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An Improved Zone-Based Routing Protocol for Heterogeneous Wireless Sensor Networks

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Abstract

In this paper, an improved zone-based routing protocol for heterogeneous wireless sensor networks is proposed. The proposed protocol has fixed the sized zone according to the distance from the base station and used a dynamic clustering technique for advanced nodes to select a cluster head with maximum residual energy to transmit the data. In addition, we select an optimal route with minimum energy consumption for normal nodes and conserve energy by state transition throughout data transmission. Simulation results indicated that the proposed protocol performed better than the other algorithm by reducing energy consumption and providing a longer network lifetime and better throughput of data packets.

Keywords

Energy Consumption, Heterogeneous Wireless Sensor Networks, Stable Election Protocol, Zone-Based

1. Introduction

Wireless sensor networks (WSNs) that consist of a large number of nodes, have emerged as an important area of research and development. These sensor nodes are deployed randomly in the target region and 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, such as computation power, energy, storage, bandwidth and dynamic changes in topology, the WSNs is unable to efficiently transmit data packets and increase the network lifetime [2]. Therefore, the task of designing routing protocols for effective network operation brings with it several challenges. The main problem encountered in route designing is that the WSNs is usually deployed in a harsh environment and the energy of the nodes cannot be recharged [3]. Accordingly, energy consideration has a great influence on route designing and we must use the energy of sensor nodes very efficiently in order to monitor an area for a longer time.

Different routing protocols have been proposed for effective routing in WSNs. Clustering is a widely used technique in WSNs that effectively reduces the energy consumption of sensor nodes [4]. However, improper clustering may cause overhead and overloaded clusters to go dead early. Moreover, many existent clustering algorithms developed for homogeneous WSNs do not perform well when applied to heterogeneous WSNs. Thus, multiple factors must be taken into account before the formation of clusters.

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Another solution for prolonging the network lifetime is to create zones for heterogeneous nodes. In this solution, it is required to divide the network into zones and vary the transmission range of the heterogeneous sensor nodes, which adjust themselves at different levels for data transmission and perform various other operations to save energy [5]. In addition, it is also necessary to analyze how the mechanisms could be used to integrate the clustering technique within the fixed zone to efficiently use the energy. Therefore, research about routing protocols is still indispensable for applications in several fields.

In this paper, an improved routing protocol for heterogeneous WSNs is introduced to solve the problem that how to save energy and ensure the network load balancing. The proposed protocol adjusts the communications method between sensor nodes and the base station according to the energy level and the distance from the base station. In this protocol, the advanced nodes equipped with more initial energy adopt clustering communication via cluster heads, while the rest of the nodes, called normal nodes, integrate multi-hop data transmission by state transition mechanism in order to avoid overhearing and reduce the energy consumption. In fact, the improved protocol can use energy efficiently and prolong the network lifetime.

The paper is organized as follows: Section 2 discusses the related work; Section 3 describes the heterogeneous WSNs model; Section 4 explains the protocol in detail, including optimal cluster head election for advanced nodes and route discovery for normal nodes to save energy; Section 5 analyzes the performance of related method; Section 6 presents the drawn conclusions and suggests directions for future work.

2. Related Work

To achieve a network with a long lifetime and low-energy consumption data acquisition, many effective routing protocols for WSNs have been proposed. Low energy adaptive clustering hierarchy (LEACH) [6] is one of the most popular clustering algorithms used in WSNs. In the LEACH algorithm, the operation is divided into rounds. Each round is defined by the setup phase and the steady phase. There are an optimal number of nodes that can be added to 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 WSNs. In addition, the minimum transmission energy (MTE) and the direct transmission (DT) do not assure a balanced use of the energy by the sensor. The stable election protocol (SEP) which is designed to deal with heterogeneous networks, introduces the concept of advanced and normal nodes for cluster head selection [7]. This is based on the weighted election probabilities of each node to be added to a cluster head according to the remaining energy in each node. The stable election protocol does not require any global knowledge of the energy for each election round, and the performance of the stable election protocol is better than Low energy adaptive clustering hierarchy. Distributed energy efficient clustering (DEEC) [8] is designed for multi-level heterogeneous networks in which cluster heads are selected using a probability governed by the ratio of the average energy of the network and the residual energy of the nodes. Thus, the node with more initial energy and residual energy is more likely to be elected as a cluster head.

