Chapter 1
An Improved Clustering Routing Algorithm for Heterogeneous Wireless Sensor Network

Huan Yao

Abstract To prolong the lifecycle of heterogeneous wireless sensor networks, an improved algorithm based on a distributed energy efficient clustering algorithm is proposed. Firstly, the proposed algorithm increases the possibility of the higher energy node to become the candidate cluster head based on the absolute value of the residual energy level. Secondly, the energy consumption rate, the ratio of residual energy, and the initial energy are added into the threshold that is used to control the probability of the node selected as the cluster head. Finally, the mixed data transmission mode is used in the data transmission phase to reduce the consumption of nodes to communicate with the base station. The simulation results show that the proposed algorithm can effectively prolong the network lifecycle and stability period.

1.1 Introduction

Wireless sensor networks (WSNs) are usually applied to battlefield surveillance, fire prevention, industrial management, and agriculture irrigation [1]. In WSNs, one of the main constraints is the battery power limit, which has a great impact on network lifecycle and quality [2]. There are two main strategies to solve this problem. One is to insert a certain proportion of heterogeneous nodes [3], and the other is to apply clustering technology [4]. Therefore, it is necessary to study heterogeneous clustering routing algorithm to prolong the network lifecycle [5].

In the literature, heterogeneous cluster routing technology is considered as one of the most mature energy-saving technologies [6]. In terms of energy heterogeneity, heterogeneous nodes have the ability to perform complex communicational tasks because the heterogeneous nodes have sustainable energy, meaning that it does not need frequent replacement [7]. While these heterogeneous nodes are expensive considering the comprehensive factors of energy efficiency and economy, how to deploy the least heterogeneous nodes reach the best effect is very important [8, 9]. In addition, cluster routing is another strategy that applies in WSNs [10]. However, it may lead

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to several cluster overloads, resulting in unreasonable cluster formation [11] leading the network to premature death. Therefore, how to design a reasonable heterogeneous clustering routing algorithm is a problem worth researching. The improved clustering routing protocol proposed in this paper is based on heterogeneous WSN (HWSN). The probability and threshold of cluster head selection is modified, and the modified hybrid transmission strategy can improve the case of path loss.

The following parts are shown as: Sect. 1.2 discusses the energy-saving work of heterogeneous cluster wireless sensor networks; Sect. 1.3 introduces the three-tier DEEC protocol; Sect. 1.4 details and describes the proposed protocol; Sect. 1.5 gives and analyzes several simulation results; Sect. 1.6 summarizes the results.

1.2 Related Work

WSNs are popular with many researchers on account of its potential application values. Aiming at the most effective clustering protocol in WSNs, a classical low-energy adaptive clustering hierarchy (LEACH) [12] algorithm is proposed, which is the earliest widely applied clustering algorithm that extends the lifetime of WSNs. In this algorithm, each cluster has a key node, called cluster heads (CHs). All nodes do not transmit data directly to the base station, but some nodes convey information to the local CHs. In each round, the CHs have a certain probability that is computed into circulation. Each round is defined by the establishment phase and the stable phase. This paper also discusses several LEACH-based adaptive clustering protocols, such as LEACH-c [13] and LEACH-m [14]. These methods are isomorphic, but are not suitable for heterogeneous wireless sensor networks. Stable election protocol (SEP) [15] was designed by Smaragdakis in 2004, which is suitable for heterogeneous networks and shows the process of cluster head selection including advanced nodes and normal nodes. It is the earliest protocol that refers to heterogeneity. According to the initial energy of each node, the probability of each node becoming a cluster head is weighted. Therefore, compared with ordinary nodes, the probability of high-level nodes becoming cluster heads is more likely, and the performance of SEP is better than LEACH. Li et al. discussed the distributed efficient clustering (DEEC) algorithm [16] about the two-level and multi-level heterogeneous network. This is developed based on SEP. When filtering cluster heads, nodes with larger initial energy and residual energy are more likely to be selected as cluster heads.

