Energy-Efficient Routing Protocol Based on Zone for Heterogeneous Wireless Sensor Networks

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Abstract
In heterogeneous wireless sensor networks, sensor nodes are randomly distributed in some regions. In some applications, they may be randomly distributed in different regions. Besides, nodes with the same type have almost the same probability to be selected as cluster head. cluster head will consume much more energy to receive and transmit data than the other nodes. If nodes with little residual energy have been elected as cluster heads, it will affect the efficiency of the network due to its early death. An improved energy-efficient routing protocol is proposed for heterogeneous wireless sensor networks. Firstly, it supposes that the different types of nodes are distributed in different zones. Secondly, by improving the threshold, nodes with large residual energy have a greater possibility of becoming cluster heads. In the end, it designs a mixed data transmission method. cluster heads of supper nodes and advance nodes directly transmit data to the base station. normal nodes adopt single hops and multiple hops mixed methods to transmit data. can minimize the energy of the communication from cluster head to base station. Simulation results show that this algorithm has achieved a longer lifetime for the wireless sensor network than stable election protocol and threshold-sensitive stable election protocol algorithm.

I. Introduction

Heterogeneous Wireless Sensor Networks (HWSN), con-sisting of many different energy nodes, have become an important focus of research and development [1, 2]. sensor nodes are dedicated to sensing environmental events and physical conditions such as floods, fires, and earth-quakes. node compresses the perceived information into data packets, which are sent to the base station (BS) [3–5]. Most of the node's energy is consumed in data transmission. However, as the battery of the nodes is difficult to change after nodes are deployed to the environment, their energy is limited. So this paper mainly discusses the energy hetero-geneity of the sensor nodes that have varying levels of energy resources in HWSN.

stable Election Protocol (TSEP) algorithm [6] is also one of typical Heterogeneous Wireless Sensor Networks. It is supposed that the network contains three different types of sensor nodes that are normal node, advance node, and supernode. normal node has the lowest initial energy. supernode has the highest initial energy. initial energy of the advanced node is between that of the normal node and supernode. It proposed three optimal probability formulas that nodes will be elected as cluster heads without considering the residual energy of the node. For the same type of sensor nodes, although they have different residual energy, they have the same probability to be selected as cluster heads. if nodes that have been elected as cluster heads have little residual energy, which will affect the efficiency of the network due to its early death. Besides, the sensor nodes directly transmit data to the cluster head in the same cluster, and the cluster head transmits the received data from other sensor nodes to the based station. normal node has less energy. When the cluster head of the normal node is far away from the base station, if it directly transmits data to the base station, this will consume much energy. also affects the lifetime of the network. To overcome these problems, we proposed an improved method based on the TSEP method to improve energy efficiency and prolong the network lifetime.

contributions of the improved TSEP method can be summarized as follows:
(1) To reduce the probability that the sensor node with little residual energy is selected as cluster head, it proposed an improved threshold formula by intro-ducing the residual energy of the sensor node.

(2) To reduce the consumed energy of cluster head, it proposed a combination method of multihop and single-hop for cluster head of normal sensor node transmitting information to the base station.

In Section 1, the introduction is given. In Section 2, we introduce the related work. TSEP method is introduced in Section 3. In Section 4, we introduce our improved method. simulation and discussion are given in Section 5. Finally, the conclusions are given in Section 6.

II. Related Work

Many effective routing protocols for HWSN have been proposed for achieving a network with a long lifetime and low-energy consumption data acquisition. Stable election protocol (SEP) [7] is a HWSN protocol with two different initial energy nodes. algorithm delays the death time of the first node because it has two different cluster head (CH) election probabilities. However, the SEP algorithm is only applicable to the two-level HWSN, and the algorithm adopts the method of single-hop routing in data com-munication. Distributed energy-efficient clustering (DEEC) [8] is designed for multilevel HWSN. It takes the estimated value of the average energy of the node as the reference point and then adjusts the rotation period of the CH adaptively by the ratio of the reference point and the residual energy.

