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AN IMPROVED ENERGY EFFICIENT ROUTING PROTOCOL FOR HETEROGENEOUS WIRELESS SENSOR NETWORKS

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Abstract. *In the stable election protocol, sensors are randomly deployed in the region without considering the balancing energy consumption of normal nodes and advanced nodes. If a normal node that has been selected as a cluster head is located far away from the base station, it will affect the efficiency of the network due to its early death. In this paper, an improved energy efficient routing protocol for heterogeneous wireless sensor networks has been proposed. We have fixed the sized zone depending upon the distance from the base station and used a clustering technique for advanced nodes to transmit data. In addition, we adopt a dormancy mechanism for normal nodes and conserve energy by state transition. Simulation results depicted that the proposed protocol performed better than SEP, modified stable election protocol, and SEA (special energy advanced node) by reducing energy consumption and providing a longer stable period, a longer network lifetime and better throughput of data packets.*
Keywords: Heterogeneous wireless sensor networks, Routing protocol, Energy consumption, Stable election protocol

1. **Introduction.** Wireless sensor network (WSN), which consists of a large number of nodes, has emerged as an important area for research and development. These sensor nodes, which are deployed randomly in the field of wireless sensor networks, are dedicated to sensing environmental events and physical conditions like floods, fires, and earthquakes. Then sensed information, which is condensed into data packets, will be transmitted to the base station [1-3]. Due to limited resources such as computation power, energy, storage, bandwidth and dynamic changes in topology, WSN is unable to provide efficiency in transmission and network lifetime [4-6]. Therefore, we must use the energy of sensor nodes very efficiently in order to monitor an area for a longer time. Two of the main problems that a WSN has to face are that the energy of the nodes cannot be recharged and the WSN is also usually deployed in a harsh environment [7-9]. One solution for prolonging the network lifetime is to employ a percentage of heterogeneous nodes. The nodes which are heterogeneous adjust themselves at different levels for data transmission and perform various other operations to save energy [10]. Clustering is also a widely used technique in WSN that effectively reduces the energy consumption of sensor nodes [11]. However, improper cluster formation with clustering technique for routing may cause overloaded clusters to go dead early. Therefore, research about routing protocols is still necessary for applications in heterogeneous environments.

The energy consumption of the nodes will increase and then affect the efficiency of the network. Previous researches fail to avoid problems such as overhearing and idle listening. The main goal for designing a new algorithm is to solve the above noted problems to enhance the lifetime and stability of the network. Therefore, we proposed an improved routing protocol for heterogeneous wireless sensor networks, which fixed the sized zone depending upon distance from the base station; in this proposed protocol, the advanced nodes formed into clusters and the normal nodes took on a dormancy mechanism with state transition. The improved protocol can utilize energy efficiently and prolong the network lifetime.

The paper is organized as follows: Section 2 presents the discussion of the related work; Section 3 provides the network model and energy model; Section 4 presents the protocol in detail, including a selection of cluster heads and state transition of normal nodes to save energy; Section 5 shows some simulation results; Section 6 draws the conclusions and suggests directions for future work.

2. **Related Work.** To achieve a long network lifetime with low data gathering consumption, many effective routing protocols for WSN have been proposed. Low energy adaptive clustering hierarchy (LEACH) is one of the most popular clustering algorithms in WSN [12]. In the LEACH algorithm, the operation is divided into rounds. Each round is defined by the setup phase and the steady phase. There is an optimal percentage of nodes that has become a cluster head in each round. However, LEACH assumes that the energy usage of each node with respect to the network is homogeneous, and it is not well suited for heterogeneous wireless sensor networks. Minimum transmission energy (MTE) and direct transmission (DT) also do not assure a balanced use of the energy of the sensor. Stable election protocol (SEP) is designed to deal with heterogeneous networks, which introduces the concept of advanced nodes and normal nodes for cluster head selection [13]. This is based on weighted election probabilities of each node to become a cluster head according to the remaining energy in each node. The SEP algorithm does not require any global knowledge of energy at each election round, and the performance of the SEP algorithm was better than LEACH. Distributed energy efficient clustering (DEEC) is designed for multi-level heterogeneous networks in which cluster heads are elected by a probability governed by the ratio of the average energy of the network and the nodes' residual energy [14]. Thus, the node with more initial energy and residual energy is more likely to be elected as a cluster head.

