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An Effective Clustering Routing Protocol for Heterogeneous Wireless Sensor Networks

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Abstract. *An effective protocol is proposed to address the problem of improper cluster head selection in the energy heterogeneous wireless sensor network in this paper. The proposed algorithm selects nodes which have more initial energy and residual energy as cluster heads to balance energy depletion and prolong the survival time of the network. Specifically, the ratio of residual energy and the initial energy is leveraged in the threshold. In addition, Pythagorean Theorem is adopted to find the appropriate routing of the network. Extensive simulations have been conducted and the simulation results verify that the algorithm has prolonged the lifetime of wireless sensor network and improved overall stability of entire network as well.*
Keywords: Cluster head selection; Heterogeneous wireless sensor network, Energy consumption, Routing.

1. **Introduction.** Wireless sensor networks (WSNs), which consist of a large number of nodes, have become an important target for research and development. These sensor nodes, which are randomly distributed in target region, are dedicated to sensing environmental events and physical conditions such as floods, fires, earthquakes, etc. Then the sensed information, condensed into data packets, will be transmitted to the base station [1]. Due to limited resources of computation power, energy, storage, bandwidth, and dynamic changes in topology, WSN is unable to provide efficiency of data packets transmission and network lifetime [2]. Therefore, the task of designing routing protocols for effective network operation presents several challenges. The main challenge in route design is that the WSN is usually deployed in a harsh environment and the battery energy of the nodes is not easily recharged [3]. Therefore, energy considerations have a great influence on optimal route design and the energy of sensor nodes must be used very efficiently to monitor an area for a sufficiently long time.

One routing solution is to employ a percentage of heterogeneous nodes. Some proposed protocols adjust the communications method between heterogeneous nodes and the base station according to the energy level and the distance from the base station [4]. Clustering is another widely used technology in WSN, which effectively reduces the energy depletion of the sensor nodes [5] and the distance between the head and the associated nodes [6]. However, incorrect cluster formation may cause the overloaded cluster to die very early. Additionally, many existent clustering algorithms developed for homogeneous WSNs do not fit well when applied to heterogeneous WSNs. So, multiple factors must be taken into account before the effective design of cluster formation. There is a significant need for research about routing protocols for improved applications in heterogeneous environments.

An improved clustering routing protocol is developed in this paper. It can improve the probability of cluster head selection process by adding parameters like residual energy, initial energy and the number of optimal cluster head. This improved protocol can balance the energy consumption of the network and prolong the network lifetime.

2. Related Work.

To achieve a long network lifetime with low data-gathering consumption, a number of efficient routing protocols have been proposed for WSNs. Low Energy Adaptive Clustering Hierarchy (LEACH) [7] is one of the most popular clustering algorithms in WSN. In the LEACH algorithm, the operation is divided into several rounds. Each round is defined by the setup phase and the steady phase. There are an optimal percentage of nodes that to be a cluster head in each round. However, LEACH assumes that the energy usage of each node with respect to the network is homogeneous, and thus is unfit for heterogeneous wireless sensor networks. Minimum Transmission Energy (MTE) and Direct Transmission (DT) also do not guarantee that they can balance energy use of the sensor nodes. The Stable Election Protocol (SEP) [8] is designed to handle heterogeneous networks, and the introduction of the concept of advanced nodes and normal nodes for cluster head selection. This is based on weighted selection probabilities for each node to turn into a cluster head based on the residual energy in each node. The SEP algorithm does not need global knowledge of energy for every election per round, and the performance of SEP algorithm is better than that of LEACH. Distributed Energy Efficiency Clustering (DEEC) [9] is designed for multi-level heterogeneous networks where the cluster head is selected by a probability controlled by the ratio of the average energy of the whole network and the nodes residual energy. Therefore, it is more likely for nodes with more initial energy and residual energy to be selected as cluster heads.