Numerous heterogeneous protocols based on SEP and DEEC have been proposed. energy dissipation forecast and clustering management [9] is an improvement of the DEEC method using a "one-step energy consumption forecast" technique. energy consumption rate based stable election protocol [10] proposes an energy heteroge-neous network clustering algorithm based on the node energy consumption rate, which introduces energy con-sumption rate parameters in the weighted probability of CH election. energy proficient clustering technique for lifetime enhancement [11] is a novel energy-efficient dis-tance-based clustering and routing algorithm using a multihop communication approach. Based on distance, the given heterogeneous cognitive radio-based wireless sensor networks are divided into regions and are allocated with a unique spectrum. zonal-stable election protocol [12] is a clustering algorithm based on zones in which the advanced nodes have the probability of becoming CHs. However, nodes cannot be randomly deployed and only advanced nodes are selected as a cluster. SEPFL routing protocol based on fuzzy logic [13] is designed by fuzzy logic to elect the optimal cluster. three fuzzy input variables are the density of nodes, battery energy level, and distance between nodes and BS. Modified stable election protocol [14] is a HWSN algorithm on account of clustering that considers the existence of different transmission types. energy-effi-cient prediction clustering algorithm [15] is a hierarchical clustering routing algorithm. All CHs are selected by the monitored object and the initial energy of the node. efficient and dynamic clustering scheme for HWSN [16] uses a novel CH selection method by introducing a universal gravitational law in the clustering process to predict the average network energy. energy preservation in HWSNs through zone partitioning [17] partitions zones that come through a unified energy efficiency network. It also decreases node communication distance and in selecting the CHs from their respective zones. energy efficient clustering scheme for prolonging the lifetime of WSN [18] considers how to deal with the processing problem of the isolated node. Stable Election Protocol (TSEP) algorithm [6] is also an improved algorithm based on the SEP method. TSEP algorithm adds supernodes to the network. However, in terms of routing, data is still transmitted to the base station (BS) using the single-hop transmission in TSEP. routing would consume a lot of energy. process of the TSEP protocol is described in detail in Section 2. Al-though some methods have been proposed for mobile sensor nodes [19, 20], this paper also still proposed that the sensor nodes cannot be moved in fixed space.

III. TSEP Method

TSEP algorithm, which improved the SEP algorithm, is a heterogeneous wireless sensor network routing algorithm. TSEP [19] algorithm adds supernodes with more initial energies than other nodes in the new protocol. TSEP algorithm is divided into two steps: the setup phase and the data transmission phase. TSEP protocol is described in detail as follows.

In the first phase, the nodes of the wireless sensor nodes are randomly distributed in the HWSN, but the location of each node is fixed. In this phase, each node may be selected as a CH. Each node will be determined by the threshold probability formula to select a CH. threshold probability proposed in [19] can be expressed as follows:

$$T(s) = \begin{cases} \dfrac{p}{1 - p[r \times \bmod(1/p)]}, & \text{if } s \in G, \\ 0, & \text{if } s \notin G, \end{cases} \quad (1)$$

where s stands the node identifier, r is representative of the current round number, p is the probability that sensor nodes will be elected as CHs, and G represents the node set which has not been selected as a CH. Different sensor nodes with different energy levels have different probabilities to be

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selected as cluster heads. TSEP algorithm is divided into three types according to the initial energy of the node: super sensor nodes, advanced sensor nodes, and normal sensor nodes, respectively, and their corresponding probabilities that sensor nodes are selected to be cluster heads can be expressed as follows [19]:

$$P_{nrm} = \frac{P_{opt}}{1 + m \times \alpha + b \times \mu'} \tag{2}$$

$$P_{adv} = \frac{P_{opt}}{1 + m \times \alpha + b \times \mu} \times (1 + \mu), \tag{3}$$

$$P_{sup} = \frac{P_{opt}}{1 + m \times \alpha + b \times \mu} \times (1 + a), \tag{4}$$

where p_{opt} represents the optimal probability that nodes will be elected as CHs, m and b are the proportion of advance nodes and supernodes to the total number of node re-spectively, μ and α is the times that the energy of advance nodes and supernodes is more than that of normal nodes, respectively.

probability that the sensor node becomes the cluster head is expressed as P_{opt}. In each $1/P_{opt}$ round, a sensor node only has one chance to become the cluster head. If a sensor node has not been selected as a cluster head, it will be added into the set G, and the process of the cluster head selection will continue in the next round. P_{opt} is a weight to each node of different initial energy. weighted probabilities of super sensor nodes, advanced sensor nodes, and normal sensor nodes are expressed as

P_{sup}, P_{adv}, and P_{nrm}, respectively. We use the probability formula (2) to (4) instead of the probability P in (1), re-

spectively. We can get the threshold formulas of sensor nodes, advanced sensor nodes, and normal sensor nodes, respectively. threshold formulas will be used in the selecting cluster head.