Numerous protocols based on LEACH, SEP and DEEC have been proposed. The energy efficient clustering and data aggregation (EECDA) protocol [9] selects the cluster head based on the maximum sum of residual energy for data transmission. The energy dissipation forecast and clustering management method [10] is an improvement of the DEEC method. The algorithm depends on a technique called a “one-step energy consumption forecast.” The energy efficient sleep awake aware protocol [11] focuses on the cluster head selection process and introduces a new pairing concept on the basis of the remaining energy. The gateway-based energy aware routing protocol [12] is based on regions, in which nodes have to decide whether to take part in clustering or in direct communication. Z-SEP [13] is a clustering algorithm based on zones in which the advanced nodes have the probability to become a cluster head. However, nodes cannot be randomly deployed and only the advanced nodes can be selected as a cluster. RMCHS [14] uses a Ridge technique to select the best cluster head, and the algorithm always chooses cluster heads from nodes with higher residual energy. Modified stable election protocol (M-SEP) [15] is a heterogeneous protocol based on clustering that considers the existence of different transmission types. ESDC [16] realizes energy efficiency in sensor network configuration by clustering the nodes only within the event-to-sink data flow corridor to avoid unnecessary cluster formation and directionally to minimize the number of hops for data forwarding. Special energy advanced node LEACH [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] is presented to prolong the stable period of Fog-supported sensor networks by maintaining balanced energy consumption. Fog technology is applied to enhance 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. ZBHCP [20] 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.

The above papers focus mainly on clustering in a hierarchical structure and do not take all the important factors into account. The global information of the sensor nodes may be required or the probabilities of the cluster head selection may be statically assigned. Accordingly, in this paper, we take into account more complicated and actual factors and situations. 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 are also considered in selecting cluster head selection and route path. 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 WSNs can use energy efficiently and prolongs the network lifetime.

3. Heterogeneous WSNs Model

In this section, we will describe 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 WSNs, the energy efficiency directly affects the lifetime of the network and thus we should utilize the energy of the node efficiently. In this paper, we assume *N* nodes are deployed in a square that is divided into three equal regions: zone 0, zone 1 and zone 2. 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 m fraction of the total nodes are advanced nodes equipped with α times more energy than normal nodes. 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. Some reasonable assumptions have been adopted as follows: 1) *n* sensor nodes are randomly distributed in the field; 2) the WSNs consists of heterogeneous nodes in terms of node energy; 3) the cluster heads perform data aggregation; 4) the base station is not energy limited in comparison with the energy of other nodes in the network.

3.2 Energy Model

In our research, we discuss the energy model, which is the same as previously defined [6]. When a node transmits *k* bit messages to a distance d, the equation to calculate the energy consumption [6] is given by Eq. (1):

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

Also, when a node receives *k* bit messages, the equation to calculate the energy consumption [6] is given by Eq. (2):

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

where E_{elec} is the energy dissipation per bit in the transmitter and receiver circuitry, *d* signifies the transmission distances, 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 distance is measured on the value of *do* [6], whose value is given by Eq. (3):

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

The energy dissipation for data aggregation [6] is given by Eq. (4):

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

As depicted in [7], the detailed calculation of energy consumption for one cluster is given by:

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

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

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

where E_{CH} signifies the energy consumption of a cluster head, 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} signifies 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 [7] 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 [7] 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 the optimal number of clusters to minimize energy consumption. Last, the probability of becoming a cluster head of every node [7] is given by:

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

where N is the total number of nodes.

4. New Algorithm

In SEP, different weighted probabilities are assigned to normal nodes and advanced nodes to select the cluster heads. The one for normal nodes [7] is given by Eq. (11):

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

The rest one for advanced nodes [7] is given by Eq. (12):

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

The value of the following threshold is used by every node to decide if it is a cluster head in the current round. The threshold for normal and advance nodes is given by Eqs. (13) and (14), respectively:

$$T\left(S_{nrm}\right)=\begin{cases}\dfrac{p_{nrm}}{1-p_{nrm}*r\bmod\left(1/p_{nrm}\right)} & i\in G\\ 0 & i\notin G\end{cases} \tag{13}$$

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

where, r is the current round and G is the set of the nodes that has not been selected as cluster heads. The SEP deploys nodes randomly and does not consider that a normal node might have more energy than an advanced one after a few rounds. The variant of SEP [7], namely M-SEP [15], implements the multilevel power transmission in the protocol to improve the efficiency of the SEP protocol. However, for selecting cluster heads, M-SEP has the same drawback as SEP. Therefore, we introduce an improved algorithm for heterogeneous WSNs to reduce energy consumption and extend the network lifetime.

In this work, we firstly partition the network into zones and two types of nodes, namely the normal and advanced nodes which different initial energy, are deployed in the different zones. Then the dynamic clustering is applied to the advanced nodes that are deployed at the farther distance from the base station and the optimal route path for the normal nodes to transmit data to the base station is selected. Lastly, we introduce the state transition mechanism to solve the problems of overhead and congestion that occurs in the route discovery process. In this section, algorithms run many rounds, and each round is divided into two phases, namely the setup phase and the data transmission phase.

4.1 Setup Phase

The setup phase includes network architecture, cluster head selection and route path selection. In this phase, the main problem is the overhead due to the formation of clusters and the cluster head selection while a specially constrained sensor node might not be able to be directly connected to the base station. To address these issues, the improved protocol considers residual energy for clustering and routing. Next we discuss the details of the improved protocol as follows.