However, in DEEC protocol, it is complicated to calculate the average energy consumption. Elbhiri [17] proposes a developed DEEC (DDEEC) for HWSN. DDEEC introduces the concept of threshold to ensure that the residual energy of high-level nodes after a certain number of rounds is equal to that of ordinary nodes and will not be repeated as CHs. Saini et al. [18] proposed enhanced DEEC (EDEEC) protocol, which extends DEEC to a three-level network by adding super nodes, but the probability of CHs selection is the same as before. Javaid proposes a new clustering routing protocol: an improved distributed energy-saving clustering scheme (EDDEEC) [19] for HWSNs, which improves the probability of cluster head (CH) selection based on dynamic changes. Xie proposed an improved distributed energy-saving clustering algorithm (IDEEC) [20] for HWSNs in 2017. IDEEC takes into account the multi-level energy model, simplifies the threshold, improves the probability of cluster head selection, and optimizes the average energy in the network. All the above algorithms only change the cluster head selection, without considering the comprehensive factors. The data transmission stage is single hop, which consumes a lot of energy and is not conducive to prolonging the life cycle of the network.

On the basis of the previous research results, the existing DEEC improvement project still has some shortcomings. Its algorithm is more complex in practical application, without considering all the important factors. Therefore, this paper proposes an improved heterogeneous WSN routing protocol, which can effectively utilize energy and then prolong the lifetime of the network.

1.3 The Three-Level Protocol of DEEC

In this section, a three-level distributed efficient clustering (DEEC) algorithm is introduced, which contributes to the research of the subsequent routing protocols. Now, we will discuss energy heterogeneity protocols in detail.

1.3.1 Network Model

The rational assumptions have the following attributes:

(1) The sole base station has an unlimited supply of power. Therefore, there are no other limitations.
(2) After deployment, all sensor nodes and base stations are static, and they all have their own identifier (ID) number
(3) Radio is symmetrical, so data transmission nodes consume the same power as node A.
(4) The distance between nodes can be calculated based on the received signal strength.
(5) Three-level nodes are deployed in the network. In addition, they have similar storage, processing, sensing, and communication functions

1.3.2 Energy Model

There are N nodes made up of three types deployed in the network that differ in their initial energy. Normal nodes contain an energy level of E_0, and the advanced nodes of fraction m have a times extra energy than the normal nodes equal to $E_0 \cdot (1 + a)$.

However, super nodes of fraction m_0 have a factor of b times more energy than the normal nodes. Therefore, $N \cdot m \cdot m_0$ is the total number of super nodes, and $N \cdot m \cdot (1 - m_0)$ is the total number of advanced nodes. The total initial energy of the three-level heterogeneous networks is given by:

$$\begin{aligned} E_{\text{total}} &= N \cdot (1 - m) \cdot E_0 + N \cdot m \cdot (1 - m_0) \cdot (1 + a) \cdot E_0 + N \cdot m \cdot m_0 \cdot (1 + b) \cdot E_0 \\ &= N \cdot E_0 \cdot (1 + m \cdot (a + m_0 \cdot b)) \end{aligned} \tag{1}$$

We can see from (1) that the three-level heterogeneous networks contain $m \cdot (a + m_0 \cdot b)$ times more energy as compared to homogeneous WSNs.

As the author proposed in [21, 22], a node transmits l bit messages to a distance d and the equation to calculate the energy consumption is given by:

$$E_{Tx}(l, d) = \begin{cases} lE_{\text{elec}} + l\varepsilon_{\text{fs}} d^2, & d < d_0 \\ lE_{\text{elec}} + l\varepsilon_{\text{mp}} d^4, & d \geq d_0 \end{cases} \tag{2}$$

Furthermore, when a node receives l bit messages, the equation to calculate the energy consumption is given by

$$E_{Rx}(l, d) = lE_{\text{elec}} \tag{3}$$

where E_{elec} signifies the energy dissipation per bit in the transmitter and receiver circuitry, the parameters ε_{fs} and ε_{mp} are the energy consumption per bit in the radio frequency amplifier, d signifies the transmission distance, and d_0 signifies the threshold distance, whose value is given by

$$d_0 = \sqrt{\varepsilon_{\text{fs}} / \varepsilon_{\text{mp}}} \tag{4}$$

The average energy of r round from [22] is given as:

$$\overline{E}(r) = \frac{1}{N} E_{\text{total}} \left(1 - \frac{r}{R}\right) \tag{5}$$

where R denotes the total rounds during the network lifetime and can be estimated as:

$$R = \frac{E_{\text{total}}}{E_{\text{round}}} \tag{6}$$

where E_{round} is the energy dissipated in a network during a single round and it can be calculated as:

$$E_{\text{round}} = l(2\text{NE}_{\text{elec}} + \text{NE}_{\text{DA}} + k\varepsilon_{\text{mp}} d_{\text{toBS}}^4 + N\varepsilon_{\text{mp}} d_{\text{toCH}}^2) \tag{7}$$

