity in a WSN. In next section, we discuss the heterogeneous distributed energy efficient clustering protocol for the proposed 3-level heterogeneous network model.

4. hetDEEC: heterogeneous distributed energy efficient clustering protocol

The distributed energy efficient clustering (DEEC) protocol is one of the important protocols. Here, we will discuss the implementation of the DEEC protocol by considering our proposed 3-level heterogeneous network model. The DEEC implementation
for the existing 1-level, 2-level, and 3-level heterogeneous network models are denoted as DEEC-1, DEEC-2, and DEEC-3, respectively, and for our proposed 3-level heterogeneous network model, the DEEC implementations are denoted as hetDEEC-1, hetDEEC-2, and hetDEEC-3, respectively. 1-level heterogeneity (DEEC-1/hetDEEC-1) and 2-level heterogeneity (DEEC-2/hetDEEC-2) are exactly same because they describe an equal number of nodes and the same amount of their energies. We first discuss the cluster head selection process for hetDEEC-3. The LEACH protocol [8,9] considers the average number of cluster heads as $N \times p_{opt}$ in every round for homogenous networks and each node becomes a cluster head once in every $r_i = 1/p_{opt}$ rounds, where $p_{opt}$ is initial optimal probability of each node to become a cluster head, and $r_i$ is round in which ith node is cluster head. The average energy $E(r)$ of the network at round $r$ given by

$$E(r) = \frac{1}{N} \sum_{i=1}^{N} E_i(r)$$

(14)

where, $E_i(r)$ is the residual energy of ith node in round $r$.

The average residual energy of ith node to be a cluster head during rth round is given by

$$p_i = \frac{1 - \frac{E_i(r)}{E(r)}}{p_{opt} \times \frac{E_i(r)}{E(r)}} = \frac{p_{opt} - E_i(r)}{E(r)}$$

(15)

The total number of cluster heads per round is given by

$$\sum_{i=1}^{N} p_i = \sum_{i=1}^{N} p_{opt} \times \frac{E_i(r)}{E(r)} = p_{opt} \sum_{i=1}^{N} \frac{E_i(r)}{E(r)} = N \times p_{opt}$$

(16)

We find $r_i$th round in which ith node is cluster head and it is given by (using (15))

$$r_i = \frac{E(r)}{p_{opt} \times E_i(r)} = r_{opt} + \frac{E_i(r)}{E(r)}$$

(17)

The nodes with high residual energy become the cluster heads in more rounds than the lower ones. The total initial energy of the heterogeneous network is $N \times (\Theta + \Theta^2 \times E_0 + (1 - \Theta - \Theta^2) \times E_2)$ as discussed in (6) and it has increased by a factor of $\left(\Theta + \Theta^2 \times E_2 + (1 - \Theta - \Theta^2) \times \frac{E_0}{E_2}\right)$. Virtually there are $\left(\Theta + \Theta^2 \times \frac{E_0}{E_2} + (1 - \Theta - \Theta^2) \times \frac{E_0}{E_2}\right) \times N$ times more type-1 (normal) nodes. In order to maintain the minimum energy consumption in each round, the average number of cluster heads per round must be equal to $N \times p_{opt}$.