Based on LEACH, SEP and DEEC, numerous protocols have been proposed. EECDA [10] selects the cluster heads based on the maximum sum of residual energies for data transmission. EDFCM [11] is an improvement of DEEC. The algorithm depends on a technique called a one-step energy consumption forecast. EESAA [12] focuses on the cluster head selection process and introduces a new pairing concept based on remaining energy. Z-SEP [13] is a clustering algorithm based on the zone in which advanced nodes have the possibility to become a cluster head. However, nodes can not be deployed randomly. RMCHS [14] uses a Ridge technique to choose the best cluster head. The algorithm always chooses cluster heads from the nodes with higher residual energy. M-SEP [15] is a heterogeneous protocol-based clustering that considers the existence of different transmission types. M-GEAR [16] is a protocol based on region, in which nodes have to decide whether to participate in clustering or direct communication. SEA [17] is an extension of SEP. It follows the hybrid approach to forward data against energy of the nodes. The improved EADUC protocol [18] considers number of nodes in the neighborhood in addition to the location of base station and the residual energy for electing cluster heads. The methodology used is of retaining the same clusters for a few rounds and is effective in reducing the clustering overhead. P-SEP[19] put forward that prolong the stable period of sensor networks supported by maintaining balanced energy consumption. Fog technology is used to enhance communication between FNs, which can be used with FN to calculate fog. ZBHCP [20] partitions zones which results in uniform energy utilization in the network and reduces intra-cluster and inter-cluster communication distances and selects cluster headers from their respective areas. Paper [21] reviews the intelligent sensor network with two viewpoints. One is to solve or optimize the wireless sensor network issues by intelligent algorithms. The other is intelligent applications that incorporate sensor networks as the data sources. ECHA [22] outperforms classical hierarchical routing protocols such as LEACH and LEACH-C by optimal selecting cluster head based on effective of the distances normal node to HC and CHs. Paper [23] investigates the energy-oriented and lifetime-oriented sink node placement strategies in the single-hop and multiple-hop WSNs. The localization algorithm [24] is proposed to solve the multi-objective optimization localization issues in wireless sensor networks based on multi-objective particle swarm optimization.

These above studies have focused mainly on clustering in a hierarchical structure but do not consider all the important factors. Global information of sensor nodes may be required or the probabilities of the cluster head selection may be statically assigned. Therefore, we further consider more complicated and realistic factors and conditions in this study. Our proposed approach is described in the following sections and is then compared through simulation with existing protocols. Our solution has advantages for both clustering and routing.

3. **Heterogeneous WSN Model.** In this section, we will provide a simple network model that facilitates design of our routing protocol. Our protocol reduces the energy consumption of data transmission using the network model. First, we discuss the energy heterogeneous network model and the energy model in detail.

3.1. **Network Model.** In WSNs, the energy efficiency affects the lifetime of the network directly and we should utilize the energy of the node more efficiently. In this study, it has two types of nodes deployed in the network that differ in their initial energy. Nodes with more initial battery energy are referred to as advanced nodes while other nodes are referred to as normal nodes. In this case, we consider that m score of all the nodes are advanced nodes with times more energy than the rest nodes. There is a sensing area with a stationary base station and high energy in the center covers $M \times M$ square meters. There are heterogeneous nodes in regard to node energy. All nodes are randomly deployed in the field and stationary once they are distributed in the field and each node in the network only has an ID. The cluster head performs data aggregation and the base station are not energy-limited.

3.2. **Energy Model.** In our research, we discuss the energy model as previously [7]. When the node sends k bits messages to a distance d, the equation to calculate the energy consumption [7]

$$E_{Tx}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs}d^2, d < do \\ lE_{elec} + l\varepsilon_{mp}d^4, d \geq do \end{cases} \tag{1}$$

where E_{elec} signifies the energy dissipation per bit in the transmitter and receiver circuitry, d signifies the transmission distance, and signifies the threshold distance. The parameters ε_{fs} and ε_{mp} are the energy consumption per bit in the radio frequency amplifier.

Also, when nodes receive k bit messages, the equation to calculate the energy consumption [7] is given by

$$E_{Rx}(l) = lE_{elec} \tag{2}$$

where E_{elec} signifies the energy dissipation per bit in the transmitter and receiver circuitry, d signifies the transmission distance, and do signifies the threshold distance. ε_{fs} and ε_{mp} are the parameters that energy consumption per bit in the radio frequency amplifier. The distance is measured on the value of do [7], whose value is given by

$$do = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \tag{3}$$

The energy dissipation for data aggregation is given by

$$E_{DA}\left(l\right) = lE_{DA} \tag{4}$$

As depicted in [8], the detailed calculation of energy consumption for one cluster

$$E_{CH} = \left(\frac{n}{k} - 1\right) l * E_{elec} + \frac{n}{k} l * E_{DA} + l * E_{elec} + l * \varepsilon_{fs} * d_{toBS}^2 \tag{5}$$