Based on LEACH, SEP and DEEC, numerous protocols are proposed. EECDA selects the cluster head based on the maximum sum of residual energy for data transmission [15]. Zonal stable election protocol (Z-SEP) is a clustering algorithm based on zone in which the advanced nodes have the probability to become a cluster head [16]. However, nodes cannot be deployed randomly and only advanced nodes are selected as a cluster. Special energy advanced node (SEA) is an extension of LEACH [17]. It follows the hybrid approach to forward data against energy of the nodes. Modified stable election protocol (M-SEP) is a heterogeneous protocol based clustering that considers the existence of different transmission types [18]. The improved energy aware distributed unequal clustering protocol considers number of nodes in the neighborhood in addition to the location of base station and the residual energy for electing cluster heads [19]. The methodology used is of retaining the same clusters for a few rounds and is effective in reducing the clustering overhead. Prolong-SEP is presented to prolong the stable period of Fog-supported sensor networks by maintaining balanced energy consumption [20]. Fog technology is applied to enhancing the communication between the FNs and it can work with FNs to take benefit of Fog computing which is never used in the recent clustering research works. Zone based heterogeneous clustering protocol partitions zones which leads to uniform energy utilization in the network and decreases the intra-cluster and inter-cluster communication distance and as selecting the cluster heads from their respective zones [21].

The above papers focus mainly on clustering in a hierarchical structure and do not take all the important factors into account. If we look into them further, then we find that a combination of clustering in a hierarchical structure and direct communication based on the position of the nodes has benefited our research. Therefore, in this paper, we further take account of more complicated and actual factors and situations. Additionally, our solution described in the following sections has advantages both in the clustering and routing. The residual energy of the sensor nodes and the energy consumption from the source node to the base station as parameters turned out to be reasonable for cluster head selection and route path selection. Moreover, to avoid the overhead and congestion, state transition is adopted for sensor nodes to cooperate with each other and to further slower the data transmission rate. As a result, the improved routing protocol for heterogeneous WSN can use energy efficiently and prolongs the network lifetime.

3. **Network Model and Energy Model.**

In this section, we will provide a simple network model that is helpful for the design of our routing protocol. In our protocol, the energy consumption for data transmission using the network model will be decreased. Now, we discuss the energy heterogeneous network model and the energy model in detail.

3.1. **Network model.**

In WSN, energy efficiency affects the lifetime of the network directly and we should utilize the energy of the node efficiently. In this work, we assume N nodes are deployed in a square that is divided into three equal regions: zone 0, zone 1 and zone 2 based on the energy levels. There are two types of nodes deployed in the network. The difference between these two types of nodes is their initial energy. Nodes with more initial battery energy are called advanced nodes, and the remaining nodes are called normal nodes. We consider that a fraction of the total nodes are advanced nodes equipped with a times more energy than normal nodes, and the sensing area is $M \times M$ square meters where the base station is stationary and high energy is located in the center. All nodes are stationary once deployed in the field and each node in the network has a unique ID.

3.2. **Energy model.**

In our research, we discuss the energy model, which is the same as defined in [12]. When a node transmits k bit messages to a distance d, the equation to calculate the energy consumption is given by

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

where l is the number of bits in each data message. Also, when a node receives l bit messages, the equation to calculate the energy consumption is given by

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

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

The energy dissipation for data aggregation is given by

$$E_{DA}(l) = lE_{DA} \tag{3}$$

As depicted in reference, the detailed calculation of energy consumption for one cluster is given by [13]

$$E_{CH} = \left(\frac{n}{k} - 1\right) l * E_{elec} + \frac{n}{k} l * E_{DA} + l * E_{elec} + l * \varepsilon_{fs} * d_{toBS}^2 \tag{4}$$

$$E_{nonCH} = l * E_{elec} + l * \varepsilon_{fs} * d_{toCH}^2 \tag{5}$$

$$E_{cluster} = E_{CH} + \frac{n}{k} E_{nonCH} \tag{6}$$

where E_{CH} signifies energy consumption of a cluster head, E_{nonCH} signifies 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} signifies the average distance between the cluster head and the cluster member. We substitute Equation (5) and Equation (6) into Equation (7). The total energy consumption in a round is given by [13]

$$E_{total} = l \left(2nE_{elec} + nE_{DA} + \varepsilon_{fs} \left(kd_{toBS}^2 + nd_{toCH}^2\right)\right) \tag{7}$$