4.1.1 Network architecture

The network area is divided into zones in our proposed protocol to solve the problem of coverage holes due to certain areas with poor accessibility. In addition, the sensor nodes also benefit from managing the efficient energy utilization in a small portion of the area, rather than the main region. It is essential to take the hop distance and transmission power into account before dividing the whole area into zones. We also confirm that only the advanced nodes use the clustering technique and participate in cluster head selection due to their higher initial energy. The normal nodes could be placed at a distance close to the base station instead of participating in cluster head selection and forming clusters. Accordingly, the total network area is divided into three zones, namely zone 0, zone 1 and zone 2, as shown in Fig. 1. Unlike the random deployment of nodes in the SEP, we deploy the advanced nodes in zones 0 and 2 of the network field and the normal nodes in zone 1.

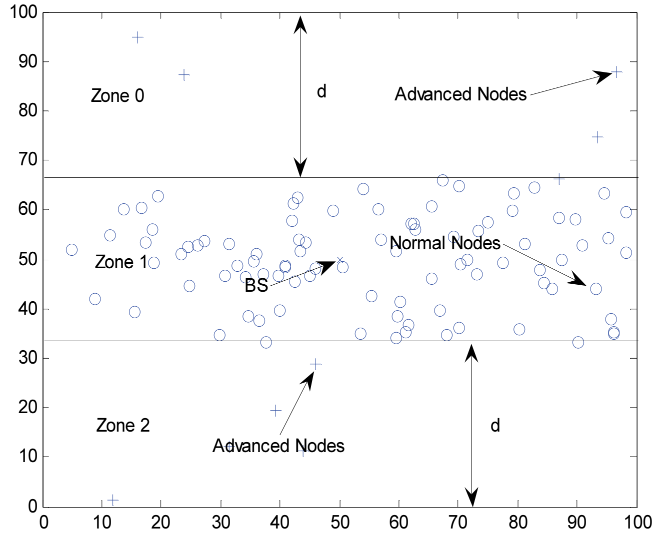

Fig. 1. Network architecture.

Let d be the partition distance of the zones in the field. It is necessary to analyze the value of d. A higher d value will make the normal nodes be densely deployed in zone 1, which can result in severe overhead and congestion. On the other hand, a lower d 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 are equally divided and the value of d is set at 33. 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 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.

4.1.2 Cluster head selection

In this section, the clustering method allows for smooth connectivity and energy efficient network operation. Regarding the clustering approach, the cluster head selection is an indispensable factor as it drastically affects the energy efficiency of the clustering approach in the case of improper selection. Hence, the cluster head selection should be optimized to minimize energy consumption during the transmission of data to the base station. Unlike SEP, in which the cluster heads are selected on a probabilistic basis, the function of our improved protocol is to select sensor nodes with the highest energy as cluster heads. The advanced nodes are divided into two groups and the nodes in each group compete to become the cluster head. If the residual energy of a node is greater than the other nodes in the same group, then the node becomes the cluster head and broadcasts the information to other nodes.

After receiving the information, the rest of the nodes in a group associate with the cluster head are as cluster members. Then, a cluster comprised of the cluster head node and the cluster member nodes is formed. In this way, the burden of aggregating the data of the cluster members and sending data to the base station will be handled by the node with the maximum energy and as a result the network performance will be better. Thus, we could make full use of the battery energy of the advanced nodes to decrease energy dissipation during data transmission and prolong the network lifetime. Next, we describe the selection process of the optimal route path for the normal nodes.

4.1.3 Route path selection

In contrast with the advanced nodes, the use the clustering approach is not suitable for the normal nodes because the formation of cluster consumes much more energy and normal nodes deployed at smaller distance from the base station. In our improved protocol, each normal node selects a route path to send data to the base station. The path is selected based on a weight which considers the distance between the nodes. To decrease the overhead and delay, which frequently occurs during route discovery and maintenance, each node sends the sensing data to the base station through the path with minimum energy consumption. The path could be direct or established via intermediate nodes to forward the aggregated data to the base station and we use an example of sensor node selection as an intermediate node is illustrated in Fig. 2.

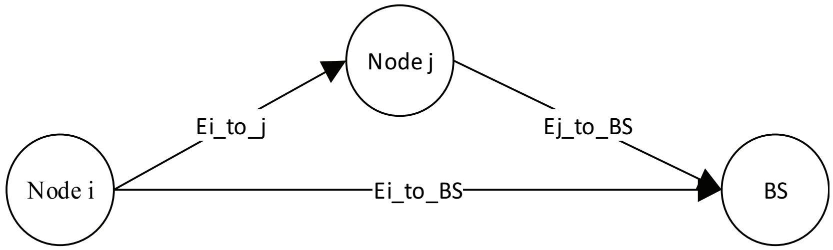

Fig. 2. An example of sensor node selection.

