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An Enhanced Heterogeneous Gateway-Based Energy-Aware Multi-Hop Routing Protocol for Wireless Sensor Networks

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Abstract: Wireless Sensor Networks (WSNs) continue to provide essential services for various applications such as surveillance, data gathering, and data transmission from hazardous environments to safer destinations. This has been enhanced by the energy-efficient routing protocols that are mostly designed for such purposes. Gateway-based Energy-Aware Multi-hop Routing protocol (MGEAR) is one of the homogenous routing schemes that was recently designed to more efficiently reduce the energy consumption of distant nodes. However, it has been found that the protocol has a high energy consumption rate, lower stability period, and poorer data transmission to the Base station (BS) when it was deployed for a longer period of time. In this paper, an enhanced Heterogeneous Gateway-based Energy-Aware multi-hop routing protocol (HMGEAR) is proposed. The proposed routing scheme is based on the introduction of heterogeneous nodes in the existing scheme, selection of the head based on the residual energy, introduction of multi-hop communication strategy in all the regions of the network, and implementation of energy hole elimination technique. All these strategies are aiming at reducing energy consumption and extend the life of the network. Results show that the proposed routing scheme outperforms two existing ones in terms of stability period, throughputs, residual energy, and the lifetime of the network.

Keywords: wireless sensor networks; heterogeneous; hazardous environment; energy efficient

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1. Introduction

We are in era in which the Internet of things (IoT) has become a popular response to various technological challenges [1–4]. RFID tags are commonly attached (or embedded) to things and wirelessly communicate to achieve certain goals. This creates complex wireless networks on which communication models are still a subject of research. Furthermore, WSNs have been deployed in various environments to assist moving objects such as drones and robots to perform various tasks [5–7].

Since its inception, the IoT, as a WSN, has provided critical assistance to humankind, especially in gathering information from hazardous environments. Indeed, the networks have the ability to collect, process, and transmit data from critical environmental conditions to safer places. These are some of the reasons they are now being used in various applications such as in agriculture, healthcare, environmental monitoring, military surveillance, structural monitoring, traffic control, and river level variation monitoring, etc. [8].

When data are collected in these networks, they are usually sent to a destination node called the Base Station (BS) for further processes [9]. These networks are usually made up of tiny sensor nodes. For the source of energy, the sensor nodes rely on rechargeable and replaceable batteries. However, charging and replacing these batteries is practically impossible when they are deployed in a hazardous environment. Therefore, the efficient use of the limited resources of the sensor nodes always helps to improve the performance of the network. The performance of a WSN can be improved by developing mechanisms (see [10,11], for example) that can reduce the energy depletion of the nodes and extend the lifetime of the network.

It is known that various units of sensor nodes, where the highest amounts of energy is being used are the sensing, data processing, and communication units. The communication unit is where the highest energy consumption is observed [12]. To minimize energy consumptions in these units many energy preservation techniques such as clustering, data aggregation, effective node deployment, cluster-based routing protocols, collection tree protocols, etc., have been developed.

Hierarchical routing protocols, in WSNs, are seen as the most energy-efficient schemes and have been widely used [13]. Any of the schemes divide the network into groups called clusters, with each cluster having a head, a central node, called Cluster Head (CH). These heads receive the sensed data from the local nodes, aggregate the data and report to the Base Station (BS) through a single-hop or multi-hop communication approach depending on the distance from the BS. Some examples of such routing models can be found in [14–16].

In the related literature, there are several cluster-based routing algorithms that have been proposed in wireless sensor networks.

In [17], a hierarchical routing has been proposed to successively improve the underling network lifetime. Here, the assumed network consists of two types of nodes (supper nodes and monitoring nodes) which are all randomly arranged in an area of interest. However, the optimal network topology would improve the the performance of the proposed algorithm. To address this, the research work in [18] proposed a routing model where the considered network is "properly" chosen. This shows that the network deployment matters and is still a subject of research for the hierarchical routing models.

More hierarchical routing model have been proposed in [19,20] for optimizing the energy consumption. However, one of the most important cluster-based routing protocols for wireless sensor network has been proposed in [21]. The protocol has become the basis for several cluster-based routing protocols in the literature. The scheme operates in rounds and each round is sub divided into two phases, namely: setup phase and steady state phase. In the setup phase, each node produces a random number between 0 and 1. Once this random number is less than a particular threshold value $T(n)$, which is given by Equation (1), then the node qualifies as a cluster head for the current round. After the CH election, non CH nodes select a CH based on the head's signal strength to be part of its cluster. These non CH then transmit the captured data through single-hop communication technique to the CH for aggregation and onward submission to the BS.

$$T(n) = \begin{cases} \frac{P}{1-P(rmod(\frac{1}{P}))} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where r is the current round, G is the set of nodes that are not selected as cluster head, and P is the desired percentage of cluster head.