Then, the optimal number of clusters is given by [13]

$$k_{opt} = \frac{\sqrt{\varepsilon_{fs}}}{\sqrt{\varepsilon_{mp}}} \frac{\sqrt{n}}{\sqrt{2\pi}} \frac{M}{d_{toBS}^2} \tag{8}$$

The optimal number of clusters plays an important role in network clustering. Therefore, we select the optimal number of clusters to make sure to minimize the energy consumption.

4. **New Algorithm.** In this section, we presented an improved algorithm, which was extension of SEP for heterogeneous wireless sensor networks to reduce energy consumption and extend the network lifetime. To save energy, we provided a novel zonal structure to deploy the different types of nodes and adopted a clustering approach and dormancy mechanism based on node location and remaining energy for data transmission. The operation of the improved algorithm continued with rounds, and each round could be divided into two phases: the setup phase, which included cluster head selection, a neighboring node selection and state transition and steady phase. We discussed the details of the improved protocol as follows.

4.1. **Setup phase.** In the setup phase, we first placed the nodes in an efficient and effective way, because we used the deployment of the sensor nodes as an important factor to investigate the network. Since the zone portioning of Z-SEP left a huge coverage area uncovered, we divided the network field into three equal zones: zone 0, zone 1 and zone 2. Nodes with more battery energy were called advanced nodes, and the remaining nodes were normal nodes. And advanced nodes should be deployed randomly in zone 0 and zone 2 while normal nodes randomly in zone 1 as advanced nodes far away from the base station needed more energy than normal nodes near the base station to transmit data. It is necessary to analyze the partition distance of the zones in the area. A higher value could cause the normal nodes to be densely deployed in zone 1, which can result in severe overhead and congestion. On the other hand, a lower value may lead to the deployment of normal nodes at a far distance from the base station, which consumes their energy very quickly. To make it fair, the three zones of the area were equally divided. Therefore, the energy consumption of the network should be balanced uniformly and the energy of nodes was utilized in the network efficiently. If an advanced node was placed in the corner, then it would have more energy to transmit the data to the base station. Figure 1 illustrated the deployment of the sensor nodes. The boundaries of the three parts are taken as: Zone 0 (0-100, 0-33), Zone 1 (0-100, 33-66), Zone 2 (0-100, 66-100). Zone 0 and zone 2 each contains advanced nodes, whereas zone 1 contains normal nodes and these nodes are all