Each node first estimates the communication energy dissipate during the transmission of k bit messages directly to the base station, which is defined as $E_{i\_to\_BS}$. The value of $E_{i\_to\_BS}$ is given by Eq. (15):

$$E_{i\_to\_BS} = E\left(k,\ d_{i\_to\_BS}\right) \tag{15}$$

where $d_{i\_to\_BS}$ is the distance between the node and the base station. The value of $d_{i\_to\_BS}$ is given by Eq. (16):

$$d_{i\_to\_BS} = \sqrt{\left(x_{BS} - x_i\right)^2 + \left(y_{BS} - y_i\right)^2} \tag{16}$$

Then each node decides whether to find an intermediate node for the current round or not. This decision is based on the follow conditions:

$$E_{i\_to\_BS} >= E\left(k, d_{i\_to\_j}\right) + E\left(k, d_{j\_to\_BS}\right) \tag{17}$$

where $d_{i\_to\_j}$ is the distance between the node i and the node j, $d_{j\_to\_BS}$ is the distance between node j and the base station. The value of $d_{i\_to\_j}$ and $d_{j\_to\_BS}$ is given by Eqs. (18) and (19):

$$d_{i\_to\_j} = \sqrt{\left(x_j - x_i\right)^2 + \left(y_j - y_i\right)^2} \tag{18}$$

$$d_{j\_to\_BS} = \sqrt{\left(x_{BS} - x_j\right)^2 + \left(y_{BS} - y_j\right)^2} \tag{19}$$

In Algorithm 1, we assume N nodes are deployed in a square that is divided into three equal regions: zone 0, zone 1, and zone 2. Advanced nodes deploys randomly in zone 0 and zone 2, while normal nodes randomly in zone 1. Each node firstly estimates the communication energy dissipation $E_{i\_to\_BS}$, if $E_{i\_to\_BS} >= E_{i\_to\_j} + d_{j\_to\_BS}$, then this node j should serve as an intermediate node in its route. Otherwise, the intermediate node is not required. Therefore, a path with a minimum sum of energy consumption will be selected for data transmission and it will be more efficient for some normal nodes that are at a long distance to use the intermediate node to communicate with the base station.

Algorithm 1. Route Path Selection

```
Z ←Number of Zones
N ←Number of Normal Nodes
if Z is for Normal Nodes
    for each node i ∈ N do
        Estimating energy consumption Ei_to_BS
        find a node j
        if Ei_to_BS>=Ei_to_j+Ej_to_BS
        node j is selected as an intermediate node
        else
        node i send data directly to BS
        end if
    end for
end if
```

The proposed protocol has better control over energy consumption and also improves lifetime of the WSNs, determined by the energy consumption for sending data to the base station. However, a drawback of such a scheme is that redundant data through multiple paths may lead to wastage of energy, as well as congestion in the network. This can be solved by grouping the nodes in pairs and only a certain number of nodes operate by switching between the active and dormant states of the nodes in every pair at a specific period of time. Once the nodes are deployed, every node uses the pairing solution to discover its neighbor node. The distance between any pair of node i and node k is given by Eq. (20):

$$d_{i\_to\_k} = \sqrt{\left(x_k - x_i\right)^2 + \left(y_k - y_i\right)^2} \tag{20}$$

where, the value of $d_{i\_to\_k}$ is restricted to 10 cm. The approach provides a simple and safe communication between two nodes in a pair and every pair of neighbor nodes can reach each other. Only the active nodes aggregate the data and send the data to the base station. The rules for defining the transitions between states are as follows:

(1) A node in the active state performs sensing and communication tasks in the current round and switches to the dormant state for the next round;
(2) A node in the dormant state in the current round switches to the active state for the next round;
(3) A node which is in the active state in the current round remains active for the next round if the neighbor of the node in a pair consumes all its energy;
(4) A node which is in the active state in the current round remains active for the next round if the node fails to couple and form a pair and becomes an isolated node.

The state scheduling is suitable for networks with densely deployed nodes for constructing an active backbone route to the base station. At this point, the optimal route path selection without overhead and congestion is completed.

4.2 Data Transmission Phase

The setup phase is followed by the data transmission phase, in which data is transmitted from the nodes to the cluster head or to the base station, and the data acquisition process for all the nodes that operated in the rounds.

In a round, the advanced nodes operate with two different clusters of the network. The member nodes of the clusters transmit data to the cluster head based on the TDMA slot. All member nodes work during their allocated time to conserve energy. Then, each cluster head receives the data, aggregates them and forward the aggregated data to the base station. For the normal nodes, transmitting data to the base station requires minimal communication energy. If an intermediate node is selected, the node should send data to the intermediate node and then the intermediate node sends data to the base station, otherwise, the node sends data to the base station directly. Admittedly, the nodes which participate in the work must be in active status, and then it subsequently decreases the number of communications. After data packets transmission are completed in a round, the new cluster head selection and route path selection will be initiated for the next round.