When sensor nodes are selected as cluster heads, they will then broadcast an advertisement (ADV) message by the no persistent carrier-sense multiple access algo-rithms. After receiving these messages, other non-CH nodes select a cluster head from cluster heads as their own cluster head according to the signal intensity of each received message. After CHs receive the request message from other nodes, cluster heads will establish a time division multiple access time slot scheduling table. cluster head then sends the schedule to another sensor node in the same cluster to indicate the presence of the member nodes. When the CH sends the data, this process can only be completed during a specific time slot and until the formation of the cluster is complete. In the steady phase, data is transmitted from the nodes to the BS, and the data collection process for all the nodes is operated in rounds. member nodes of clusters transmit information to CHs based on the time division multiple access slots. Each CH receives the information, aggregates, and sends the information directly to the BS.

After data transmission is finished in a round, the new CH selection will be initiated in the next round. research results show that the TSEP algorithm has a longer life cycle than the SEP protocol. TSEP algorithm only prolongs the life cycle of the network by increasing the initial energy of the node. However, there is no fundamental solution to the problem that low-energy nodes consume a large amount of energy and die early.

IV.   Proposed Algorithm

In this section, an improved algorithm is introduced to solve the problem of TSEP. At the setup phase, we place three different initial energy nodes in 3 areas. By improving the threshold formula, the node with larger residual energy has a greater probability of being selected as the CH. We also use a node state transformation mechanism to control the number of CHs in high-density node areas in Area 2. At the data transmission phase, we adopt single hop and multiple hops to minimize the energy of the communication from CHs to the BS. We discuss the details of the improved protocol as follows.

4.1. Setup Phase. In the TSEP algorithm, all nodes are randomly deployed in HWSN. All nodes have the potential to be elected as the CHs. node that has low residual energy may also be elected as the CH. will reduce the survival time of nodes.

According to the radio energy consumption model proposed in the literature [7], a CH that is far from the BS to transmit data will quickly deplete more energy.

the algorithm places supernodes and advanced nodes in an area far from the BS, and other nodes are placed in an area

close to the BS. we divide the square $M \times M$ into three areas of equal size, and they are called Area 1, Area 2, and Area 3. BS is located in Area 2. Nodes that are in Area 2 consume less energy than nodes that are in Area 1 and Area 3 as transferring data to the BS. we randomly placed

5 supernodes and 10 advanced nodes in Area 1 and Area 3, respectively, and Area 2 is randomly distributed with 70 normal nodes. distribution of sensor nodes is shown in Figure 1.

After that, the nodes are placed, all nodes in the network broadcast their own information including the node label, the remaining energy of the node, and the node status.
BS receives messages and stores the node information table including the node label, the remaining energy of the node, and the node status. normal node receives its own neighbor node messages and stores a neighbor node in-formation table including the node label and the node status. process is done only once after the node is deployed. we will take two methods to select the CH. Area 1 and Area 3 use one method, while Area 2 uses another method.
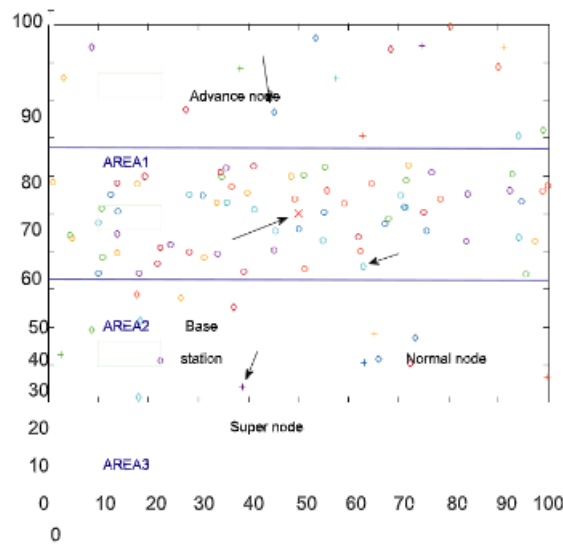

FIGURE 1: Distribution of sensor nodes.