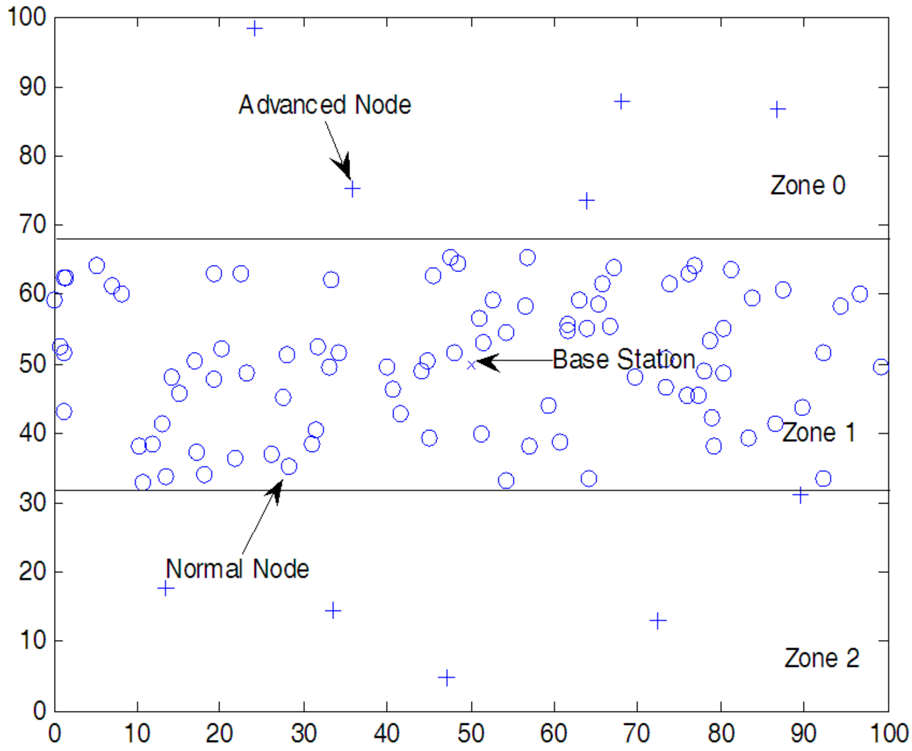

FIGURE 1. Deployment of sensor nodes

randomly distributed in their defined areas. In this way, maximum energy utilization, good coverage and connectivity, which lead to longer network lifetime and most of all to the achievement of the stability period in our proposed routing protocol. Once all the nodes are deployed in the defined areas, the next part involves the clustering of the advanced nodes.

After the deployment of the sensor nodes was completed, we used two techniques to send data to the base station. To decrease the energy dissipation of the nodes, we organized advanced nodes as clusters and selected the cluster heads among them. Then the cluster heads sent data to the base station. In contrast to the advanced nodes, the normal nodes transmitted data to the base station directly depending upon the status of the node itself and its neighbor node. In the next sections, we describe the cluster head selection for the advanced nodes, and the neighboring node selection accompanied by the state transition for the normal nodes.

4.1.1. *Cluster head selection.* Here, we describe the selection process of the cluster heads. Unlike the cluster head selection in SEP, only the advanced nodes were responsible for clustering to save energy in our protocol. We considered that whether a sensor node was selected as a cluster head depended on its residual energy; thus, the advanced nodes were more suitable than the normal nodes to become cluster heads. The base station broadcasted information to all the nodes in the network. Then, the advanced nodes received the message and decided which node would be selected as a cluster head. We did not change the fraction of the total nodes and initial energy of each node in [13]. Therefore, the new heterogeneous setting had no effect on the optimal number of clusters p_{opt}, and the weighted probability of advanced nodes p_{adv} was given by

$$p_{adv} = \frac{p_{opt}}{1 + am}(1 + a) \tag{9}$$

where advanced nodes had a times more energy than normal nodes and m was the rate of the advanced nodes. The threshold for advanced nodes was given by

$$T(S_{adv}) = \begin{cases} \dfrac{p_{adv}}{1 - p_{adv} * r \bmod (1/p_{adv})}, & S_{adv} \in G; \\ 0, & S_{adv} \notin G \end{cases} \tag{10}$$

where r was the current round of the network and G was the set of the advanced nodes that had not been selected as cluster heads in the last $1/p_{adv}$ round.

At the start of the selection, if an advanced node that belonged to set G generated a random number between 0 and 1, and the number was less than the value of Equation (10), then the node became the cluster head in the current round and the other advanced nodes in the region became members of the cluster. In this way, we could make full use of the battery energy of the advanced nodes to decrease energy dissipation for data transmission and prolong the network lifetime. Next, we described the selection process of the neighboring node for the normal nodes.

4.1.2. *Neighboring node selection.* As the network, which contained numerous normal nodes was dense, it was easy to cause transmission interference, data redundancy and collision. This would increase energy consumption and affect the efficiency of energy limited WSN. Therefore, we used a dormancy mechanism to put some nodes into sleep mode to overcome these problems. However, the dormancy mechanism required the collaboration of nodes and their neighboring nodes. The selection process of neighboring nodes was introduced herein. Initially, each node broadcasted within its range a message containing the information about the node ID, residual energy and current status. After receiving the message with the node information, the closest corresponding neighboring node stored the neighbor node information. If a node failed to find a neighbor node and became an isolate node, this occurred because that the minimum distance between the isolate node and other node was more than its range. For any normal node in zone 1, we predicted the node status in the next process based on the neighbor node information, and we switched the status of the node between active and asleep.