The practice primarily aims to help reduce the number of clusters and achieve better connectivity, and hence provides better clustering, maintains routing with lower overhead and minimizes energy consumption. In the proposed protocol, we implement logical partition of the network for deploying different nodes. On the basis of residual energy the advanced nodes select the cluster heads to communicate with the base station. Normal nodes choose the optimal route path based on minimum energy consumption. The flow chart of the improved protocol is depicted in Fig. 3.

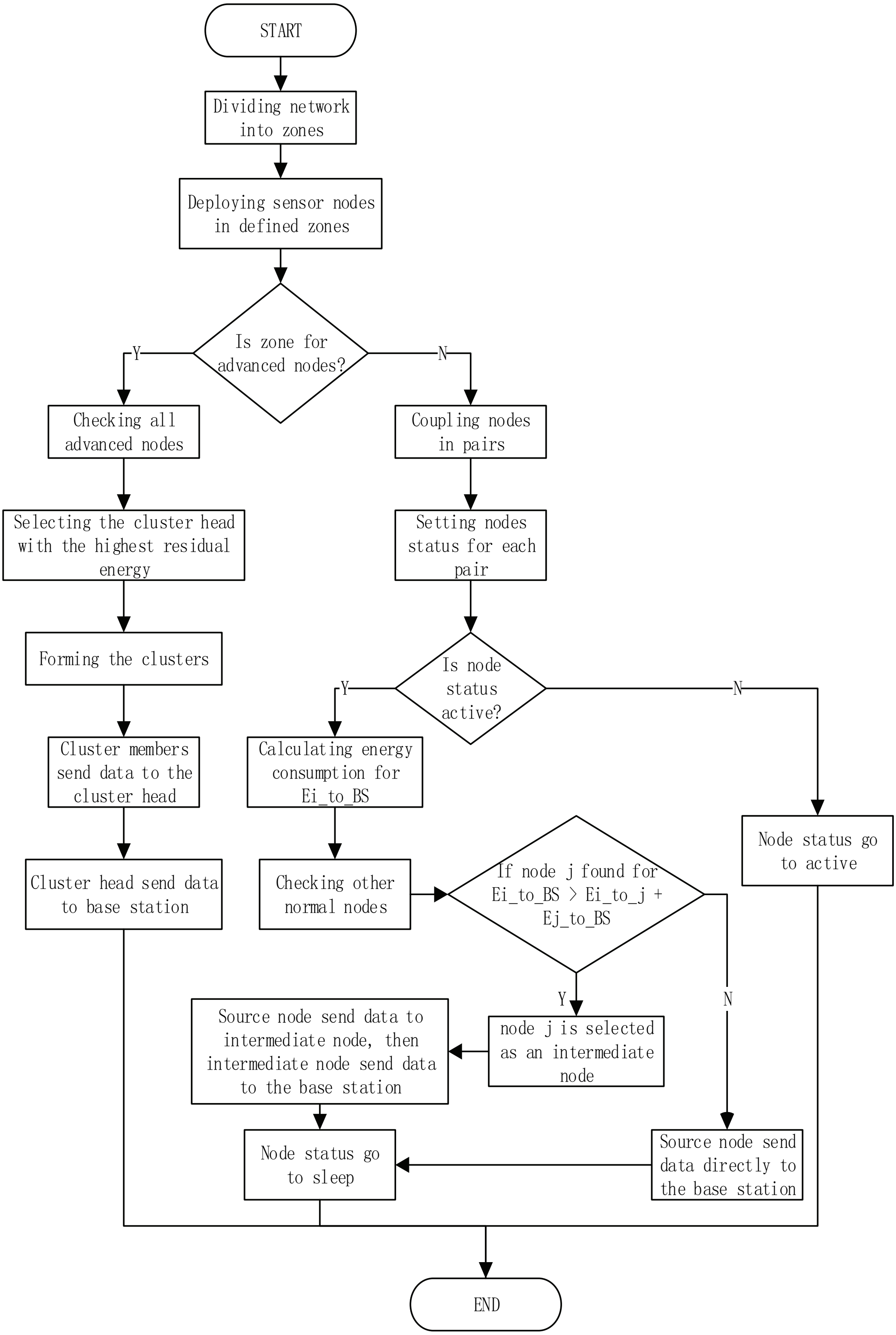

Fig. 3. The flow chart of the improved protocol.

5. Performance Analysis

In this section, we discuss the implementation of the improved protocol for our heterogeneity network model. In our simulations, we assume that 10 percent of the sensor nodes are advanced nodes, equipped with 1 fold more energy than normal nodes, and we deploy these 100 nodes in a 100×100 m^2 region, where the base station is located in the center of the sensing region. The initial energy of the normal node is 0.5 Joules, while the initial energy of the advanced node is 1 Joules. We simulate the new protocol using MATLAB. Next, we discuss the comparison of the performance of our protocol with SEP [7] and M-SEP [15], focusing on the stability period, network lifetime, throughput, energy dissipation and residual energy.