$$E_{nonCH} = l * E_{elec} + l * \varepsilon_{fs} * d_{toCH}^2 \tag{6}$$

$$E_{cluster} = E_{CH} + \frac{n}{k} E_{nonCH} \tag{7}$$

where E_{CH} signifies the energy consumption of cluster heads, E_{nonCH} signifies the energy consumption of a member node of the cluster, $k$signifies the number of cluster heads, d_{toBS} signifies the average distance between the cluster head and the base station and d_{toCH} the average distance between the cluster head and the cluster member. We substituted Eqs. (5) and (6) into Eq. (7). The total energy consumption in a round [8] can then be written as

$$E_{total} = l\left(2nE_{elec} + nE_{DA} + \varepsilon_{fs}\left(kd_{toBS}^2 + nd_{toCH}^2\right)\right) \tag{8}$$

Then, the optimal number of clusters [8] is given by

$$k_{opt} = \frac{\sqrt{\varepsilon_{fs}}}{\sqrt{\varepsilon_{mp}}} \frac{\sqrt{n}}{\sqrt{2\pi}} \frac{M}{d_{toBS}^2} \tag{9}$$

The optimal number of clusters plays an important role in network clustering. Therefore, we selected this to minimize energy consumption. Last, the probability of becoming a cluster head of every node [8] is given by

$$p_{opt} = \frac{k_{opt}}{N} \tag{10}$$

where N is the total number of nodes.

4. **Heterogeneous WSN Model.** In SEP, different weighted probabilities are assigned for normal nodes and advanced nodes to select cluster heads. The one for normal nodes [8] is given by

$$p_{nrm} = \frac{p_{opt}}{1 + \alpha m} \tag{11}$$

where m score of all the nodes are advanced nodes and these nodes are equipped with times more energy than normal nodes and p_{opt} is the probability of becoming a cluster head.

The one for advanced nodes [8] is given by

$$p_{adv} = \frac{p_{opt}}{1 + \alpha m} * (1 + \alpha) \tag{12}$$

The value of the following threshold is used by each node to determine if it can be a cluster head in the current round. The thresholds for normal and advanced nodes [8] are given by Eqs. (13) and (14), respectively

$$T\left(S_{nrm}\right) = \begin{cases} \frac{p_{nrm}}{1 - p_{nrm} * r \bmod (1/p_{nrm})} i \in G' \\ 0, i \notin G' \end{cases} \tag{13}$$

$$T\left(S_{adv}\right) = \begin{cases} \frac{p_{adv}}{1 - p_{adv} * r \bmod (1/p_{adv})} i \in G \\ 0, i \notin G \end{cases} \tag{14}$$

where r is the current round and G' and G'' are the set of normal nodes and advanced nodes that were not selected as cluster heads in the last $1/p_{nrm}$ and $1/p_{adv}$ round, respectively. However, the SEP does not consider the possibility that a normal node may have more energy than an advanced node after few rounds. A variant of SEP, M-SEP [15] incorporates multilevel power transmission to improve the efficiency of the protocol. However, for selecting cluster heads, M-SEP has the same drawback as SEP. Therefore, we developed an improved algorithm that is an improved version of SEP and considers energy levels of nodes to reduce unnecessary energy consumption and extend the lifetime of a heterogeneous wireless sensor network. In this section, the operation of the improved algorithm continues with rounds. Each round is divided into two phases, the setup phase and the data transmission phase.

4.1. **Setup Phase.** Initially, we deployed the nodes randomly in the target area. Next, we adopted a clustering method for energy efficient network operation. In our clustering approach, the cluster head selection is of key importance as improper selection can drastically affect the energy efficiency of the network. The cluster head selection must be optimized to efficiently transmit data message to the sink. Unlike cluster head selection in SEP in which only the advanced nodes are responsible for clustering, in our routing protocol, normal nodes always transmit data message to the sink directly. This is because the cluster head requires much more energy for clustering approach in routing data. We have considered threshold levels as the parameters. Each advanced node generates a random digital between 0 and 1, and if the generated digital is less than the threshold value, that node will become a cluster head. To increase the probability that a residual energy node will be cluster head, the algorithm adjusts the value of the threshold in which the specific value of remaining energy of the node to the initial energy of the node and optimal number of clusters are added. Therefore, the new threshold for advanced nodes is set as

$$T\left(S_{adv}\right) = \begin{cases} \frac{p_{adv}}{1-p_{adv}*r \bmod \left(1/p_{adv}\right)} * \frac{E_i * k_{opt}}{Eo} i \notin G \\ 0, i \notin G \end{cases} \tag{15}$$