The authors in [22] explained a probability-based clustering algorithm called Distributed Energy-Efficient Clustering algorithm (DEEC). The algorithm elects cluster heads based on the ratio between the residual energy of each node and the average energy of the network. However, the single-hop communication approach is used in sending data to the BS. This makes the distant nodes dissipate a huge amount of energy, thereby affecting the lifetime of the network. In [23], Sharma and Verma analyzed the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol, which is a homogeneous system, and then studied the impact of heterogeneity. The authors then proposed a LEACH heterogeneous system which seeks to compare two systems; the heterogeneous and homogeneous systems. Simulation results using MATLAB show that the proposed LEACH heterogeneous system significantly reduces energy consumption and increases the total lifetime of the wireless sensor network. The main problem identified in this scheme is that the cluster heads (CHs) are not chosen based on their residual energy, and this affects the lifetime of the network. A model called Developed Distributed Energy-Efficient Clustering (DDEEC) for heterogeneous wireless sensor networks has been proposed in [24]. It is the enhanced version of DEEC. This scheme resolves the penalizing effect in the DEEC protocol. However, the DDEEC has a similar problem as DEEC, where a single-hop communication approach is used in sending data to the BS in the network. This makes the distant nodes dissipate a huge amount of energy, thereby affecting the lifetime of the network.

An Enhanced Distributed Energy Efficient Clustering Scheme (EDEEC) for heterogeneous WSN has been described in [25]. This is an extended version of DEEC with normal, advanced, and super-node classification based on the node's energy. The problem identified in this protocol is similar to that of DEEC, SEP, and DDEEC in which no appropriate communication approach was introduced to reduce the energy depletion of the distant nodes deployed in the network.

In [26], the authors proposed a new optimization scheme. The new algorithm modified the average probability of advanced nodes whose residual energy is less than the Threv (threshold residual energy value) to now depend on the average distance of the nodes from the Base station rather than the average energy of the network. The scheme further implemented TEEN and different amplification energy levels in the protocol to conserve energy in the network. Results showed that the proposed protocol performed better than the existing scheme in terms of throughputs, residual energy, and network lifetime. However, the single-hop communication technique used affected the lifetime of the distant nodes.

An improved form of E-DEEC has been proposed in [27]. iE-DEEC improved the election probability of the protocol in [8] by taking into account the distance of super-nodes and the average distance of all the nodes to the BS in selecting CHs. The scheme has also introduced different amplification energy levels to minimize the energy consumption during the communications between the CHs and BS and also within inter and intra clusters. MATLAB R2017a was used for simulation to evaluate the effectiveness of the scheme. The simulation results showed that the proposed protocol performed better than E-DEEC in terms of throughputs, residual energy, and network lifetime.

Jibreel, in [28], explained an extended form of Threshold Stable Election Protocol called eTSEP. The new scheme introduces the distance and residual energy into the election probabilities of each level of the nodes. This allows nodes with high residual energy and closer to the Base station to stand a better chance of becoming a cluster head. The performance of the scheme was evaluated using MATLAB R2017a and compared with TSEP. It has been shown that the new protocol performed better than TSEP in terms of throughputs, residual energy, and the network lifetime. However, the single-hop communication technique is used in data transmission from the CHs to the BS. This depletes the energy of the distant nodes.

A heterogeneous form of Modified Low Energy Adaptive Clustering Hierarchy, Servant-MODLEACH (S-MODLEACH), was presented in [29]. The algorism uses three levels of nodes, namely advanced, servant, and normal nodes. The protocol chooses cluster heads based on their residual energy and assigned data aggregation role to a group of nodes called servant nodes. It has been shown that S-MODLEACH achieved better outcomes than MODLEACH in respect of throughputs and the network lifetime. Although the scheme used a multi-hop communication approach to reduce the energy depletion of the distant nodes, no mechanism was put in place to reduce energy holes created in the network.

An enhanced form of Threshold Distributed Energy Efficient Clustering protocol (TDEEC) has been proposed in [30]. The algorithm, Gateway based-TDEEC, introduced a gateway node at the middle of the sensing area and then installed the BS far away from the sensing field. The cluster heads relay their data to the gateway which will then aggregate the data and send the final report to the BS. Results showed that the proposed protocol outperformed the TDEEC in terms of stability period, throughput, residual energy, and network lifetime. However, it did not consider a multi-hop communication strategy to reduce the energy expenditure of the distant nodes as well as reducing the energy holes created in the system.

A modified heterogeneous routing protocol called Distance-DEEC (D-DEEC) has been proposed in [31]. The protocol took into consideration the residual energy, distance of the individual nodes, and average distance of all the nodes from the base station in selecting the cluster heads. This has allowed the scheme to select cluster heads with high residual energy, closer to the Base station and their neighbors. The performance of the proposed algorithm was evaluated using MATLAB R2017a, and the outcomes showed that the D-DEEC protocol outperformed DEEC in terms of energy consumption, throughputs, and the network lifetime.