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T_{S_{nrm}} = \begin{cases} \dfrac{p_{nrm}}{1 - p_{nrm} \left(r \times \bmod 1/p \right)} \times \dfrac{E^{re}_{s}(r)}{E_{init-nrm}}, & \text{if } s \in G_1, \\[4mm] 0, & \text{if } s \notin G_1, \end{cases} \tag{5}
$$

$$
T_{S_{adv}} = \begin{cases} \dfrac{p_{adv}}{1 - p_{adv} \left(r \times \bmod 1/p \right)} \times \dfrac{E_{res}(r)}{E_{init-adv}}, & \text{if } s \in G_2, \\[4mm] 0, & \text{if } s \notin G_2, \end{cases} \tag{6}
$$

$$
T_{S_{sup}} = \begin{cases} \dfrac{p_{sup}}{1 - p_{sup} \left(r \times \bmod 1/p_{sup} \right)} \times \dfrac{E^{re}_{s}(r)}{E_{init-sup}}, & \text{if } s \in G_3, \\[4mm] 0, & \text{if } s \notin G_3, \end{cases} \tag{7}
$$

where p_{nrm}, p_{adv}, and p_{sup} are the optimal probability of normal nodes, advance nodes, and supernodes to become a CH, respectively, while G_1, G_2, and G_3 are sets of normal nodes, advance nodes, and supernodes that have not been selected as CHs, respectively. $E_{res}(r)$ is the residual energy of node at r round, $E_{init-nrm}$, $E_{init-adv}$, and $E_{init-sup}$ are the initial energy of normal nodes, advance nodes, and supernodes, respectively.

Area 2 contained numerous normal nodes and was dense and likely to cause transmission interference, data redun-dancy, and collision. would increase energy con-sumption and affect the efficiency of energy limited WSN. We will adopt the following CH election method as follows.

In Area 2, the normal node selects a node paired with itself within the communication range according to the neighbor node information table. If a node fails to find a neighbor node and becomes an isolated node, this occurred because the minimum distance between the isolated node and other nodes was outside its range. We then set half of the pairs of nodes to be active and set the other half of the pairs of nodes to be asleep at the current round. isolate nodes are set to be active all of the time. active nodes are selected as CH according to equation (5).

After the nodes are clustered, all nodes send the label, the remaining energy, and the perceived environment param-eters to CHs. CHs aggregate the information into data packets and wait for the information from the BS. in-formation includes paths through which CHs will transmit the data to the BS.

By establishing a new network model, low-energy nodes save energy during data transmission. Furthermore, by improving the threshold formula, nodes with large residual energy will have a greater probability of electing CHs.

4.2. Data Transmission Phase. In the TSEP algorithm, the information will be directly transmitted from the cluster head to the base station. If the distance between the cluster head and base station is longer, it will consume much energy of the cluster head. reduces the lifetime of the cluster head. In our improved protocol, we will adopt two schemes for data transmission. CHs of Area 1 and Area 3 directly transmit information to the BS. However, the node energy of Area 2 is less than that of Area 1 and Area 3. the CH of Area 2 will adopt a combination method of multihop and single-hop to transmit information to the BS [21]. transmission mode of Area 2 is described in detail below.

BS according to the node information table calcu-lates the CH i communication energy consumption during the transmission of l bit messages directly to the BS, which is defined as E_{Ci-BS}. value of E_{Ci-BS} is given by the fol-lowing equation:

$$E_{Ci-BS}\left(l, d_{Ci-BS}\right) = \begin{cases} lE_{elec} + l\varepsilon_{fs}d_{Ci-BS}^2, & d_{Ci-BS} < do, \\ lE_{elec} + l\varepsilon_{mp}d_{Ci-BS}^4, & d_{Ci-BS} \geq do, \end{cases} \quad (8)$$

where E_{elec} expresses the consumed energy that one sensor node receives or transmits 1-bit information. parame-ters ε_{fs} and ε_{mp} are used to express the consumed energy that signal amplifier processing 1-bit information in free-space propagation model and multipath fading model, respec-tively. d_{Ci-BS} is used to express the distance between sensor node i and base station. It can be expressed as follows:

$$d_{Ci-BS} = \sqrt{\left(x_{Ci} - x_{BS}\right)^2 + \left(y_{Ci} - y_{BS}\right)^2}, \quad (9)$$

where (x_{Ci}, y_{Ci}) is the location coordinate of sensor node i, the (x_{BS}, y_{BS}) is the location coordinate of the base station. parameter do is just a threshold. It can be expressed as follows:

$$do = \sqrt{\varepsilon_{fs}/\varepsilon_{mp}}. \quad (10)$$

Based on (8)–(10), we can obtain the E_{Ci-BS}. If formula (11) can be satisfied, the cluster head node j will be used as an intermediate sensor node between the cluster head node I and base station. If the following equation is not be satisfied, the cluster head node i will directly transmit data to the base station without using the intermediate cluster head.

$$E_{Ci-BS} \, l, d_{Ci-BS} \geq E \, l, d_{Ci-Cj} + E \, l, d_{Cj-BS}, \quad (11)$$

where d_{Cj-BS} expresses the distance between the base station and cluster head node j, d_{Ci-Cj} is the distance between the cluster head node i and the cluster head node j. ex-pressions of d_{Ci-Cj} and d_{Cj-BS} are given by the following equation:

$$d_{Ci-Cj} \blacklozenge \quad x_{ci} - x_{cj} \,^2 + y_{ci} - y_{cj} \,^2,$$

$$(12)$$

$$d_{Cj-BS} \blacklozenge \quad x_{cj} - x_{BS} \,^2 + y_{cj} - y_{BS} \,^2.$$

method can reduce the consumed energy that the cluster head transmits data to the base station. Suppose the distance between the cluster head and base station, and the cluster head will transmit data to the intermediate cluster head. In that case, the intermediate cluster head node transmits the received data to the base station.

After the cluster head node completes the data trans-mission, the cluster head will change its state. If the sensor node and its neighbor sensor node are not dead, then the two nodes should keep their current state. If a pair of sensor5 nodes have one dead node, its partner would keep an active status and try to find another node to complete a pair. After receiving the information, the BS updates the node infor-mation table and broadcasts the information to all nodes, and all nodes update the neighbor node information table according to the received information. indicates the completion of this round. proposed algorithm flow chart is shown in Figure 2.

V.   Simulation and Discussion

5.1. Experiments. experiment assumes that there are 100 nodes, 10% of the nodes are supernodes, 20% of the nodes are advanced nodes, and the remaining nodes are normal nodes. Each of the advanced nodes has 50% more initialized energy than each of the normal nodes, and each of the supernodes has 100% more initialized energy than each of the normal nodes. experiment assumes that each supernode has 1 Joules energy, so each advanced node and normal node have energy of 0.75 Joules and 0.5 Joules, respectively. experiment randomly places these nodes in

a square area of $100*100$ m^2, and the BS is located at the center. best probability that each node becomes a CH is set to 0.1. Since the TSEP algorithm is based on the SEP algorithm, our proposed algorithm is also based on the TSEP algorithm. So this experiment uses the TSEP algorithm and SEP algorithm to compare the performance of dead nodes, network residual energy, and throughput with our proposed algorithm using the MATLAB platform as a simulation tool. parameters required for the experiment are shown in Table 1.

Firstly, the sensor nodes are distributed in three zones that are shown in Figure 1. It can be used in monitoring the water quality of the fish pond. normal sensor nodes are distributed in the center of the fish pond. advance and supernodes are distributed at the edge of the pond. It is convenient to change the battery of sensor nodes that are distributed at the edge of the pond. Besides, if all sensor nodes have the same initial energy, the network can become a heterogeneous wireless sensor network after changing the battery of sensor nodes that are distributed at the edge of the pond. Figure 3 shows the percentage of death nodes per round. Figure 4 shows the residual energy of all nodes for SEP, TSEP, and the proposed algorithm. Figure 5 displays the number of packets that are between the BS and the CHs with respect to the number of rounds.