Where G is the set of advanced nodes that were not selected as a cluster head in the last $1/p_{nrm}$ and $1/p_{adv}$ round respectively, E_i is the residual energy of any node, Eo is the initial energy of the node, and k_{opt} is the optimal number of cluster heads. In the new threshold, nodes with more initial energy and residual energy have increased election probability in cluster head election. Therefore the proposed protocol has better control over energy consumption and also improves lifetime of the WSN, determined by the ratio of the current energy to the initial energy of the nodes. Finally, the cluster head establishes TDMA schedule. Then the cluster head sends this schedule to the members of the cluster. In order to reduce the energy consumption between members of the clusters and the base station, we used the Pythagorean theorem for path selection. It uses a heuristic function to make this decision and the heuristic function is given by

$$d(i, BS)^2 = d(i, CH_j)^2 + d(CH_j, BS)^2 \tag{16}$$

Where $d(i, BS)$ is the distance between node and the base station, $d(i, CH_j)$ is the distance between node i and cluster head CH_j , and $d(CH_j, BS)$ is the distance between cluster head CH_j and the base station. The member nodes select a path with minimal energy consumption to join the cluster through the heuristic function.

4.2. **Data Transmission Phase.** After the setup phase was the steady phase, in which data was transmitted from the nodes to the base station, and the data collection process for all the nodes operated in rounds. There were two kinds of communication between advanced nodes and normal node: multi-hop communication and single-hop communication.

Multi-hop communication for the advanced nodes operated with the different clusters of the network, which were elected in the setup phase. The member nodes of clusters transmitted data to the cluster head based TDMA slot. Then, each cluster head received the data message, aggregated it and forwarded it to the sink node. In contrast, the normal nodes always send packets to the sink node directly. Therefore, the energy consumption for the normal nodes will be reduced and balanced based on routing rules. After data transmission is finished in a round, the new cluster head selection will be initiated in the next round.

4.3. **Algorithm.** The algorithm of the improved protocol is divided into two modules namely: Setup(), Data Transmission().

1:Initialize WSNs characteristics
2:Define heterogeneous characteristic of proposed protocol
3:Deploy sensor nodes in the network field
4:Setup() function is checking the nodes for cluster heads selection
    STEP 1:check node i is advanced
    STEP 2:calculate the value of the threshold
    STEP 3:if node i < threshold, then node i is selected as CH
    STEP 4:CH broadcasts the success message
    STEP 5:other nodes join the CH using the Pythagorean theorem
  Data Transmission() function is selecting the proper routing path
    STEP 1:if node i is normal, then send data packets to the sink node directly
    STEP 2:if node i belongs to a cluster, then send data packets to the CH and CH send data packets
        to the base station
5:END

5. **Simulations and discussions.** In stable election protocol, the selection of cluster head node did not consider the residual energy of node and the selected cluster head send data to based station directly. This caused that some nodes with lower energy were used as cluster head to make it die early. To address the problem of improper cluster head selection, the proposed algorithm selects nodes which have more initial energy and residual energy as cluster heads to balance energy depletion and the ratio of residual energy and the initial energy is leveraged in the threshold. In addition, Pythagorean Theorem is adopted to find the appropriate routing of the network. The new algorithm set up a low cost routing mechanism between the cluster head and the base station to conserve much energy. Therefore, the new protocol verifies that it is actually useful for some of the WSN issues and it is possible to compare this work with other papers proposed more recently.

To test the performance of proposed method, in our simulations, we assumed that 10 percent of sensor nodes were advanced nodes, which have double energy than normal nodes, and we deployed these 100 nodes in a square meter region where the sink node was located at the center of the sensing area. We initialized p_{opt} to 0.1. The initialized energy of the normal node was 0.5 Joules and the initialized energy of the advanced node was 1 Joules. We simulated the new protocol using MATLAB. The parameters under in our simulations are given in Table 1.Next, we discuss the performance of our protocol compared with SEP and M-SEP for stability period, network lifetime, throughput, energy dissipation, and residual energy.