Using our heterogeneous network, all nodes become cluster head exactly once in every $1/p_{opt}$ ($\Theta + \Theta^2 \times \frac{E_0}{E_2} + (1 - \Theta - \Theta^2) \times \frac{E_0}{E_2}$) rounds. In this scenario, the average number of cluster heads per round is equal to $\left(\Theta + \Theta^2 \times \frac{E_0}{E_2} + (1 - \Theta - \Theta^2) \times \frac{E_0}{E_2}\right) + N \times p_{opt}$ ($p_{opt}$ is defined below) because each virtual node has the initial energy equal to that of a normal node. If the same threshold is set for the super, advanced, and normal nodes, then there is no guarantee that the number of cluster heads per round will be $N \times p_{opt}$. By incorporating heterogeneity, each normal node becomes a cluster head once in every $\left(\Theta + \Theta^2 \times \frac{E_0}{E_2} + (1 - \Theta - \Theta^2) \times \frac{E_0}{E_2}\right)/p_{opt}$ rounds, each advanced node becomes a cluster head once in every $\left(\Theta + \Theta^2 \times \frac{E_0}{E_2} + (1 - \Theta - \Theta^2) \times \frac{E_0}{E_2}\right)/p_{opt}$ rounds, and each super node becomes a cluster head once in every $\left(\Theta + \Theta^2 \times \frac{E_0}{E_2} + (1 - \Theta - \Theta^2) \times \frac{E_0}{E_2}\right)/p_{opt}$ rounds. Thus, the constraint of $N \times p_{opt}$ cluster heads per round is violated. Our approach assigns weights to obtain optimal probability for each type of node. For clustering in our proposed heterogeneous network model, we divide $p_i$ given in (15) by the factor of the total increased energy in heterogeneous network. The weighted probabilities of the normal, advanced and super nodes for hetDEEC-3, denoted by $p_{nrm}$, $p_{adv}$, and $p_{sup}$ respectively, are given by

$$p_{nrm} = \frac{p_{opt} \times E(r)}{\left(\Theta + \Theta^2 \times \frac{E_0}{E_2} + (1 - \Theta - \Theta^2) \times \frac{E_0}{E_2}\right) + E(r)}$$

(18)

$$p_{adv} = \frac{p_{opt} \times (1 + \alpha) \times E(r)}{\left(\Theta + \Theta^2 \times \frac{E_0}{E_2} + (1 - \Theta - \Theta^2) \times \frac{E_0}{E_2}\right) + E(r)}$$

(19)

$$p_{sup} = \frac{p_{opt} \times (1 + \beta) \times E(r)}{\left(\Theta + \Theta^2 \times \frac{E_0}{E_2} + (1 - \Theta - \Theta^2) \times \frac{E_0}{E_2}\right) + E(r)}$$

(20)

In our work, we use the similar approach as that of the LEACH protocol [8]. For cluster head selection, the probability is calculated as follows.

$$T(s) = \begin{cases} p_{nrm} \times \left(1 - p_{opt} \frac{1}{r_{mod \times p_{opt}}} \right) & \text{if } s \in G' \\ 0 & \text{Otherwise} \end{cases}$$

(21)

where $p_{opt}$ is a predetermined percentage of cluster heads (e.g., $p_{opt} = 0.05$, $p_{opt}$ is 5% of total nodes are initially selected as cluster heads), and $G$ is set of nodes that have not been cluster heads in last $1/p_{opt}$ rounds.

We replace $p_{opt}$ in (21) by the weighted election probabilities $p_{nrm}$, $p_{adv}$, and $p_{sup}$ to obtain the thresholds for normal, advanced, super nodes, respectively, in order to elect the cluster heads in each round. The thresholds $T(s_i)$ for normal, advanced, and super nodes are given by

$$T(s_i) = \begin{cases} \frac{p_{nrm}}{\Gamma \times p_{nrm} \times \frac{1}{mod \times p_{opt}}} & \text{if } s_{nrm} \in G' \\ \frac{p_{adv}}{\Gamma \times p_{adv} \times \frac{1}{mod \times p_{opt}}} & \text{if } s_{adv} \in G'' \\ \frac{p_{sup}}{\Gamma \times p_{sup} \times \frac{1}{mod \times p_{opt}}} & \text{if } s_{sup} \in G''' \\ 0 & \text{Otherwise} \end{cases}$$

(22)

where $G'$, $G''$ and $G'''$ are set of normal, advanced, and super nodes that have not become cluster heads within last $1/p_{nrm}$, $1/p_{adv}$, and $1/p_{sup}$ rounds, respectively. We have evaluated the weighted election probabilities and thresholds for effective cluster head selection in order to increase the network lifetime for hetDEEC-3. Now, in the next section, we will discuss the simulation results of our heterogeneous network model and compare with the existing heterogeneous network models.