4.1.3. *State transition.* After the selection process of the neighboring node for the normal nodes was completed, in our protocol each node determined its state transition with respect to its own energy state and the state of its neighboring node in the future. Here, we describe the process of state transition in detail. If a node were not dead, then the status of the node could be active or sleep. During the active mode, the node sent the data to the base station while its neighbor node went to sleep, which meant the neighboring node turned off its radio for the same time period to save energy. Once the certain time period was over, the node in sleeping mode would wake up and the corresponding node of the sleeping node would go to sleep if it had not used up its battery energy during the last time period. If a node was isolated, it would remain in active mode for the entire network lifetime. Based on the collaboration of neighboring nodes, we propose Algorithm I to describe how to execute the dormancy mechanism.

Among all the normal nodes, if a node were coupled in a pair, then its status would be checked. If the node was in active mode, and its neighbor node was not dead, then the node transmitted data to the base station directly and switched its status from active to sleep. If the node were in sleep mode, then it would drop out of receiving packets and change its status from sleeping to active mode. If each node were dead in a pair, its partner would keep an active status. If normal nodes could not find any neighboring node to help the partner to couple a pair to send a data, then it would try to send the data to the base station itself each time until it had used up the battery energy and

Algorithm I. State transition for dormancy mechanism

Initialization: all the normal nodes

```
if (node.neighbour_flag==1)
    if (node.state==Active)
        send the data to the base station;
        if (node.neighbour!=dead)
            node.state=Sleep;
        end
    end
    if (node.state==Sleep)
        node.state==Active
    end
end
if (node.neighbour_flag==0)
    send the data to the base station;
end
```

become dead. When the time expired, all the normal nodes decided to perform the state transition again.

4.2. **Steady phase.** After the setup phase, data was transmitted from the nodes to the base station in 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, aggregated it and forwarded it to the base station. The process of data aggregation for the normal nodes adopted single-hop communication, which made active nodes forward data to the base station directly in the current round. In the next round, the clusters for the advanced nodes were reformed and the state transition of the normal nodes was restarted. Figure 2 is a graphic of the improved protocol.

5. **Simulation and Discussion.** In this section, we discuss the implementation of the improved protocol for our heterogeneity network model. In our simulations, we assumed that the 10 percent of sensor nodes were advanced nodes, equipped with 1 times more energy than normal nodes, and we deployed these 100 nodes in a 100×100 square meters region where the base station was located in the center of the sensing region. We initialized p_{opt} to 0.1 depending on k_{opt} which was given by Equation (9). The initialized energy of the normal node is 0.5 Joules while the initialized energy of the advanced node is 1 Joules. We simulated the new protocol by using MATLAB. The parameters used in our simulations are given in Table 1. The parameter *do* signifies the threshold distance, ε_{fs} and ε_{mp} are the energy consumption per bit in the radio frequency amplifier, E_{elec} signifies the dissipation of energy per bit in the transmitter and receiver circuitry, E_{DA} is the energy dissipation for data processing, and l is the number of bits in each data message.

Now, we discuss the performance of our protocol with SEP, M-SEP and SEA on the basis of stability period, network lifetime, throughput, energy dissipation and residual energy. Figure 3 shows the number of alive nodes per round in the network. We observe from the figure that even after 2000 rounds, the number of alive nodes using the new