Figure 1 displays the quantity of alive nodes in each round in the network. We observe from the figure that even after 2000 rounds, the quantity of alive nodes using the new protocol was higher as compared to that of other protocols. The time space between the

Table 1. Simulation parameters

Parameters	Values
do	87m
ε_{fs}	10pJ/bit/m^2
ε_{mp}	0.0013pJ/bit/m^4
E_{elec}	50nJ/bit
E_{DA}	5nJ/bit
l	4000

beginning of the operation and the last sensor nodes death is called the network lifetime. As observed, the network life time is highly improved in regard to existence of alive nodes for more amount of rounds as shown in the Figure 3. And this is due to the energy balanced in the network in a better way. We can also conclude that the number of dead nodes using the new protocol was lower than that of other protocols per round. Meanwhile it was noticed that existent nodes were not dead even after 2500 rounds in the proposed protocol while most nodes were almost dead in SEP, M-SEP. This enhancement is due to the difference in the mechanism of cluster head selection and routing of the sensed data. The improved protocol accounts fully the energy value of heterogeneous nodes and normal nodes regarding their less energy than advanced nodes in cluster head selection. So, normal nodes are located next to the base station so that it can send the base station data directly to conserve much more energy instead of forming the clusters. The other algorithms perform poorly because all the nodes participate in cluster head selection and thus lead to more energy waste. Thus, we can conclude that the proposed protocol is able to use as much energy of nodes as possible and prolongs the lifetime of network successfully.

Figure 2 shows the quantity of dead nodes per round in the network. We observe from Figure 2 that the amount of dead nodes using the new protocol was lower than that for the other protocols per round. The time interval between the beginning of the operation and the last sensor nodes death is called the network lifetime. The existent nodes were not dead even after 2500 rounds of the proposed protocol, but most nodes were dead in SEP and M-SEP. Based on this, we concluded that the proposed protocol could lengthen the network lifetime. The improved clustering technique decreased the number of clusters and shortened the distance for data forwarding, resulting in less consumption of the energy for the sensor nodes. In addition, the shortened distance is also beneficial to data transmission [25-26]. When it takes a longer time for the first node to die, there is an increase in the network lifetime.

Figure 3 displays the quantity of packets send to the base station with respect to the number of rounds. It is easily found from the Figure 3 that it is very efficient for the proposed protocol in successful data delivery. The proposed protocol also has more amounts of packets delivered to the base station compared to SEP and M-SEP. It means that the proposed protocol ensures a proper allocation of cluster head and cluster heads in more rounds. These cluster heads will deliver packets to the base station hence throughput increases. As the network lifetime is increasing, the quantity of packets that received by the sink node also increases correspondingly.

Figure 4 displays the energy consumption of the network with respect to the number of rounds. It is worth noticing that the energy consumption during the protocol operation was quite lower than that of other protocols. Meanwhile, we can know that the residual energy of the proposed protocol was higher in the network with respect to the number of

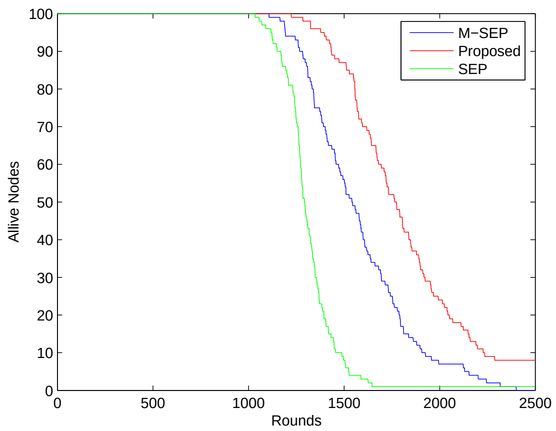

FIGURE 1. Alive nodes with increasing number of rounds

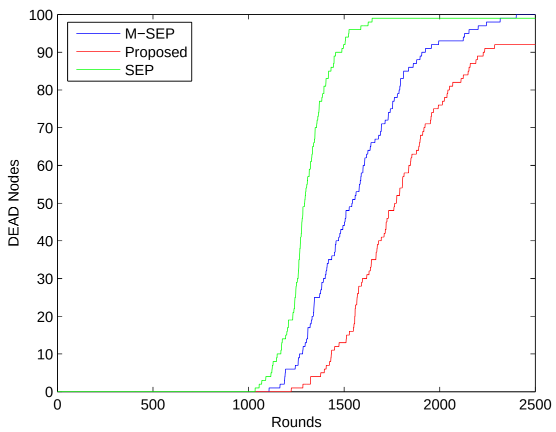

FIGURE 2. Dead nodes with increasing number of rounds

rounds. Furthermore, we also observe that the rate of energy consumption in the case of the proposed protocol was much slower than in SEP, M-SEP. This is the reason that the optimal cluster head selection conserved much of the energy, together with the appropriate routing path for the protocol. Thus, the residual energy of the network performed better using our new protocol than did SEP and M-SEP, as shown in Figure 5. Therefore, we conclude that the proposed protocol conserves energy and lengthens the network lifetime.