### 5. Simulation results and discussions

In this section, we discuss the performance of DEEC-1, hetDEEC-1, DEEC-2, hetDEEC-2, DEEC-3, and hetDEEC-3 and compare the performance of DEEC-1 with that of the DEEC-2, DEEC-3, and hetDEEC-3. In our simulations, we consider random deployment of 100 sensor nodes in a square field of dimension $100 \times 100$ M. The base station is located at the center and it can be at the maximum distance of $70 = 50 \sqrt{2}$ M approximately from any node. The initial energy of a normal node is set as $E_0 = 0.5$ J. Though this value is arbitrarily taken for simulation purpose, yet this does not affect the behavior of our simulation results.

The radio dissipation model used in our work is exactly same as discussed in [8,9]. The model and input parameters used in our...
simulation setup for the DEEC protocol, and their heterogeneous variants are given in Table 1. We have incorporated 1-level heterogeneity (homogeneous network), 2-level heterogeneity, and 3-level heterogeneity in these protocols and compared their performances. The 1-level and 2-level heterogeneity of our proposed and existing heterogeneous models are exactly same because both the model (proposed and existing) describe an equal number of nodes each having same amount of their energies. The results of the existing and proposed 3-level heterogenous network models are compared in terms of rounds, the network lifetime. In our simulations, we vary the parametric values while maintaining the same amount of total network energy in both existing and proposed 3-level heterogenous models. In 1-level heterogeneity, all the sensor nodes are equipped with the same amount of energy (a node equipped with 0.5 J initial energy). For 2-level heterogeneity, 20% of the nodes are advanced nodes \((m = 0.2)\), each is equipped with 200% more energy than a normal node \((\alpha = 2)\). For 3-level heterogeneity, we have considered eleven cases for existing and proposed heterogeneity network models by varying the parameter values for the DEEC protocol.

The results of DEEC-1 & hetDEEC-1 for one level heterogeneity and that of the DEEC-2 & hetDEEC-2 for two level heterogeneity are exactly same because they describe an equal number of nodes and the same amount of their energies. The results for 1-level and 2-level heterogeneity are shown in Tables 2 and 3, respectively.

For hetDEEC-3 and DEEC-3, the network lifetime has been computed in terms of rounds by taking an equal number of nodes \((i.e., 100)\) and the same amount of total network energy \((i.e., 100 J)\). Figs. 1–4 show the number of alive nodes with respect to the number of rounds for the DEEC-1, hetDEEC-1, DEEC-2, hetDEEC-2, DEEC-3, and hetDEEC-3. We have included the graphs for DEEC-1 and DEEC-2 in order to make a comparative study of different levels of heterogeneity.

In our proposed model, we have taken model parameter \(\theta = 0.52\), which gives 21 super, 27 advanced, and 52 normal nodes. We have taken the energy of a normal node 0.5 J, which will be same in existing models. Using \(\theta = 0.52\) and \(E_0 = 0.5 J\) in (7) and (12), we get \(E_1 = 1.45 J\), and \(E_2 = 1.68 J\). We have taken the same number of nodes of each type in the existing model that