In [25], the author proposed TEEN-MGEAR(T-MGEAR). The scheme modified the election probability by considering the distance and the residual energy of the nodes in selecting the cluster heads. It also employed hard and soft thresholds to determine when nodes can transmit their sensed data. No heterogeneity and multi-hop communication technique has been employed in this scheme.

In [32], an Enhanced M-Gear Protocol for Lifetime Enhancement in Wireless Clustering System was proposed. In this scheme, the network was divided into a number of sections with each section having its own gateway node. The nodes capture data and transmit them to the gateway in their immediate section for onward submission to the next gateway or to the BS. The results showed that it outperforms MGEAR in terms of throughput, energy consumption, and network lifetime. However, having several gateways will lead to an increase in the cost of the network; also, the absence of heterogeneous nodes affects the stability period of the network.

The authors in [33] explained a Gateway-Stable Election Protocol (G-SEP). The G-SEP scheme altered the election probability of selecting the cluster heads by considering the distance, average distance, and residual energy of the advanced nodes. The algorithm further introduced a gateway node at the middle of the network and then installed the BS outside the field. Simulation results using MATLAB R2017a showed that the G-SEP performs better than the Zonal-Stable Election protocol (ZSEP) in terms of coverage, stability period, and extension of the lifetime of the network.

Having reviewed the literature related to increasing the network lifetime of WSNs, it is important to note that selecting CHs based on their residual energy of nodes, introducing heterogeneous nodes to strengthen the ability of nodes, introducing multi-hop communication technique to reduce the energy depletion of distant nodes, and implementing energy holes removal mechanism to further conserve the energy of the nodes can remarkably improve the network lifetime.

This paper proposes an energy-efficient routing scheme for wireless sensor network. The scheme selects cluster heads based on their residual energies and introduces Heterogeneous nodes to strengthen the homogeneous nodes in the existing scheme. The protocol further employs a multi-hop communication strategy, the effectiveness of which has been proven in [33], and finally implements an energy hole removal scheme to reduce the energy depletion of the nodes. These techniques are employed in this protocol to reduce energy consumption and extend the lifetime of the network.

It is important to mention that this paper has been motivated by the work in [25]. Here, MGEAR has been improved using the original homogeneous nodes deployed in all the regions. In this model, the cluster heads are selected based on distance/residual energy, because they were purely homogeneous nodes. This model has been complemented by the scheme proposed in [33], where the authors only employed a gateway node to the Stable Election Protocol (SEP) so that the BS can be repositioned outside the network. Here, distance/average distance and residual energy were also considered while modifying SEP protocol. It is only the homogeneous nodes that capture data and transmit them to the heads which are heterogeneous nodes of the same energy level to the gateway node to the base. No direct transmission has been employed in any part of this network. It has nothing to do with the model used in GMEAR. The proposed model complements the work in the literature in the following four ways.

1. Heterogeneity has been introduced in the existing MGEAR: we have introduced heterogeneous nodes of different energy levels to the existing scheme, especially in regions 3 and 4 which, to the best of our knowledge, have not been employed before. These nodes have higher energy than the homogeneous ones used in the existing scheme and therefore can transmit data effectively for a long period of time
2. Cluster heads are selected based on only residual energy, because heterogeneous nodes are deployed in Regions 3 and 4. These nodes give a better supporting role for long periods and provide a better stability period than the homogeneous nodes deployed in the case of the models in [25,33]. This is to prevent the weak nodes from being chosen as cluster heads, as they would not transmit data effectively.
3. In the proposed scheme, both the direct and multi-hop communication technique have been employed from Region 4 to the BS, which has not happened in [25,33]. This technique reduces the energy consumption of the nodes by preventing unnecessary data transmission by the distant nodes to the distant Base station.
4. Energy hole elimination technique has been implemented to prevent nodes from losing their entire energy during data transmission, which none of the models in [25,33] considered. This is to prevent nodes from transmitting when their energies are below certain threshold.

The remainder of the paper is organized as follows. Section 2 describes the proposed scheme; simulation results and analysis are discussed in Section 3; and the conclusion is then drawn in Section 4.

2. Proposed Routing Scheme

In this section, the proposed heterogeneous protocol called HMGEAR is explained. This scheme builds on the homogeneous routing protocol suggested in [34].

In this scheme, the network divides the sensor nodes into four logical regions on the basis of predefined threshold distance. The Base station and a gateway node are placed outside the sensing field and at the center of the network, respectively. The nodes whose distance from either the Base station or gateway node is less than the predefined distance are assigned to Regions 1 and 2, respectively. In this case, they transmit their data to either the Base station or gateway node using direct communication approach. These are the homogeneous nodes. However, if their distance is more than the predefined threshold distance and closer to the gateway node they are placed in Region 3, else in Region 4, as illustrated in Figure 1. These are the heterogeneous nodes. Elections are conducted in these two regions and heads are selected based on the residual energy of the nodes. Data are transmitted to the BS through a multi-hop communication technique (see [10], for example) from these regions. The gateway node receives the final report from CHs in Region 3, aggregates the data before transmitting them to the BS. The nodes in each region transmit their data based on the energy threshold set out for them, below which the nodes cannot transmit data but sleep to conserve their energies.