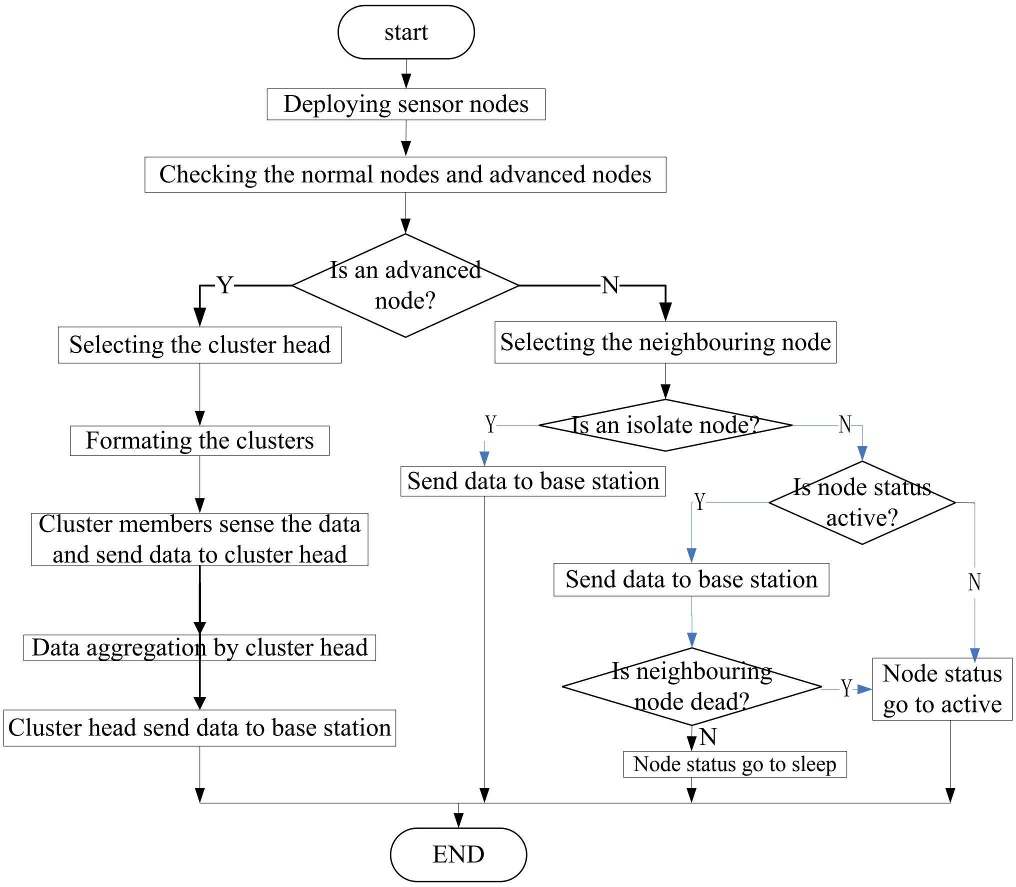

FIGURE 2. Flow chart of the proposed algorithm

TABLE 1. Simulation parameters

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

protocol was higher as compared to that of other protocols. The time interval between the start of the operation and the death of the last sensor node is called the network lifetime. As observed, the network life time is highly improved in terms of existence of alive nodes for more number of rounds as shown in 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 and SEA. 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 near the base station and send data to the base station directly to conserve much more energy instead of forming the clusters. The other three 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 make full use of energy of nodes and prolongs the network lifetime successfully.