The number of alive nodes and dead nodes per round in the network are shown in Figs 4 and 5. The results in Figs. 4 and 5 shows that even after 2,000 rounds, the number of alive nodes using the new protocol is higher compared with the other protocols in the network. 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 the Fig. 4, due to the energy balanced in the network in a better way. We can also see that the number of dead nodes using the new protocol is lower than that of other protocols per round. Meanwhile it notices that existent nodes are not dead even after 2,500 rounds in the proposed protocol, while most nodes are 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 near the base station and send data to the base station 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 make full use of energy of nodes and prolongs the network lifetime successfully.

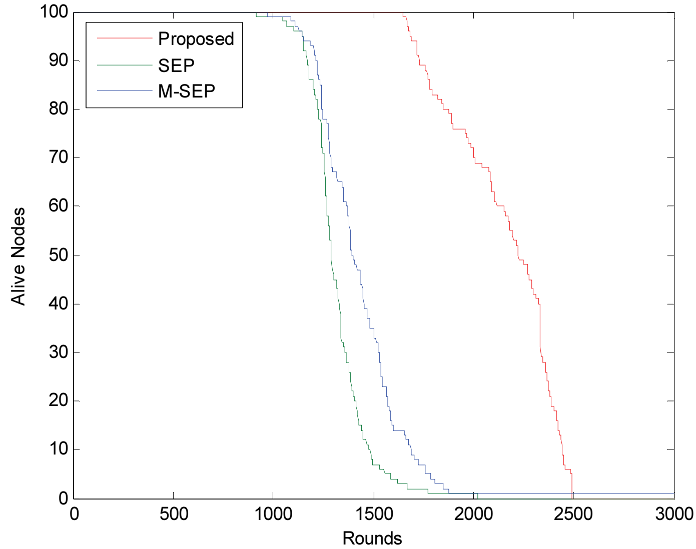

Fig. 4. Alive nodes.

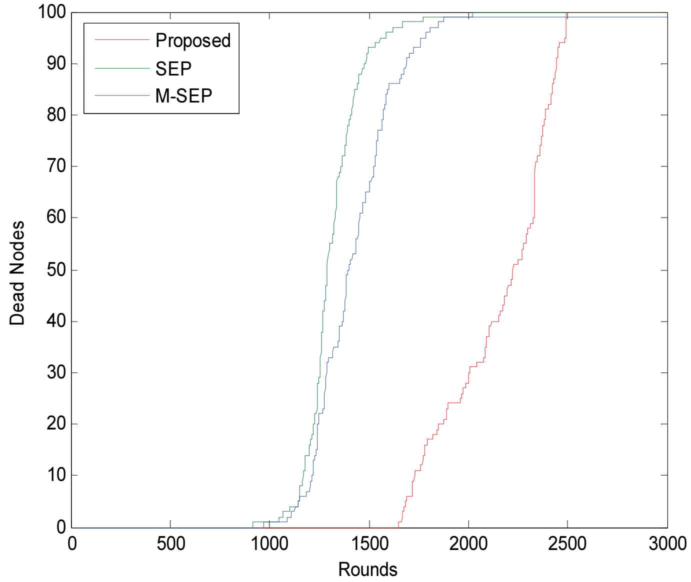

Fig. 5. Dead nodes.

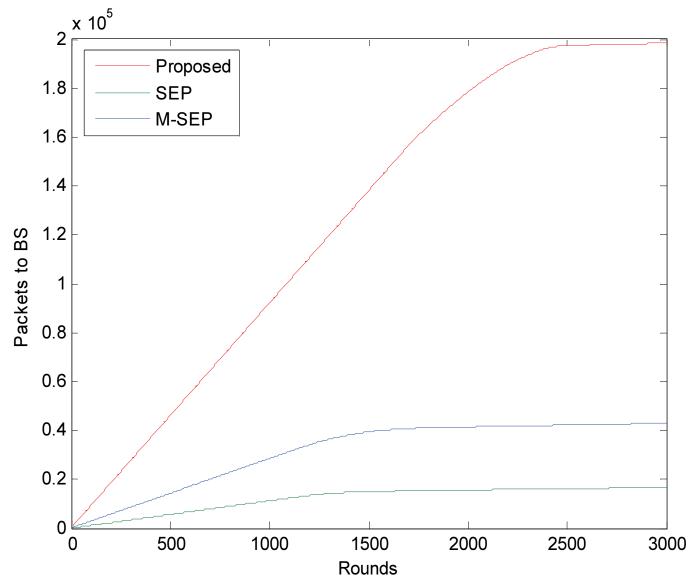

Fig. 6. Throughput.

The number of packets delivers to the base station with respect to the number of rounds is shown in Fig. 6, where it is evident that the proposed protocol delivered higher number of packets to the base station compared with the SEP and M-SEP protocols. Severe network congestion leads to packet loss and decreases throughput. To address this problem, the intermediate node selection is adopted by the improved protocol to avoid forwarding packets directly to the base station from a great distance. The status transition also prevents the network from getting congested. For this reason, the improved protocol performers better than the other algorithms.