2.1. Proposed Network Model

The network model as depicted in Figure 1 is defined as follows. It is a network $G(BS, GW, Ho, He, L)$, where BS is the network base station, GW is the network gateway, Ho is the set of homogeneous nodes, He is the set of heterogeneous nodes, and L is the set of links connecting any of the defined nodes (any node in the union $BS \cup GW \cup Ho \cup He$).

The following are the network properties.

- The network can be subdivided in four subnetworks. located in Regions 1, 2, 3, and 4 as shown in Figure 1.
- There exists at least one node in Region 4 connected with a node in Region 3.
- The gateway is in Region 2 and is connected to the BS.
- The gateway is connected with the base station.
- Each node in Region 1 is connected to the base station.
- All nodes in Regions 3 and 4 are not connected with the base station.

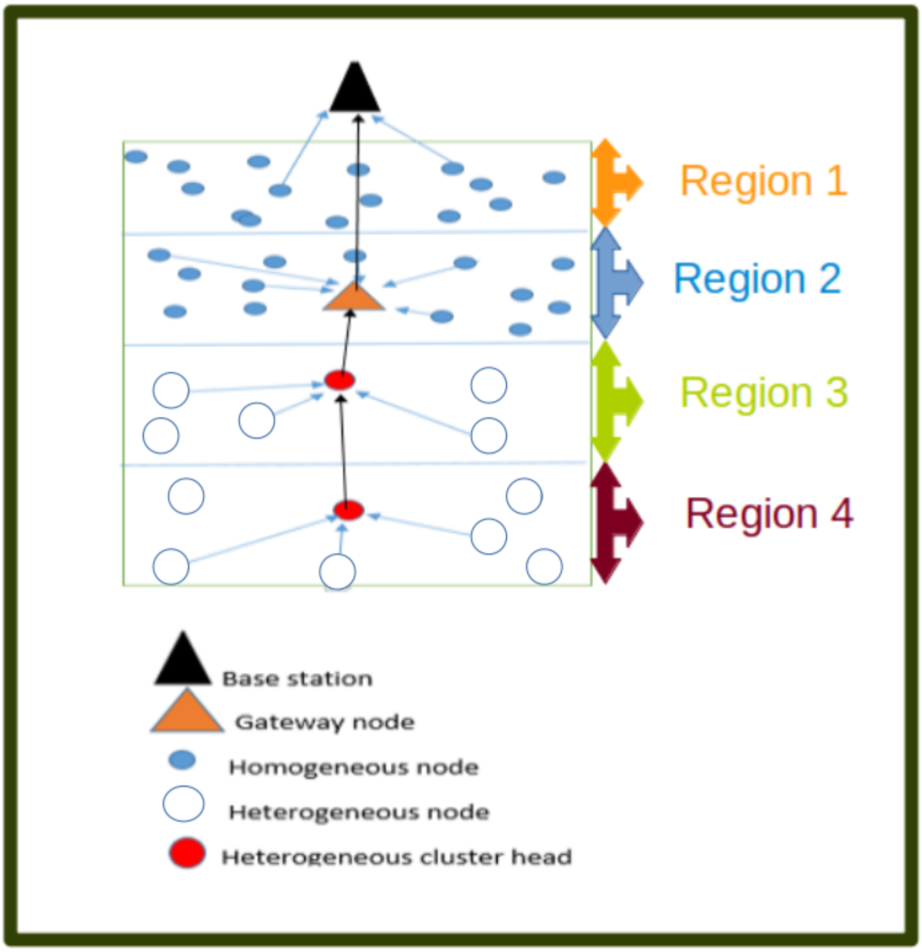

Figure 1. Proposed network model.

2.2. The Routing Scheme

The proposed scheme is made up of two phases.

1. The setup phase. It consists of allocating nodes in 4 Regions as well as election of the cluster heads.
2. The steady phase. It relates to how data are transmitted among the nodes within the four regions. The energy involved in this data transmission is mostly determined in this phase.

2.2.1. Setup Phase

This session is similar to the setup phase suggested by the authors in [34]. The authors here divided the homogeneous sensor nodes into four logical regions on the basis of their location in the sensing field. The base station is installed outside the sensing area and the gateway node is placed at the centre of the network. The nodes whose distance from either the Base station or the gateway node is less than the predefined distance threshold transmit their data using direct communication techniques. The nodes whose distance is beyond the threshold distance are divided into equal regions. Elections of heads are conducted in these regions using the probability approach. These heads aggregate the data and transmit their report directly to the gateway node then to the Base station.