### Table 1
Simulation parameters for radio dissipation model, DEEC and hetDEEC.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumed by the amplifier to transmit at a shorter distance</td>
<td>10 nJ/bit/m^2</td>
</tr>
<tr>
<td>Energy consumed by the amplifier to transmit at a longer distance</td>
<td>0.0013 pJ/bit/m^4</td>
</tr>
<tr>
<td>Energy consumed in the electronics circuit to transmit or receive the signal</td>
<td>50 nJ/bit</td>
</tr>
<tr>
<td>Energy for data aggregation</td>
<td>5 nJ/bit/signal</td>
</tr>
<tr>
<td>Threshold distance</td>
<td>70 m</td>
</tr>
<tr>
<td>Message size</td>
<td>4000 bits</td>
</tr>
<tr>
<td>Network size</td>
<td>100 M x 100 M</td>
</tr>
<tr>
<td>Base station position</td>
<td>(50, 50)</td>
</tr>
<tr>
<td>No. of sensor nodes</td>
<td>100</td>
</tr>
<tr>
<td>Cluster radius</td>
<td>25 M</td>
</tr>
<tr>
<td>Initial energy of a node</td>
<td>0.50 J</td>
</tr>
<tr>
<td>Constant</td>
<td>10</td>
</tr>
</tbody>
</table>

### Table 2
Network Lifetime (in Rounds) for DEEC-1/hetDEEC-1 for deploying 100 normal nodes with initial energy 0.5 J.

<table>
<thead>
<tr>
<th>Number of alive nodes</th>
<th>100</th>
<th>75</th>
<th>50</th>
<th>25</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime (in rounds)</td>
<td>1108</td>
<td>1275</td>
<td>1319</td>
<td>1392</td>
<td>1558</td>
</tr>
</tbody>
</table>

### Table 3
Network Lifetime (in Rounds) for DEEC-2/hetDEEC-2 for deploying 80 normal nodes and 20 advanced nodes with their respective energies 0.5 J and 1.5 J.

<table>
<thead>
<tr>
<th>Number of alive nodes</th>
<th>100</th>
<th>75</th>
<th>50</th>
<th>25</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime (in rounds)</td>
<td>1445</td>
<td>1650</td>
<td>1756</td>
<td>1882</td>
<td>2391</td>
</tr>
</tbody>
</table>

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to the DEEC-3. Fig. 2 shows the number of alive nodes using the model parameter \( \theta = 0.55, E_0 = 0.5 \text{ J} \) in hetDEEC-3 and \( m = 0.45, m_0 = 0.33, \alpha = 1.66, \) and \( \beta = 3.33 \) in the DEEC-3. Here, also hetDEEC-3 provides longer lifetime as compared to the DEEC-3. Figs. 3 and 4 show the number of alive nodes for \( \theta = 0.58, E_0 = 0.5 \text{ J} & \theta = 0.60, E_0 = 0.5 \text{ J} \) in hetDEEC-3 and \( m = 0.42, m_0 = 0.21, \alpha = 1.73, \beta = 4.76 & m = 0.45, m_0 = 0.33, \alpha = 2.2, \) and \( \beta = 5.2. \) Here, also the hetDEEC-3 provides longer lifetime. For all levels of heterogeneity, we carried out simulations for large number of input parameters, i.e., by taking different energy levels of the nodes and various values of fraction parameters. In all cases, we got similar types of results for each type of heterogeneity. However, we have shown the results for eleven cases in tables along with their parametric values for hetDEEC-3 and DEEC-3. The reason for showing 11 cases of the results is that we have varied the model parameter \( \theta \) as 0.51, 0.52, . . . , 0.61 obtained from \([9]\).

As evident from Tables 4 and 5, the hetDEEC-3 provides longer lifetime than that of the DEEC-3 for all cases. The values of the average network lifetime 1558, 2391, 3960, and 4404 by using total network energy as 50\text{ J}, 70\text{ J}, 100\text{ J}, and 100\text{ J}, for the DEEC-1/hetDEEC-1, DEEC-2/hetDEEC-2, DEEC-3, and hetDEEC-3, respectively. The network lifetime in DEEC-2/hetDEEC-2, DEEC-3, and hetDEEC-3 increases by 53.46%, 154.17%, and 182.67% for increasing 40%, 100%, and 100% in the network energies, respectively, with respect to the original DEEC, i.e., the DEEC-1/hetDEEC-1. Thus, nodes in the DEEC-1/hetDEEC-1 protocol die much faster and in the hetDEEC-2 the nodes die slowly as compared to the hetDEEC-1 due to the advanced nodes. In DEEC-3 and hetDEEC-3, the nodes die further slowly due to advanced and super nodes. However, the nodes in the hetDEEC-3 die slower than that of the DEEC-3 because it elects the cluster heads in an effective manner which helps in prolonging the network lifetime.