where k is the number of clusters, E_{DA} is the data aggregation cost expended in CH, d_{toBS} is the average distance between CH to BS, and $d_{\text{to CH}}$ is the average distance between cluster members to CH. Now, $d_{\text{to BS}}$ and $d_{\text{to CH}}$ can be calculated as:

$$d_{\text{to CH}} = \frac{M}{\sqrt{2\pi k}} \tag{8}$$

$$d_{\text{to BS}} = 0.765\frac{M}{2} \tag{9}$$

Through finding the derivative of E_{round} with respect to k, and setting the derivative as zero, we can get the optimal number clusters k_{opt} as:

$$k_{\text{opt}} = \frac{\sqrt{N}}{\sqrt{2\pi}}\sqrt{\frac{\varepsilon_{\text{fs}}}{\varepsilon_{\text{mp}}}}\frac{M}{d^2_{\text{to BS}}} \tag{10}$$

Hence, we can calculate the energy dissipated per round by substituting Eqs. (8), (9), and (10) into (7). When the number of the clusters is k_{opt}, the total energy consumption of the entire network is minimal. So, we can determine the optimal cluster head ratio P_{opt} by

$$P_{\text{opt}} = \frac{k_{\text{opt}}}{N} \tag{11}$$

1.3.3 Cluster Heads Selection Method

In DEEC, each round node decides whether to become a cluster head based on the threshold calculated by the suggested percentage of cluster heads for the network. This decision is that the nodes automatically generate a random number between 0 and 1. If the number is less than the threshold $T(S_i)$, then the node becomes a cluster head for the current round. The threshold is set as:

$$T(S_i) = \begin{cases} \frac{p_{\text{nrm}}}{1-p_{\text{nrm}}\left(r \bmod \frac{1}{p_{\text{nrm}}}\right)} & S_{\text{nrm}} \in G' \\ \frac{p_{\text{adv}}}{1-p_{\text{adv}}\left(r \bmod \frac{1}{p_{\text{adv}}}\right)} & S_{\text{adv}} \in G'' \\ \frac{p_{\text{sup}}}{1-p_{\text{sup}}\left(r \bmod \frac{1}{p_{\text{sup}}}\right)} & S_{\text{sup}} \in G''' \\ 0 & \text{Otherwise} \end{cases} \tag{12}$$

where p_{nrm}, p_{adv}, and p_{sup} are the weighted election probabilities for normal, advanced, and super nodes. G', G'', and G''' stand for the sets for which relevant nodes have not become cluster heads within the last $1/p_{\text{nrm}}$, $1/p_{\text{adv}}$, and $1/p_{\text{sup}}$ rounds.

The weighted election probabilities p_{nrm}, p_{adv}, and p_{sup} are given by

$$p_i = \begin{cases} \frac{P_{\text{opt}} E_i(r)}{(1+m(a+m_0 b))\overline{E}(r)} & \text{for Nrm nodes, if } E_i(r) > T_{\text{abs}} \\ \frac{P_{\text{opt}}(1+a) E_i(r)}{(1+m(a+m_0 b))\overline{E}(r)} & \text{for Adv nodes, if } E_i(r) > T_{\text{abs}} \\ \frac{P_{opt}(1+b) E_i(r)}{(1+m(a+m_0 b))\overline{E}(r)} & \text{for Sup nodes, if } E_i(r) > T_{\text{abs}} \end{cases} \tag{13}$$

We can substitute (13) into (12), and the threshold formula of the final cluster head is obtained.

where T_{abs} is the threshold of energy, which can be expressed by:

$$T_{\text{abs}} = z E_0 \tag{14}$$

where E_0 is the initial energy of the normal node and the range of $z = 0$ is 0 to 1. If $z = 0$, we will have the previous DEEC algorithm, the threshold to be a cluster head will be equal to zero for all nodes, and all advanced nodes and super nodes have few opportunities to be a cluster head. So, they go to transmit data directly to the base station in a large part; thus, they die quickly. Through lots of simulations with a random topology, the value z directly controls the cluster heads number. If z is higher, the cluster heads will increase. But, it cannot increase without limit, and it will lead to the phenomenon that cluster head overloads. To solve this problem, put the reasonable value that it is worth researching. And in the following experiment, it is researched that when z is 0.74, the network performance is optimal.