The proposed scheme modified the election probabilities to take into account the residual energy of the nodes. The selection probabilities for the respective heterogeneous nodes in Region 3 and 4 are given by Equations (2) and (3).

$$P_{het1} = \left(\frac{P_{opt}(1+b)}{1+am} \right) \frac{E_i}{E_0} \tag{2}$$

$$P_{het2} = \left(\frac{P_{opt}(1+a)}{1+am} \right) \frac{E_i}{E_0} \tag{3}$$

where E_i is the residual energy of the node, E_0 is the initial energy of the node, m is the percentage of sensor nodes equipped with a and b times more energy resources than the homogeneous sensor nodes in the network and P_{opt} is the probability by which each node can become a CH. However, $b = \frac{a}{2}$.

Their respective thresholds are also given in Equations (4) and (5).

$$T_{het1} = \begin{cases} \frac{P_{het1}}{1-P_{het1}\left(rmod\left(\frac{1}{P_{het1}}\right)\right)} & \text{if } n \in He \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

where He is the set of heterogeneous nodes that has not become a CH in the past $\frac{1}{P_{het1}}$ round r in Region 3.

$$T_{het2} = \begin{cases} \frac{P_{het2}}{1-P_{het2}\left(rmod\left(\frac{1}{P_{het2}}\right)\right)} & \text{if } n \in Ho \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

where Ho is the set of heterogeneous nodes that has not become cluster head in the past $\frac{1}{P_{het2}}$ round r in Region 4.

As shown by Algorithm 1, the proposed protocol assumes a network as specified in Section 2.1. As shown by the algorithm, Line 4–6, the homogeneous nodes which are closer to the BS and therefore communicate directly to BS are put in Region 1. Region 2 is considered to be where the gateway node is located, and it contains the homogeneous nodes. Once these nodes are also closer to the gateway node, they are considered to be in the region (see Lines 7–8). Regions 3 and 4 contain heterogeneous nodes. These nodes have higher energy than the homogeneous nodes placed in Regions 1 and 2 and therefore can sustain the energy of the network for a longer period of time despite their distance from the gateway nodes. Nodes are allocated to these two regions in Lines 9–14.

Algorithm 1: The set up algorithm.

1 **for** *all the nodes in N, BS* **do**
2 ▷ N is the number of nodes in the network
3 Calculate D ▷ D is the distance of nodes from BS
4 **if** $D < D_{max}$ *and closer to BS* **then**
5 ▷ D_{max} is the maximum distance
6 Put nodes in Region 1
7 **else if** $D < D_{max}$ *and closer to Gateway(GW)* **then**
8 Put nodes in Region2
9 **else if** $D \geq D_{max}$ **then**
10 BS divide the nodes into 2 regions
11 **else if** $D \geq D_{max}$ *and closer to Gateway(GW)* **then**
12 Put nodes in Region3
13 **else**
14 put the nodes in Region 4

2.2.2. Steady Phase

In this section, the energies dissipated by the active sensor nodes in each region are determined and the total energy of the network is calculated. Applying the energy dissipation equation proposed by [35], the equations below are obtained. The energy

$E_{non\text{-}BS}$ each low energy sensor in Region 1 $R1$ spent in relaying k bits report to BS is given by Equation (6).

$$E_{non\text{-}BS} = E_{TX}(K, d_{BS}) \tag{6}$$

where d_{BS} is the distance between the homogeneous nodes in Region 1 and the BS.

Each low energy sensor in Region 2 $R2$ spent energy $E_{gw\text{-}BS}$ in relaying k bits report to the gateway node and is given by Equation (7).

$$E_{non\text{-}gw} = E_{TX}(K, d_{gw}) \tag{7}$$

where d_{gw} is the distance between the homogeneous nodes in Region 2 and the gateway node.

The energy $E_{gw\text{-}BS}$ spent by the gateway node in receiving k bits of data from Region 2 and 3, aggregating them, and relaying the report to the BS is given by Equation (8).

$$E_{gw\text{-}BS} = kE_{elect} + kE_{elect}\left(\frac{n}{c}\right) + k\left(\frac{n}{c}\right)E_{DA} + E_{TX}(k, d_{BS}) \tag{8}$$

where E_{elect} is the electronic energy of the transmitter, n is the number of nodes deployed in the network, c is the number of clusters in the network, and E_{DA} is energy for data aggregation.

The energy spent in receiving and relaying k bits report by the cluster head $CH1$ in Region 3 to the gateway node is given by Equation (9).

$$E_{CH1\text{-}gw} = kE_{elect} + kE_{elect}\left(\frac{n}{c} - 1\right) + E_{TX}(k, d_{gw}) \tag{9}$$

The energy spent in receiving and relaying k bits report from the cluster head $CH2$ in Region 4 to the cluster head $CH1$ in Region 3 is given by Equation (10).

$$E_{CH2\text{-}CH1} = kE_{elect}\left(\frac{n}{c} - 1\right) + E_{TX}(k, d_{CH1}) \tag{10}$$

where $dCH1$ is the distance between the cluster heads in Region 3 and 4.