Secondly, the sensor nodes are distributed in a single zone. percentage of death nodes in a single zone is shown in Figure 6. residual energies of all nodes for SEP, TSEP, and proposed algorithm are shown in Figure 7. throughputs of the three methods are shown in Figure 8.

5.2. Results Analysis. In Figure 3, it can be seen that the nodes start to die at about 1200 rounds when using SEP and TSEP, but they start to die at 1700 rounds when using the proposed method. nodes completely died at about 2000, 2500, and 4500 rounds when using SEP, TSEP, and our
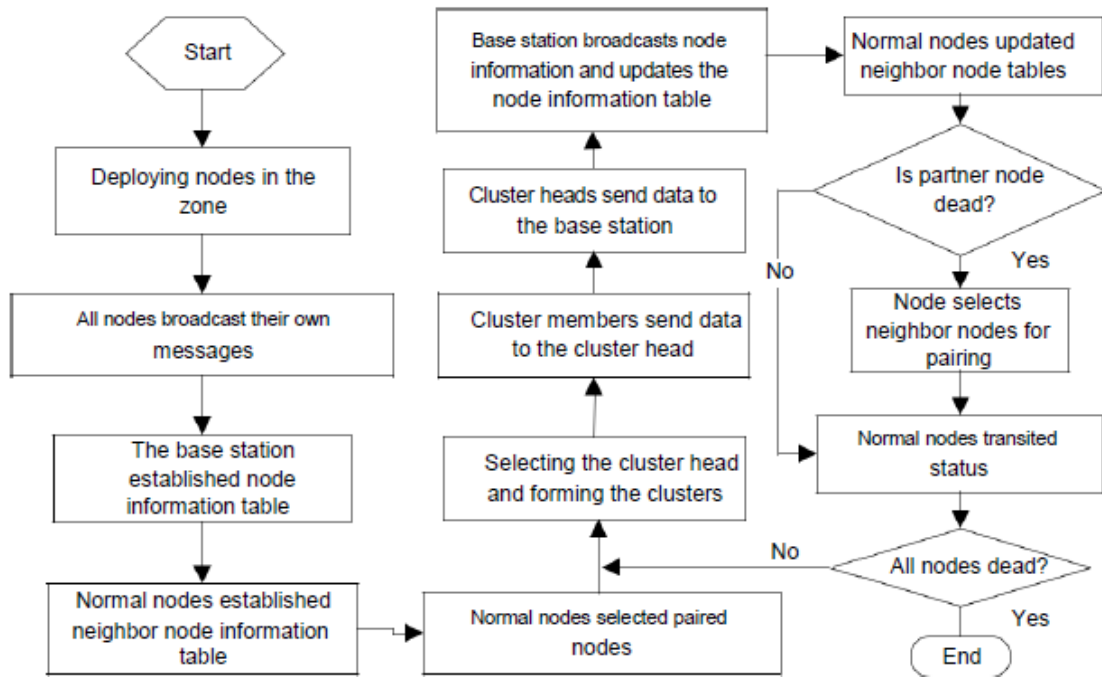
FIGURE 2: Flow chart of our proposed algorithm.

TABLE 1: simulation parameters of the experiment.