1.3.4 Setup of the Cluster and Data Transmission

First filter the candidate CH in the first round. When the selected candidate CH is formed, it will send the data to the competing CH within the competition radius. At the same time, the member node can get the distance to join the cluster according to the received signal strength and can get the minimum value according to the received strongest signal information. The cluster member nodes send data to the cluster head according to the time slot of TDMA. Then, each cluster head receives data, aggregates it, and forwards it to the base station. The data transmission mode is single hop mode. After completing one round of data transmission, new cluster head selection will begin in the next round.

1.4 Proposed Algorithm

1.4.1 Cluster Head Selection

1.4.1.1 The Improvement of Probability

From (13), it can be seen that nodes with large residual energy on the circle are more likely to become cluster heads. Therefore, nodes with higher residual energy or higher nodes are more likely to be selected as cluster heads than those with lower energy or normal nodes. However, when the residual energy of super node, advanced node, and ordinary node is almost the same, the probability of choosing super node or advanced node as a cluster head is still higher than that of choosing ordinary node. This makes super and advanced nodes to have less residual energy than normal nodes, and they will die faster than normal nodes. To avoid this unbalanced problem, the probability formulas are changed. All the nodes will use their respective probability formula until they reach a threshold energy level T_{abs}. The paper adds a condition that when the residual energy of all three-level nodes reaches the threshold T_{abs} or below, the cluster head elections can still work efficiently, and then, all the nodes will use a common probability formula as given below:

$$p_i = c\frac{P_{\text{opt}}(1+b)E_i(r)}{(1+m(a+m_0 b))\overline{E}(r)}, \text{for Nor, Adv, Sup, if } E_i(r) \leq T_{\text{abs}} \tag{15}$$

where c is a positive value which adjusts the probability of cluster head election, the range of c is 0 to 1, and it will be shown in Part 5 (Simulation and Discussion). Formula (15) is an improvement for the election probability of cluster heads. It can well improve the trend of rapid decline of energy of high-energy nodes when the residual energy of all nodes is less than the threshold value. Therefore, the probability of improved nodes makes the energy consumption more balanced.

Thus, the whole improved probability is expressed as (16):

$$p_i = \begin{cases} \frac{P_{\text{opt}}}{(1+m(a+m_0 b))} & \text{for Nrm nodes, if } E_i(r) > T_{\text{abs}} \\ \frac{P_{\text{opt}}(1+a)E_i(r)}{(1+m(a+m_0 b))\overline{E}(r)} & \text{for Adv nodes, if } E_i(r) > T_{\text{abs}} \\ \frac{P_{\text{opt}}(1+b)E_i(r)}{(1+m(a+m_0 b))\overline{E}(r)} & \text{for Sup nodes, if } E_i(r) > T_{\text{abs}} \\ c\frac{P_{\text{opt}}(1+b)E_i(r)}{(1+m(a+m_0 b))\overline{E}(r)} & \text{for Nor,Adv,Sup,if } E_i(r) \leq T_{\text{abs}} \end{cases} \tag{16}$$

Formula (16) completely describes the cluster head election probability under different conditions for the three node types, where P_{opt} represents the optimal cluster head election probability, and a and b, respectively, represent the multiples of the energy of advanced node and super node higher than that of ordinary node.

1.4.2 The Improvement of Threshold

Starting from (12), the threshold depends only on probability and integer. However, due to the heterogeneity of nodes in the network, the initial energy and energy consumption rate of nodes are different. Therefore, it is unreasonable to choose a cluster head based on the above factors. We consider natural factors, including the speed of node energy consumption and residual energy.

We believe that the initial energy of nodes should have different probability of cluster head selection, and the corresponding threshold should reduce the lower initial energy of premature death to some extent. However, in the actual operation of the network, only considering the initial energy cannot solve the problem of unbalanced energy consumption. The residual energy of nodes in the network undergoes dynamic changes. Some nodes usually act as cluster heads, which makes the stability period of the network very short. Therefore, we need to consider the residual energy factor. In addition, the initial energy of the node is higher, but the energy consumption is higher. Therefore, if only considering the high residual energy factor, the nodes will consume energy quickly in the next round, which is not the best strategy to select cluster heads.

From another point of view, if only one factor of node energy consumption rate is considered, there is a problem of loss of energy consumption rate of the node in the first round. In this case, the threshold will become zero. As a result, all nodes become cluster heads, and network performance decreases dramatically.