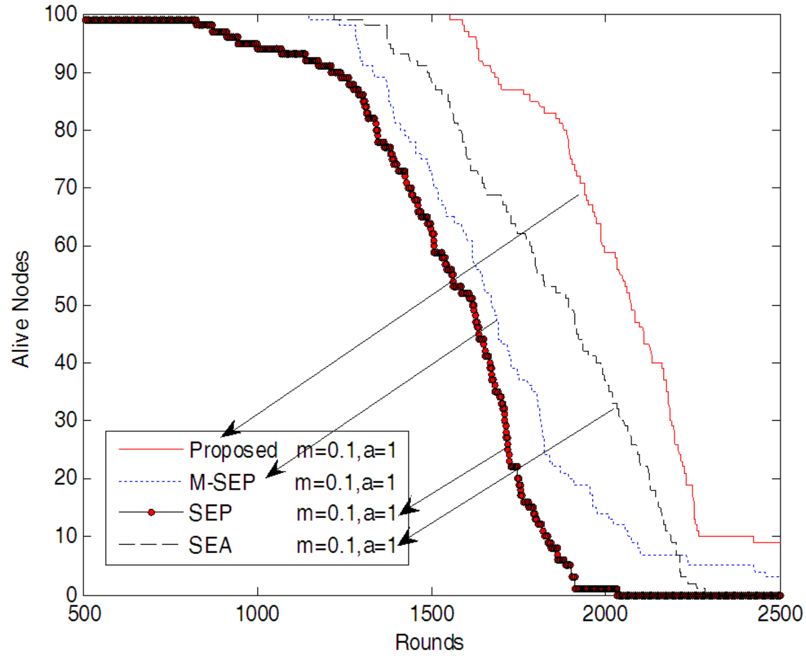

FIGURE 3. Number of alive nodes per round

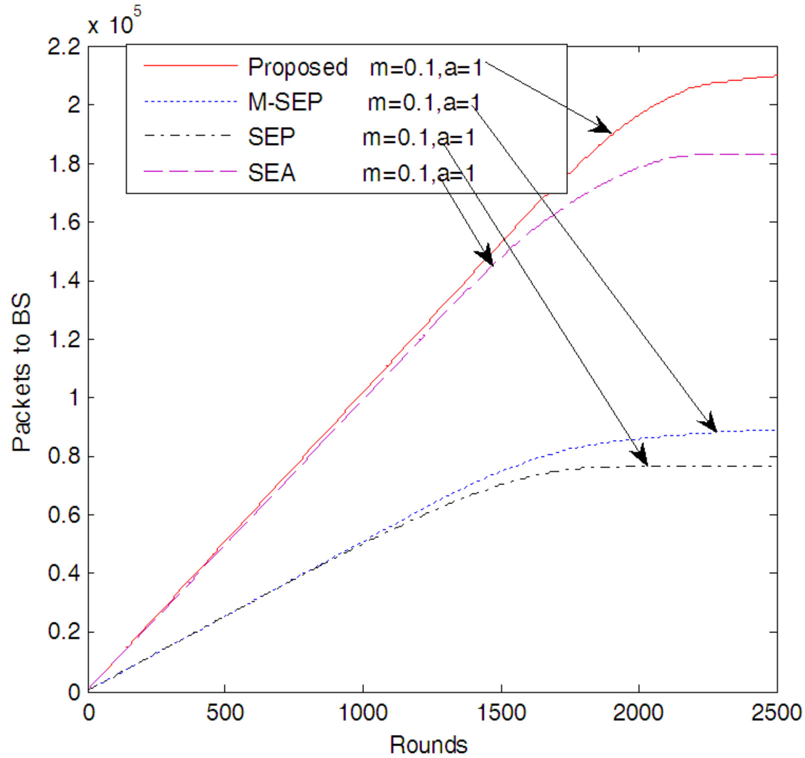

FIGURE 4. Throughput

Figure 4 shows the number of packets delivered to the base station with respect to the number of rounds. It is easily found from Figure 4 that the proposed protocol is very efficient in successful data delivery and has more numbers of packets delivered to the base station in comparison to SEP, M-SEP and SEA. With the increase of the network lifetime, the number of packets received by the base station also increases correspondingly. The reason is that the normal nodes have not organized themselves as clusters, and they send data to the base station directly. With the collaboration of neighboring nodes, the state transition mechanism for the normal nodes can address the data conflict and redundancy problems successfully which severely occurred in other protocols and improve the throughput of the proposed routing protocol. Hence, in the proposed protocol, the nodes conserve more energy to work and perform better than in the other three algorithms.

Figure 5 shows the energy consumption of the network with respect to the number of rounds. Energy consumption in a round comprises the whole energy consumed during clustering formation and data transmission. 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 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 and SEA. This is because the node dormancy mechanism, together with the sleep-active status switch technique conserves much of the energy in the case of the proposed protocol. Therefore, we can conclude that the proposed protocol conserves more energy and prolongs the lifetime of the network.

We show the death time of the first dead node in Figure 6. Four different algorithms were compared in terms of the time when the first node went dead. From Figure 6, it can be seen that the first death time of the proposed algorithm was 1555, which was much longer than that of other three algorithms, in which it was 453, 1149 and 1223 respectively. This improvement is achieved by the proposed protocol through an optimal cluster head selection. The time interval between the start of the operation and the death of the first alive node 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 and SEA. 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.