Total energy E_T used in the network is given by Equation (11)

$$E_T = E_{non\text{-}BS} + E_{gw\text{-}BS} + E_{CH1\text{-}gw} + E_{CH2\text{-}CH1} \tag{11}$$

Elections of the cluster heads is conducted in Regions 3 and 4. As shown in Algorithm 2, the election probabilities in the HMGEAR protocol are based on the residual energy of the nodes. Hence, the node with high residual energy has a higher chance of becoming a cluster head. This is to delay the weak nodes which cannot transmit data effectively to the BS from becoming heads immediately. A multi-hop communication approach is introduced in these regions (3 and 4) between the two elected heterogeneous cluster heads before the final report reaches the gateway node which will then aggregate it before onward submission to the BS. This is to reduce the energy consumption of nodes in Region 4, which may be far from the region. Finally, the Energy-efficient HOle Removing Mechanism (E-HORM) technique proposed in [34] is implemented. This technique finds the maximum distance nodes to calculate the maximum energy before data transmission. This maximum energy is referred to as a threshold energy E_{th}. Therefore, each node will first check its energy level, and if the energy level of the node is less than E_{th}, it cannot transmit data. This helps to conserve energy.

Algorithm 2: Selection of in Regions 3 and 4 and data transmission.

Choose first S_{CH} in Region 3 ▷ S_{CH} is the set of cluster heads.
compute P_{het1} using Equation (2)
Choose first S_{CH} in Region 4
compute P_{het2} using Equation (3)
for *every node in Region 1* **do**
  if $E > E_{max1}$ **then**
    ▷ E is the energy of nodes
    ▷ E_{max1} is the maximum energy for homogeneous nodes
    Send data to BS
  else
    sleep
for *every node in Region 2* **do**
  if $E > E_{max1}$ **then**
    Send data to GW
  else
    sleep
for *every node in Region 3* **do**
  if $E > E_{max2}$ **then**
    Send data to GW to aggregate and then to BS
    ▷ E_{max2} is the maximum energy for heterogeneous nodes
  else
    sleep
for *every node in Region 4* **do**
  if $E > E_{max2}$ **then**
    Send data to CH_1 ▷ CH_1 is cluster head in Region 3
    CH_1 Send data to GW for aggregation
    GW Send data to BS
  else
    sleep

3. Simulation Results and Analysis

The proposed heterogeneous routing protocol was compared with the SEP and MGEAR routing protocols using MATLAB R2018a simulation. For the simulation, a system consisting of 100 sensor nodes was randomly deployed in a field of dimension 100 m × 100 m. The BS and the gateway node were positioned, respectively, at (50 m, 120 m) and (50 m, 50 m) in the network. Approximately 20% of heterogeneous nodes are prepared with greater energy than the homogeneous nodes ($m = 0.2$ and $\alpha = 1$). All the nodes are stationary after deployment. Table 1 defines the simulation parameters used in this research work. As assumed in [21,25], the cluster heads and gateway node receive the reports and successfully aggregate them before transmission. Therefore, the fusion validation is not considered in this experiment, though it could be a good contribution for future research.

The performance evaluation was based on the following performance metrics as used in [21,35]. Note that the efficiency is multi-dimensional and may be determined by each of the following parameters.

1. Number of alive nodes per cluster round. It indicates the number of nodes alive from the network for every cluster round, and this depends on the availability of energy remaining in the network. A routing algorithm is more efficient if it can keep several nodes alive after many routing rounds.
2. Number of dead nodes per cluster round. As a result of changing energy, it levels inside the network during network survival time. This also indicates the possible lifetime

remaining of the network. A routing scheme is more efficient if it reduces the number of dead nodes in each cluster.

3. Throughput. It means the numbers of packets sent to the BS by the nodes in each round. The throughput really shows the effective energy utilization corresponding to the underlying routing algorithm.
4. Packets received. indicates the actual packets acknowledged by BS. A routing scheme is more efficient if it maximizes the number of delivered packets to the destination (base station in our case).
5. The residual energy of the network. It helps to analyze the energy consumption of nodes in each round. In many cases, a routing algorithm which ensures less energy consumption is considered to be more efficient.

Table 1. Simulation parameters.

Parameters	Values
Network field	100 m × 100 m
Number of nodes	100
Initial energy of normal nodes (E_0)	0.5 J
Message size	4000 bits
E_{elec}	50 Nj/bit
E_{fs}	10 Nj/bit/m^2
E_{mp}	0.0013 Pj/bit/m^2
P_{opt}	0.1

For balancing the energy in the network, clustering has been applied in many rounds to update the routing tree. For each round, the value of each of the above parameters is calculated.

The network lifetime is studied and results are presented in Figure 2. The figure shows the number of active sensors for each clustering round in SEP, MGEAR, and the proposed routing protocol HMGEAR. The figure shows that, in HMGEAR, all the 100 nodes stayed alive longer than both SEP and MGEAR and hence have a better lifetime than the two protocols. The figure also shows that the number of alive nodes per round, in the case of HMGEAR, decreases slowly compared to the two other protocols and converges to zero the last. This confirms the fact that for each round it is safest to use HMGEAR.