In order to realize the former method without considering node energy consumption rate and residual energy consumption, we modify the threshold, which adds influence factor η, which is multiplied by the original probability, and proposes that:

$$T(S_i)\begin{cases} \frac{p_{\text{nrm}}}{1-p_{\text{nrm}}\left(r \bmod \frac{1}{p_{\text{nrm}}}\right)} * \eta_{\text{nrm}} & p_{\text{nrm}} \in G' \\ \frac{p_{\text{adv}}}{1-p_{\text{adv}}\left(r \bmod \frac{1}{p_{adv}}\right)} * \eta_{adv} & p_{\text{adv}} \in G'' \\ \frac{p_{\text{sup}}}{1-p_{\text{sup}}\left(r \bmod \frac{1}{p_{\text{sup}}}\right)} * \eta_{\text{sup}} & p_{\text{sup}} \in G''' \\ 0 & \text{Otherwise} \end{cases} \tag{17}$$

The η is a factor, and the formula is given by

$$\eta = \alpha \frac{E_i(r)}{E_{\text{ini}}} + \beta \frac{r-1}{E_{\text{ini}} - E_i(r)} \tag{18}$$

There is also the practical significance of $\frac{r-1}{E_{\text{ini}}-E_i(r)}$, which is the reciprocal of the energy consumption rate. In addition, E_{ini}, $E_i(r)$, and r represent the initial energy, residual energy, and the current round, while α and β are the weight factor which adjust the factors that $\frac{E_i(r)}{E_{\text{ini}}}$ and $\frac{r-1}{E_{\text{ini}}-E_i(r)}$.

We can also draw the forecast conclusion by determining that the cluster head selection in the next round is based on the η of the previous round. Then, the node will have a greater chance to become a cluster head in the next round. The η is an advantage over the previous round, which contributes to filter the cluster head.

1.4.3 State Transition

According to the characteristic that the node energy in the wireless sensor network is limit, considering that it will consume plenty of energy since each node needs to join in the cluster header's election, we adopt reasonable dormancy mechanism during the process of cluster head election.

In the process of forming clusters, there is the dedupe-aware neighboring node relationship between the node and node in the network. In our protocol, each node is determined by its state of transition with respect to its own energy state and the state of its neighboring node in the future. Therefore, we describe the dormancy mechanism in detail. When the node is not dead, the state of the node is alive, and the state flag of node is "active." Otherwise, the state flag of node is "dead." Once it is found that the neighbor node is in the dead state, we will set the neighbor node to sleep state, which meant that the neighboring node turned off its radio for the same time period to save energy. 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.

Algorithm I. The demonstrate of dormancy mechanism.