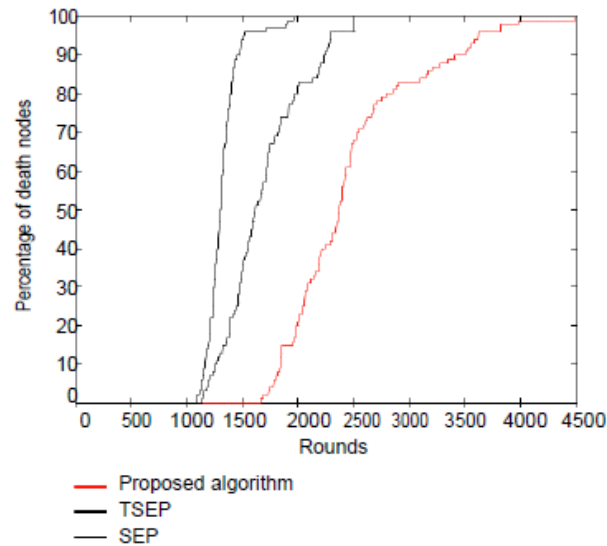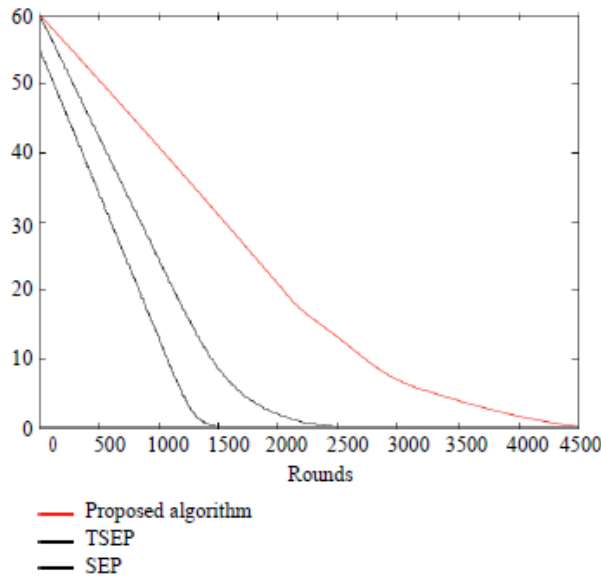| Parameters	do	c_{fs}	c_{mp}	E_{elec}	E_{DA}	l
Values	87	10	0.0013	50	5	4000

FIGURE 3: percentage of death nodes with tree zones.

FIGURE 4: Residual energy with tree zones.

proposed method, respectively. still are about 30 surviving nodes for the proposed method at 2500 rounds.
In Figure 4, we can see that the residual energy decreases with the increasing of rounds for all methods, but the proposed method has more residual energy than the others. enhancement is due to the improved protocol in the mechanism of CH selection and routing. By improving the threshold, nodes with large residual energy have a greater possibility of becoming CHs to prevent premature death of low-energy nodes due to excessive energy consumption. In SEP and TSEP, the CH directly transmits data to the BS, but the proposed protocol adopts single hop and multiple hops to minimize the energy of the communication from CH to BS. this proves that the proposed method pro-longs the network's lifetime.

If there is a higher number of surviving nodes, there will be a higher number of selected CHs, which means the proposed method prolongs the network's lifetime. state transition mechanism in Area 2 can also successfully address
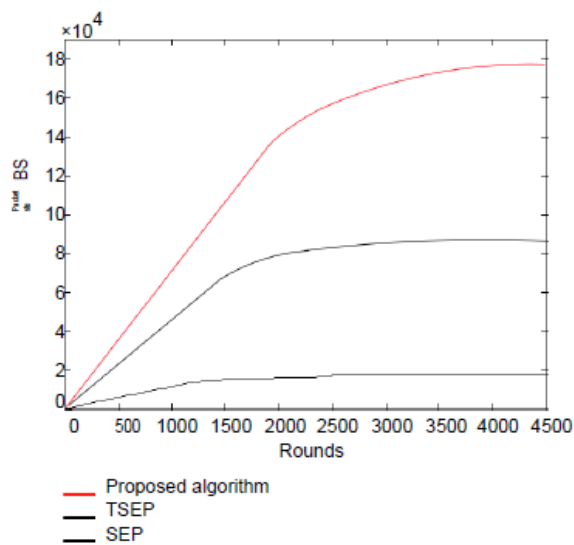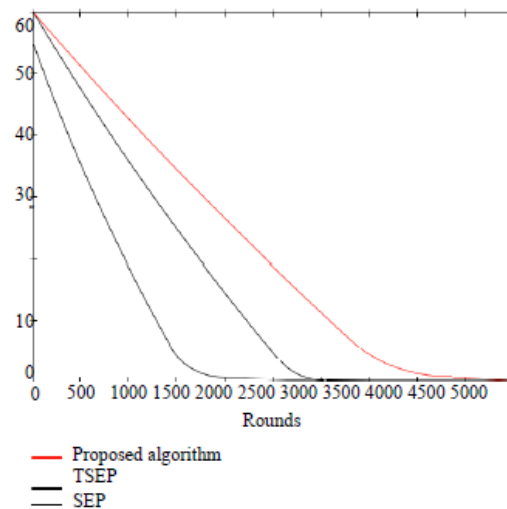

FIGURE 5: with tree zones.