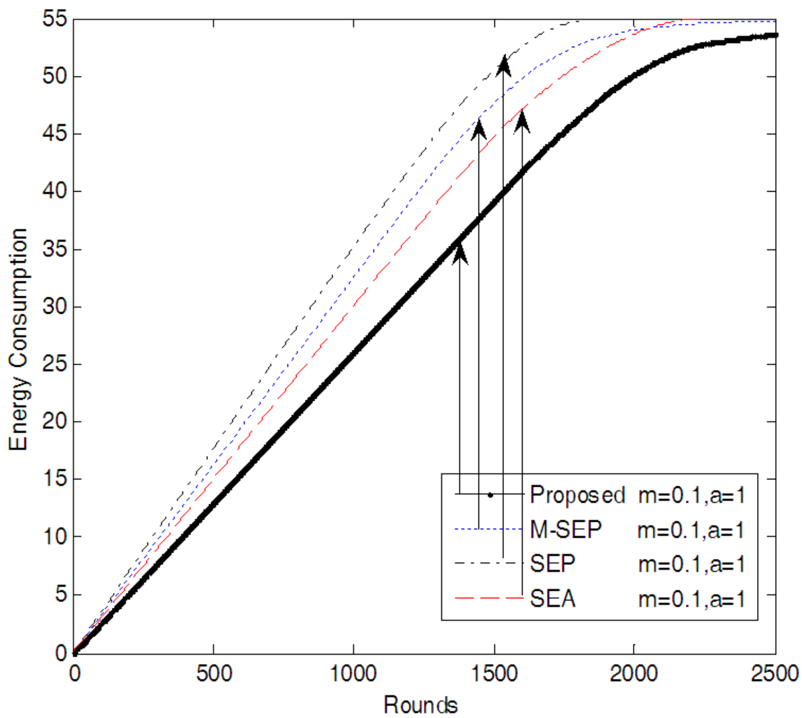

FIGURE 5. Energy consumption

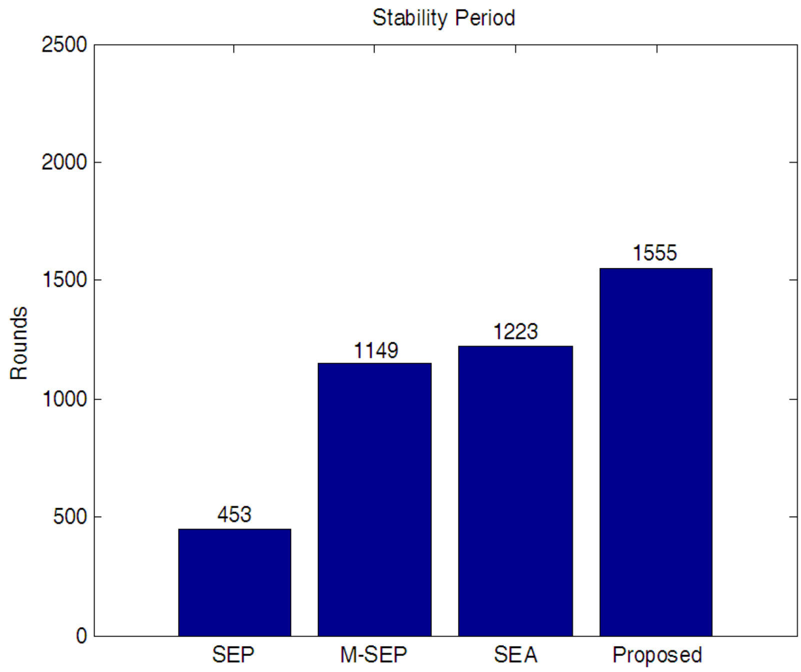

FIGURE 6. Death time of first dead node

As a result, in our new protocol, the nodes remain alive for a longer time. More data packets are sent to the base station, and then the energy consumption decreases. Our new protocol clearly performs better than SEP, M-SEP and SEA, and it prolongs the stability period and network lifetime. The dormancy mechanism of the nodes and effective clustering assured that the nodes located a distance from the base station had enough energy to send data packets, and this contributed to conserving more energy and extending the network lifetime.

6. **Conclusions.** In this paper, an improved protocol has been designed for two level energy heterogeneous networks in order to reduce energy consumption and increase network lifetime. We divided the sensing area into three regions and deployed the advanced nodes and normal nodes separately. Then, we used a clustering technique and dormancy mechanism to enable the nodes to communicate with the base station. To ensure its efficiency, we compared the performance of SEP, M-SEP and SEA and the new protocol. Among the existing heterogeneous protocols, our protocol proves to own a better stability period and network lifetime. Considering the limitations of the environment, it is difficult to deploy nodes respectively in reality and only advanced nodes were selected as cluster heads. It is still a challenge to solve this problem and break the limitation of clustering. More practices will be put into the network energy efficiency innovation followed by the protocol research in the future.

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