Figs. 5 and 6 show an instance of total energy consumption and number of packet transmitted to the base station with respect to the number of rounds for 1-level, 2-level, and 3-level of heterogeneity, respectively. We have also computed the total energy consumed by the network per round as shown in Fig. 5. This measure refers to the instantaneous amount of energy exhausted in the network per round, i.e., the energy difference from the beginning of the round till its end. Here, the total initial energies are 50\text{ J}, 70\text{ J}, and 100\text{ J}, for type-1, type-2, and, type-3 nodes, respectively. The hetDEEC-3 performs better than all the levels of the DEEC. Thus, the rate of energy dissipation is much slower in case of the hetDEEC-3 than that of the DEEC for all levels of heterogeneity. We have computed the number of packets transmitted to the base station in a round as shown in Fig. 6. This measure refers to the amount of information collected by the network from the sensor field and sent to the base station. The hetDEEC-3 sends maximum number of packets to the base station among all variants as evident

**Table 4**

Network lifetime (in Rounds) for DEEC-3 protocol.

<table>
<thead>
<tr>
<th>Super nodes &amp; energy of a node</th>
<th>Advanced nodes &amp; energy of a node</th>
<th>Normal nodes &amp; energy of a node</th>
<th>Parameters ( m, m_0, \alpha, \beta )</th>
<th>Network lifetime in terms of round for</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 &amp; 1.67</td>
<td>26 &amp; 1.38</td>
<td>51 &amp; 0.5</td>
<td>0.49, 0.47, 1.76, 2.34</td>
<td>1743 1928 2193 3152 3635</td>
</tr>
<tr>
<td>21 &amp; 1.71</td>
<td>27 &amp; 1.41</td>
<td>52 &amp; 0.5</td>
<td>0.48, 0.44, 1.82, 2.42</td>
<td>1766 1943 2040 3298 3683</td>
</tr>
<tr>
<td>19 &amp; 1.81</td>
<td>28 &amp; 1.41</td>
<td>53 &amp; 0.5</td>
<td>0.47, 0.40, 1.82, 2.62</td>
<td>1790 1915 2080 3265 3748</td>
</tr>
<tr>
<td>17 &amp; 1.86</td>
<td>29 &amp; 1.40</td>
<td>54 &amp; 0.5</td>
<td>0.46, 0.37, 1.80, 2.72</td>
<td>1677 1895 2087 3364 3741</td>
</tr>
<tr>
<td>15 &amp; 2.17</td>
<td>30 &amp; 1.33</td>
<td>55 &amp; 0.5</td>
<td>0.45, 0.33, 1.66, 3.33</td>
<td>1736 1895 2041 3390 3893</td>
</tr>
<tr>
<td>13 &amp; 2.26</td>
<td>31 &amp; 1.37</td>
<td>56 &amp; 0.5</td>
<td>0.44, 0.29, 1.75, 3.32</td>
<td>1779 1915 2021 3258 3695</td>
</tr>
<tr>
<td>11 &amp; 2.75</td>
<td>32 &amp; 1.30</td>
<td>57 &amp; 0.5</td>
<td>0.43, 0.26, 1.59, 4.50</td>
<td>1829 1988 2120 3205 3985</td>
</tr>
<tr>
<td>9 &amp; 2.88</td>
<td>33 &amp; 1.36</td>
<td>58 &amp; 0.5</td>
<td>0.42, 0.21, 1.73, 4.76</td>
<td>1789 1994 2113 3357 4112</td>
</tr>
<tr>
<td>7 &amp; 2.92</td>
<td>34 &amp; 1.47</td>
<td>59 &amp; 0.5</td>
<td>0.41, 0.17, 1.95, 4.84</td>
<td>1750 1922 2113 3357 4270</td>
</tr>
<tr>
<td>4 &amp; 3.1</td>
<td>36 &amp; 1.60</td>
<td>60 &amp; 0.5</td>
<td>0.40, 0.10, 2.20, 5.20</td>
<td>1690 1882 2001 3635 4337</td>
</tr>
<tr>
<td>2 &amp; 3.52</td>
<td>37 &amp; 1.69</td>
<td>61 &amp; 0.5</td>
<td>0.39, 0.05, 2.38, 6.04</td>
<td>1703 1862 1975 3688 4462</td>
</tr>
</tbody>
</table>
The energy heterogeneity helps increasing the network energy and utilizing the network energy efficiently increases the network lifetime. The hetDEEC-3 increases the network lifetime by 182.67%, by increasing the network energy by 100% with respect to its original version. Thus, we have shown that our heterogeneous network model uses network energy in effective manner for enhancing the network lifetime.