The remaining energy of the proposed protocol plots against those of the SEP and M-SEP is shown in Fig. 7, while Fig. 8 shows the average residual energy of the proposed plots against the SEP and M-SEP. The residual energy of the advanced nodes and normal nodes are shown in Fig. 9. The energy consumption of the proposed protocol plots against those of SEP and M-SEP are depicted in Fig. 10. These indicate that even after 2,000 rounds, the residual energy of the proposed protocol is higher than the SEP and M-SEP. The advanced nodes lose a large amount of energy due to the far distance to the base station. If a normal node is deployed far from the base station, then it will quickly die due to the heavy energy burden. Therefore, it is necessary to reasonably divide the sensing area for deploying the different nodes. The SEP and M-SEP algorithms use up more energy than the proposed protocol with regard to the number of rounds and the rate of energy consumption. In contrast, the proposed protocol is much more efficient than the SEP and M-SEP. The reason is that the clustering technique, together with the multi-hop routing mechanism, conserves much of the energy in the proposed protocol. Therefore, we can conclude that the proposed algorithm can send the aggregated data to the base station more efficiently thus conserving more energy and prolonging the lifetime of the network.

Three different algorithms are compared in terms of the time when the first node went dead. The results show that the first death time of the proposed algorithm is 1652, which is much longer than that of the SEP and M-SEP algorithms, whose first death time is 918 and 973, respectively. The results also indicate that the stability period of the proposed protocol is much longer than with the other algorithms. Thus, the proposed protocol is helpful in extending the network lifetime.

The distribution of the sensor nodes in different quadrants is illustrated in Fig. 11, where it is seen that nodes are deployed in different areas which make full use of advanced nodes. Moreover, the solution helps the normal node to conserve energy and avoid premature death. Accordingly, the proposed protocol is also helpful in extending the stability period.

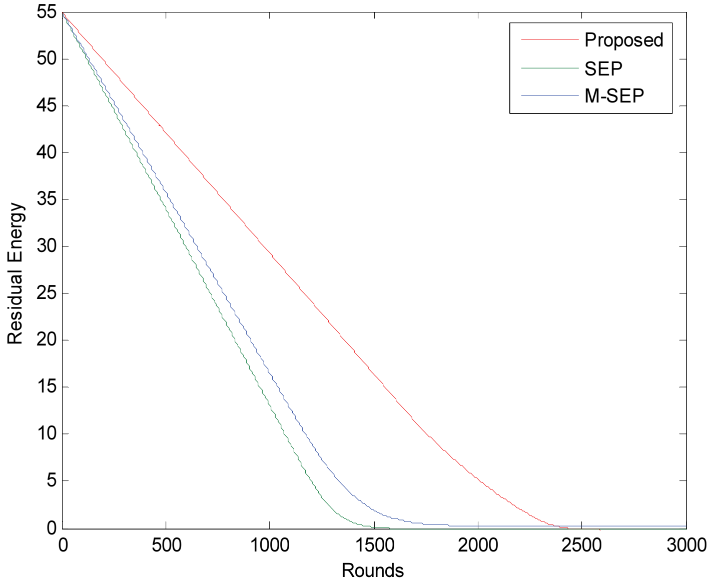

Fig. 7. Residual energy.

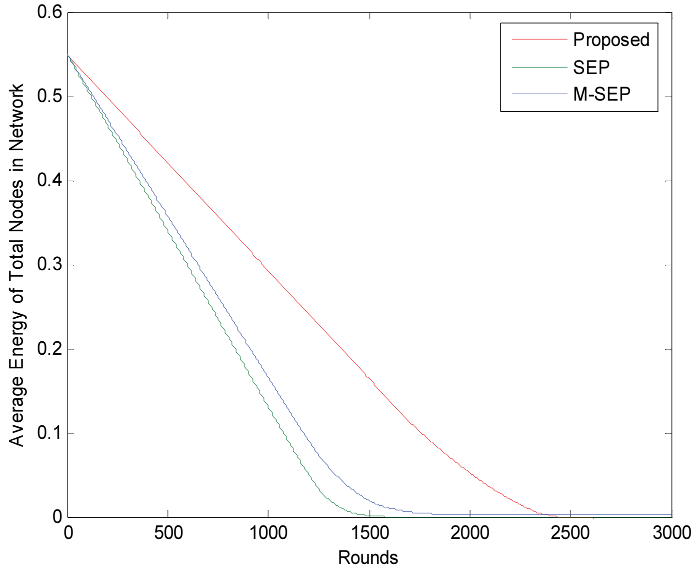

Fig. 8. Average residual energy of the network.