We show the first alive nodes death time in Table 2. Three different algorithms were compared in terms of the time that the first death node appeared. From the Table 2, we can see that the first death time of the proposed algorithm was 1224 rounds, which was much longer than that of other algorithms, in which it was 1035, and 1108 respectively. This improvement is achieved by the proposed protocol through an optimal cluster head selection. The time interval between the beginning of the operation and the first alive nodes death is called the stability period. Thus, we can see that the network stability period using the proposed protocol is much longer than that of SEP, M-SEP. In SEP and M-SEP, the low energy nodes selected as cluster heads bring to the stability period to an end quickly. Thus, the proposed protocol is helpful in extending the network lifetime.

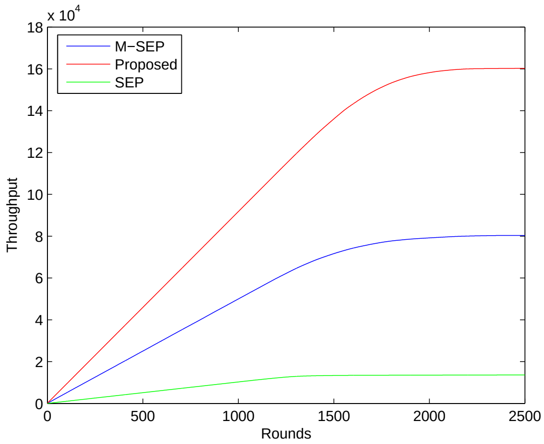

Figure 3. Throughput

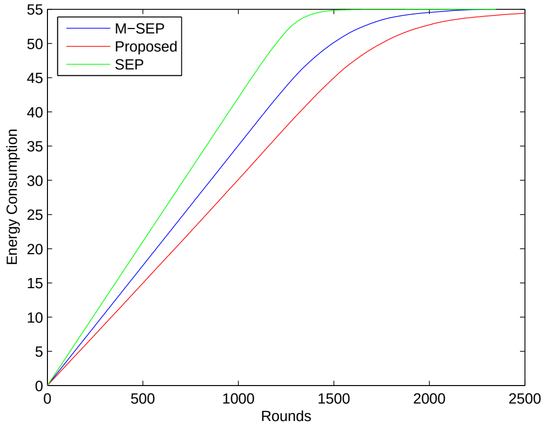

Figure 4. Energy Consumption

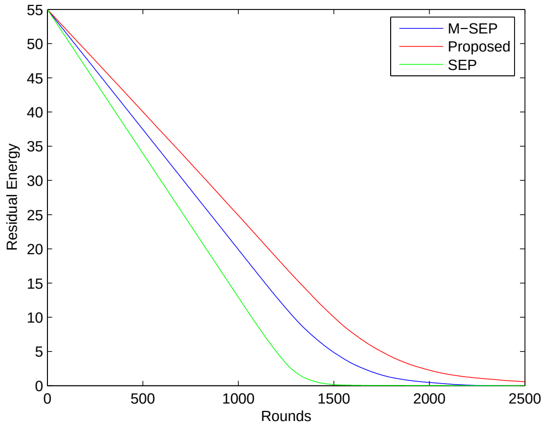

Figure 5. Residual Energy

TABLE 2. Rounds that the first death node appears

Algorithms	Rounds that the first death node appears
SEP	1035
M-SEP	1108
Proposed	1224

6. **Conclusions.** An effective protocol in this paper is designed for a two rank energy heterogeneous wireless sensor network to cut down energy consumption and prolong the entire network lifetime. To solve the problem of improper cluster head selection, we adjust the threshold to select the nodes which have higher initial energy and residual energy as cluster heads. Additionally, we select the path which consumes minimum energy as the optimal routing path to further reduce energy consumption. Extensive simulations have been conducted and the simulation results verify that the proposed protocol shows a better stability period and longer network lifetime in comparison of the current protocols. Our future work mainly focuses on solving the energy-hole problems where nodes which are close to a static cluster head degrade rapidly. Firstly, cluster head mobility is one of the methods to address this problem. In addition, routing protocols which enable mobile routings are also our research direction. Those two future research directions would be beneficial to the design and implementation of heterogeneous wireless sensor networks.

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