Table 6

Number of rounds in DEEC, SEP, and HEED using 100 number of nodes and 100 J network energy for 1-level, 2-level, and 3-level heterogeneity.

<table>
<thead>
<tr>
<th>Protocols</th>
<th>Nature of networks</th>
<th>No. of rounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEEC [17]/hetDEEC-1</td>
<td>1-level heterogeneity</td>
<td>2961</td>
</tr>
<tr>
<td>SEP [16]</td>
<td>1-level heterogeneity</td>
<td>2756</td>
</tr>
<tr>
<td>HEED [13]</td>
<td>1-level heterogeneity</td>
<td>2845</td>
</tr>
<tr>
<td>DEEC-2/hetDEEC-2</td>
<td>2-level heterogeneity</td>
<td>3323</td>
</tr>
<tr>
<td>SEP-2</td>
<td>2-level heterogeneity</td>
<td>3164</td>
</tr>
<tr>
<td>HEED-2</td>
<td>2-level heterogeneity</td>
<td>3264</td>
</tr>
<tr>
<td>DEEC-3</td>
<td>3-level heterogeneity</td>
<td>3690</td>
</tr>
<tr>
<td>SEP-3</td>
<td>3-level heterogeneity</td>
<td>4004</td>
</tr>
<tr>
<td>HEED-3</td>
<td>3-level heterogeneity</td>
<td>3984</td>
</tr>
</tbody>
</table>

Fig. 5. Total energy dissipation vs number of rounds.

Fig. 6. Number of data packets sent to the base station vs. number of rounds.

from Fig. 6. The number of packets transferred to the base station using the DEEC-1, DEEC-2, DEEC-3, and hetDEEC-3, are, respectively, $1.2 \times 10^4$, $2.1 \times 10^4$, $3.3 \times 10^4$, and $3.8 \times 10^4$, with respect to the number of rounds. The performance of some of the protocols have been computed by using the heterogeneous networks and compared with our proposed protocols. As evident from Table 6, our protocols perform much better than other protocols by taking equal amount of energy.

6. Conclusions

In this paper, we have proposed a 3-level heterogeneous network model characterized by a single model parameter and can describe 1-level, 2-level and 3-level energy heterogeneity in a network. The energy heterogeneity helps increasing the network energy and utilizing the network energy efficiently increases the network lifetime. The hetDEEC-3 increases the network lifetime by 182.67%, by increasing the network energy by 100% with respect to its original version. Thus, we have shown that our heterogeneous network model uses network energy in effective manner for enhancing the network lifetime.

References

33rd Hawaii Int. Conf. on Systems Science (HICSS ‘00), vol. 8, pp. 3005–3014, 2000.