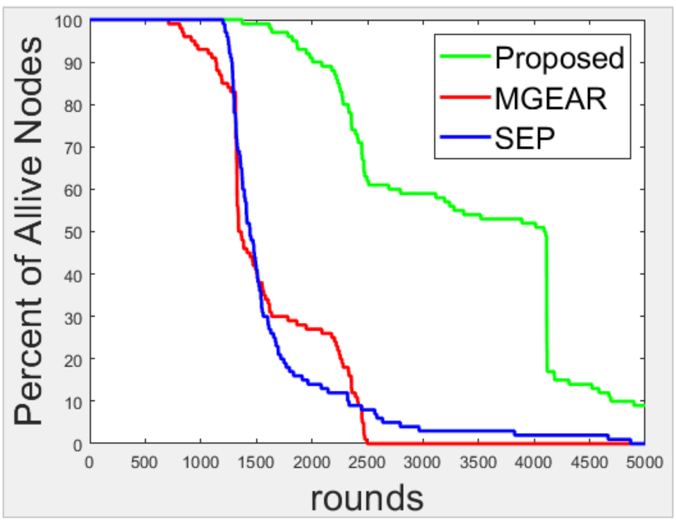

Figure 2. Number of alive nodes per round.

Note that the effective performance of the proposed protocol is due to the adoption of the multi-hop transmission between cluster heads, gateway, and the BS. This has minimized the rate of data transmission and hence decreases the energy exhaustion in the network.

Figure 3 shows the number of dead nodes per rounds in a network while using any of the three routing protocols. It can be observed that the new scheme has a better stability period than the existing protocol. The figure confirms the results presented in Figure 2 and shows that the proposed algorithm maintains a low death rate of the nodes for all rounds until all nodes are dead.

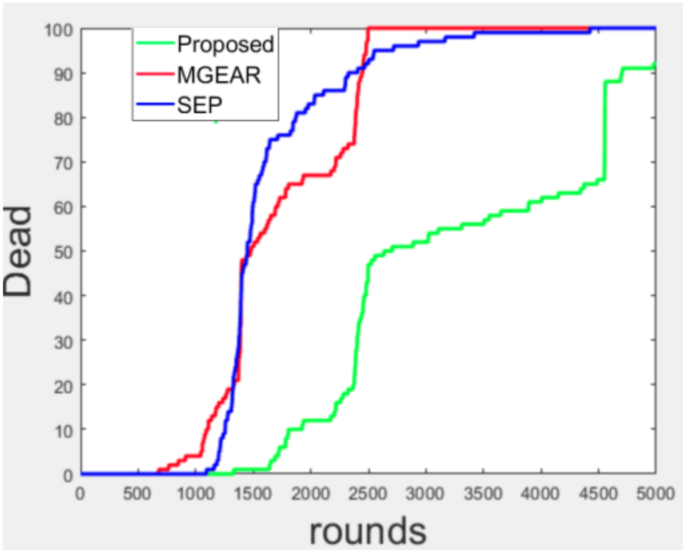

Figure 3. Number of dead nodes per round.

In Figures 4 and 5, the number of packets forwarded to the BS and quantity of the packets received by the BS are compared in all the routing algorithms. It was realized that the proposed protocol sent more packets to the Base station and also the BS received more packets from the new scheme compared with the existing schemes, as shown in Figures 4 and 5. This is due to the multi-hop communication approach that was introduced in the new protocol. The nodes require less energy to relay their report to the next Region until it arrives at the Sink. Additionally, the gateway node aggregates the report rather than the CHs. This also conserved the energy of the CHs and therefore transmits more data to the gateway node.

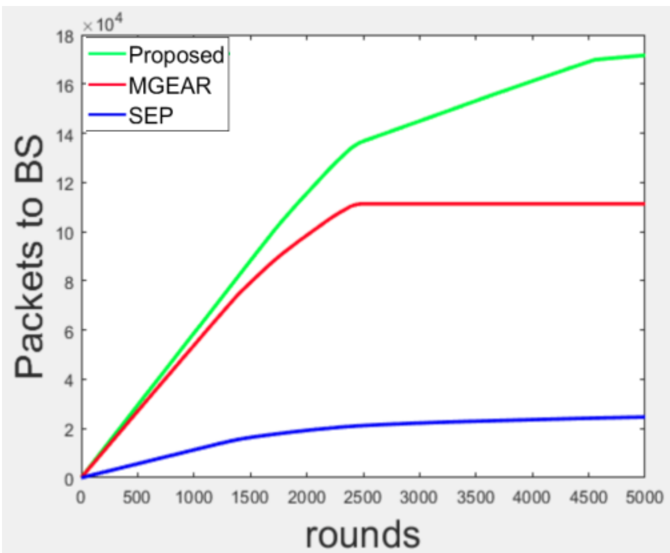

Figure 4. Packets sent to BS per round.