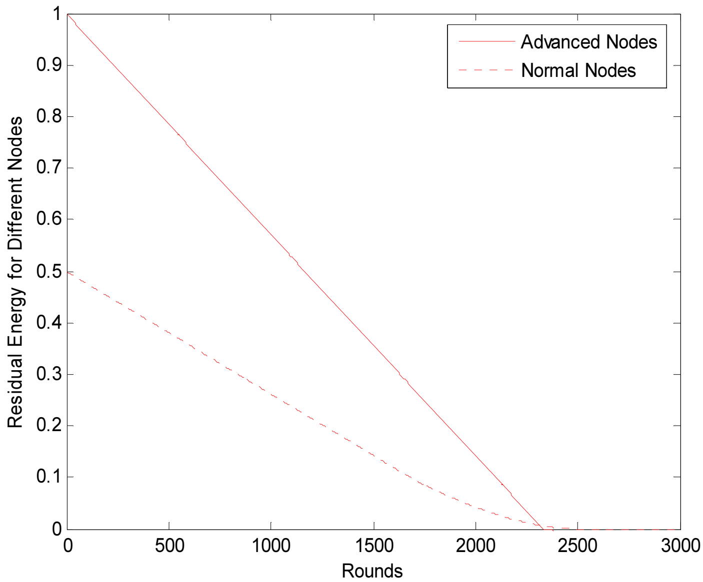

Fig. 9. Residual energy of different nodes.

As a result, with our new protocol, the nodes remain alive for a longer period of time. More data packets are sent to the base station and the energy consumption decreases. Our new protocol clearly performs better than the SEP and M-SEP, as it not only prolongs the stability period but also the network lifetime. The effective clustering and optimal route selection ensure that the nodes located at a distance from the base station have enough energy to send data packets, and this conserves more energy and extends the network lifetime.

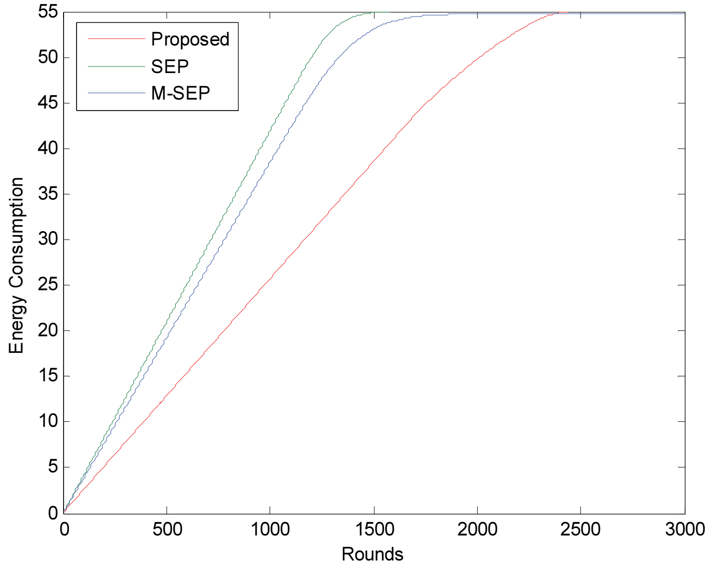

Fig. 10. Energy consumption.

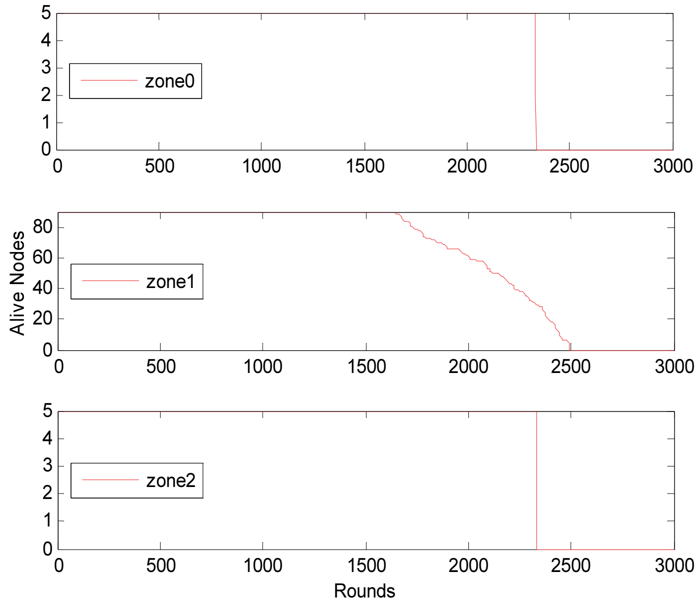

Fig. 11. Nodes distribution in network.

6. Conclusions

In this paper, an effective protocol is designed for a two level energy heterogeneous wireless sensor network to reduce energy consumption and increase the entire network lifetime. To solve the problem of improper cluster head selection, we adopt a state transition mechanism. Additionally, we select the path which consumes minimum energy as the optimal routing path to further reduce energy consumption. Simulation results show that the proposed protocol has a better stability period and longer network lifetime in comparison of the current protocols. Our future works will focus 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 will be beneficial to the design and implementation of heterogeneous wireless sensor networks.

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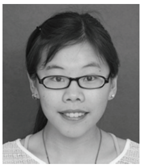

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