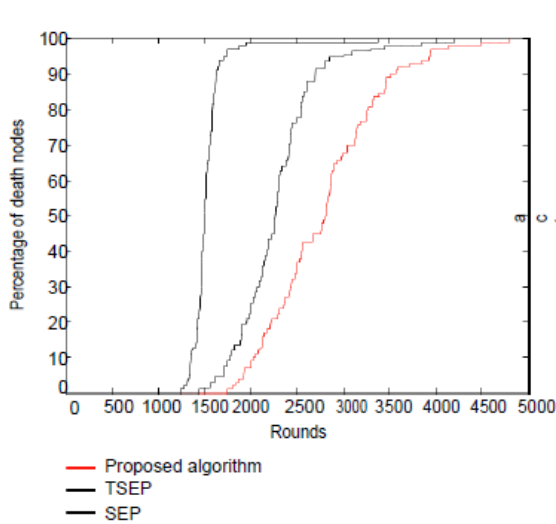FIGURE 7: Residual energy with a single zone.

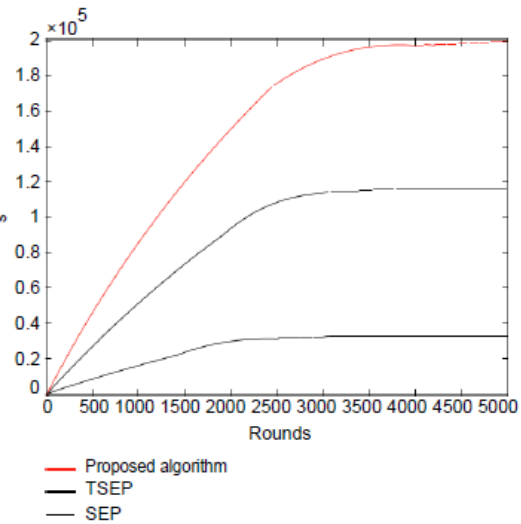FIGURE 6: percentage of death nodes with a single zone.

FIGURE 8: with a single zone.

redundancy problems and the data conflict in TSEP and SEP. In Figure 5, the throughput of SEP and TSEP is less than our proposed method because only the cluster head sends data to the base station. In our proposed method, the data of the normal sensor node is directly sent to the base station, and the data of super and advanced sensor nodes that have more energy is sent to the base station by cluster head. Besides, the proposed method has a longer network lifetime than others. It has a longer time to transmit data.

In Figure 6, the nodes start to die at about 1300, 14000, and 1800 rounds when using SEP, TSEP, and our proposed method, respectively. Besides, nodes completely died at about 3000, 4000, and 5000 rounds when using SEP, TSEP, and our proposed method, respectively. In Figure 7, the residual energies reach zero at about 2000, 3000, and 4500 rounds for SEP, TSEP, and our proposed method, respec-tively. In Figure 8, we can also see that the number of packets for the proposed method is more than that of the other methods, and its lifetime is also longer than the other protocols. Based on the above analysis, this shows that the proposed method has better performance in prolonging the lifetime of the network for the sensor nodes that are dis-tributed in tree zones and single zones.

VI. Conclusions

An improved method has been designed to reduce the energy consumption and prolong network lifetime for three levels of energy HWSN. We divided the sensing area into three regions and deployed the supernodes, advanced nodes, and normal nodes separately. At the setup phase, it adjusts the threshold to select the nodes that have higher residual energy, which solves the problem of improper CH selection. It also uses a node state transformation mechanism to control the number of CHs in high-density node areas in Area 2. At the data transmission phase, it selects the path that consumes the minimum amount of energy as the op-timal routing path to further reduce energy consumption. In comparison with the other methods, the proposed method prolongs the network lifetime.

In the proposed method, we supposed that the normal sensor node directly sends data to the base station. If the number of normal nodes is small or the space is large, it will affect the lifetime of the network. Besides, the proposed method increased time complexity, so this will affect the real-time of the network. algorithm ignores the hotspot problem caused by the multihop transmission of data packets. data loss problem and time complexity also should be research in the feature. paper supposed that the sensor nodes cannot be moved, how to prolong the lifetime of movable sensor nodes should also be research in the feature.

Data Availability

data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

authors declare that they have no conflicts of interest.

Acknowledgments

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