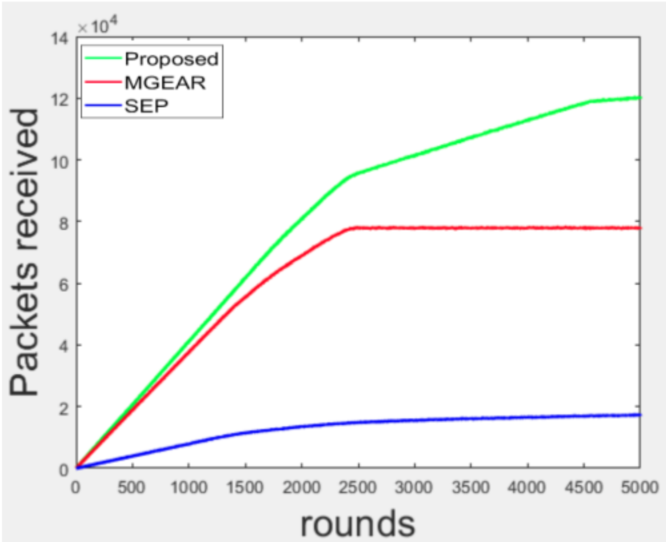

Figure 5. Packets received by the BS per round.

Figure 6 shows the leftover energy of the sensors per round in all the schemes. Initial energy values are different for considered schemes due to the difference in energy optimization parameters used in each protocol and the distance of the Base station from the deployment area (50 m, 200 m). In the proposed protocol, the Base station is far away from the field, but heterogeneous nodes (nodes with the highest energy than homogeneous), gateway nodes, and energetic heads were used. In MGEAR, only homogeneous nodes and gateway were used. In the SEP scheme, although only the heads are heterogeneous, its network was originally designed with the Base station at the center and closer to the nodes. However, positioning the Base station outside and also far away from the field compelled it to have the highest energy consumption rate, and that makes its residual energy reach zero within that shortest possible time.

It can be noticed that the rate of energy depletion in the proposed scheme is lower than the existing algorithms. This reflects the energy-conserving mechanisms that were introduced and implemented in the new scheme which includes selecting heads using residual energy of the nodes, the multi-hop communication technique employed, and implementation of energy hole removing technique. The proposed scheme achieves all these successes while remaining the most energy efficient for all the rounds.

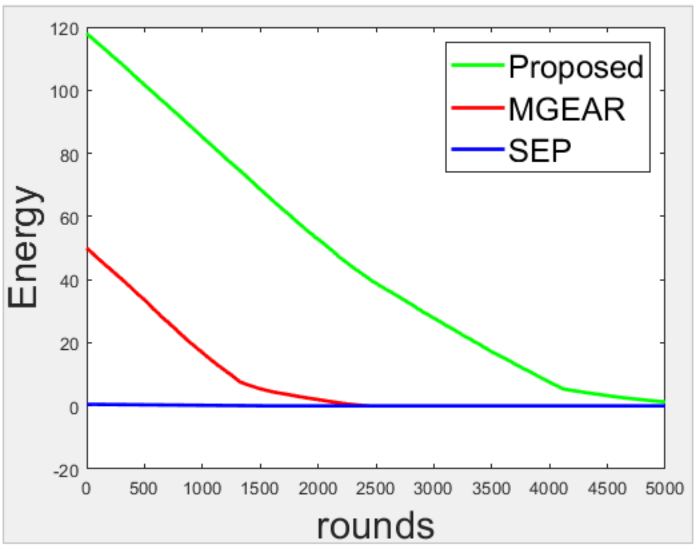

Figure 6. Residual energy per round.

It is important to note that the number of alive nodes in the network remains highest for the proposed routing algorithm, while the number of dead nodes remains least for all routing rounds. On the other hand, the number of packets sent and received to the base station is always (for all routing rounds) highest for the proposed routing scheme when compared with MGEAR and SEP. The proposed model achieves these mentioned qualities while nodes in the network retain the most potential (i.e., are more energetic) when compared to the two algorithms.

4. Conclusions

In this paper, a heterogeneous MGEAR routing protocol, HGEAR, has been proposed to act as a remedy to the shortcomings of traditional MGEAR Protocol. The new scheme solved the problem of using a probabilistic approach in selecting cluster heads. This was achieved by introducing the residual energy heads selection approach. The approach has ensured that nodes with higher residual energy are selected as the heads and are able to effectively transmit data to the Base station. The new algorithm also introduced heterogeneous nodes in the regions that are far from the Base station as well as employing multi-hop communication technique among nodes in all the regions. This has reduced the energy depletion of distant nodes as they transmit their reports to the Base station as shown in Figure 4. The scheme further implements an energy hole removal mechanism to prevent holes that may be created as a result death of nodes. With this, nodes transmit their data based on a certain energy threshold below that which they can transmit. This has reduced the death rate of nodes, as shown in Figure 3. Each energy-saving technique that has been introduced in this scheme has resulted in low energy consumption, as indicated in Figure 6. A simulation was conducted, and results showed that the new protocol performed better than the existing schemes in respect to stability period, throughputs, residual energy, and network lifespan.

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