Initialization: all the 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;
```

1.4.4 Data Transmission

For data transmission, the previous algorithms used single hop mode. When the node is far away from the base station, it consumes unnecessary energy, so we adopt hybrid transmission mode. When member nodes are close to base stations, single hop mode should be used. When it is far away from the base station, multi-hop mode is adopted.

In the actual situation of cluster routing protocol, multi-hop transmission mode can share energy consumption with multiple clusters instead of focusing on one cluster. It can effectively balance the energy consumption inside the cluster.

In our improved protocol, each normal node chooses a routing path to send data to the base station. The path choice depends on the weight of distance between nodes. To reduce the overhead and delay, each node sends sensing data to the base station in the path of minimum energy consumption. Paths should be established directly or through transit nodes to forward aggregated data to the base station.

Each node first estimates the communication energy consumed by sending l bit messages directly to the base station. Its value depends on:

$$E_{CHi\_to\_BS} = E\left(l,\ d_{CHi\_to\_BS}\right) \tag{19}$$

where $d_{\mathrm{CH}i\_\mathrm{to}\_\mathrm{BS}}$ is the distance between the node i and the BS(base station). The value of $d_{\mathrm{CHi}\_\mathrm{to}\_\mathrm{BS}}$ is given by:

$$d_{\mathrm{CH}i\_\mathrm{to}\_\mathrm{BS}} = \sqrt{(x_{\mathrm{BS}} - x_{\mathrm{CH}i})^2 + (y_{\mathrm{BS}} - y_{\mathrm{CH}i})^2} \tag{20}$$

, each node decides whether to find an intermediate node or not in the current round. This decision depends on the following conditions:

$$E_{\mathrm{CH}i\_\mathrm{to}\_\mathrm{BS}} \geq\ E\left(k, d_{\mathrm{CH}i\_\mathrm{to}\_\mathrm{CH}j}\right) +\ E\left(k, d_{\mathrm{CH}j\_\mathrm{to}\_\mathrm{BS}}\right) \tag{21}$$

where $d_{\mathrm{CH}i\_\mathrm{to}\_\mathrm{CH}j}$ is the distance between the node i and the node j, and $d_{\mathrm{CH}j\_\mathrm{to}\_\mathrm{BS}}$ is the distance between node j and the base station. The value of $d_{\mathrm{CH}i\_\mathrm{to}\_\mathrm{CH}j}$ and $d_{\mathrm{CH}j\_\mathrm{to}\_\mathrm{BS}}$ is given by

$$d_{\mathrm{CH}i\_\mathrm{to}\_\mathrm{CH}j} = \sqrt{\left(x_{\mathrm{CH}j} - x_{\mathrm{CH}i}\right)^2 + \left(y_{\mathrm{CH}j} - y_{\mathrm{CH}i}\right)^2} \tag{22}$$

$$d_{\mathrm{CH}j\_\mathrm{to}\_\mathrm{BS}} = \sqrt{\left(x_{\mathrm{BS}} - x_{\mathrm{CH}j}\right)^2 + \left(y_{BS} - y_{\mathrm{CH}j}\right)^2} \tag{23}$$

The mixed data transmission scheme is presented in Fig. 1.1.

1.5 Simulation and Discussion

In our simulations, we deployed 100 nodes in a 100 × 100 square meter region in which the base station was located in the center of the region. We initialized p_{opt} to 0.1 depending on k_{opt}, which was given by Eq. (11). The initialized energy of the normal node is 0.5 Joules. Through these simulations, we can obtain the appropriate parameter that α is 0.35 and β is 0.65. We simulated the new protocol by using MATLAB. The values of radio characteristics are set as same as [16]. Those

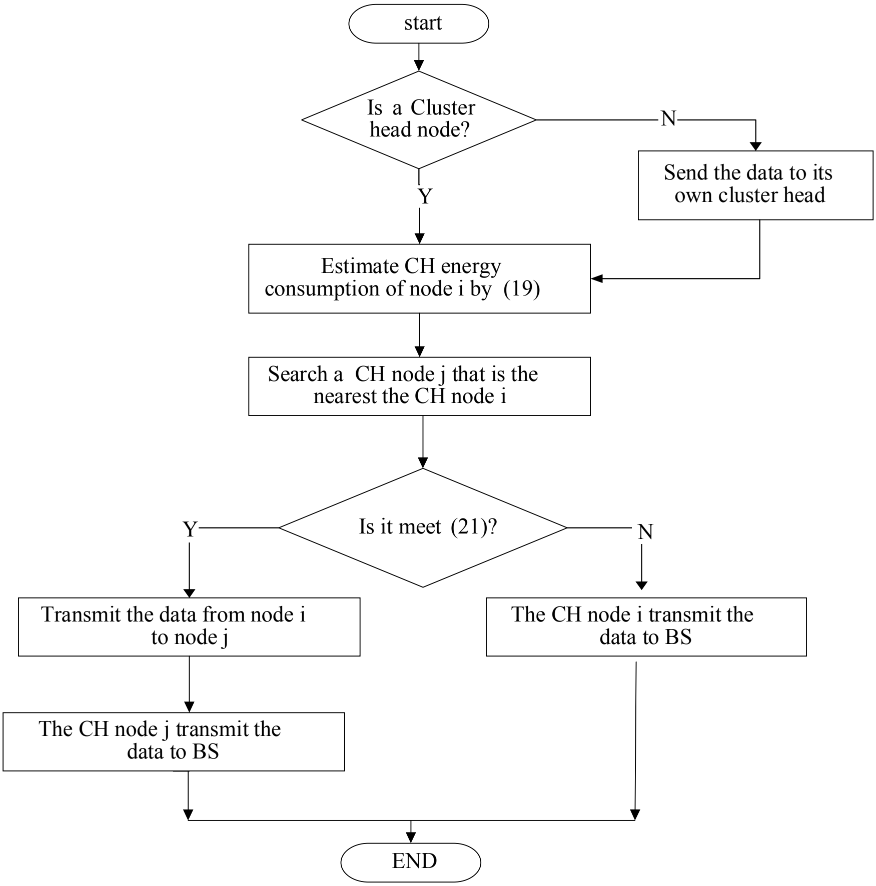


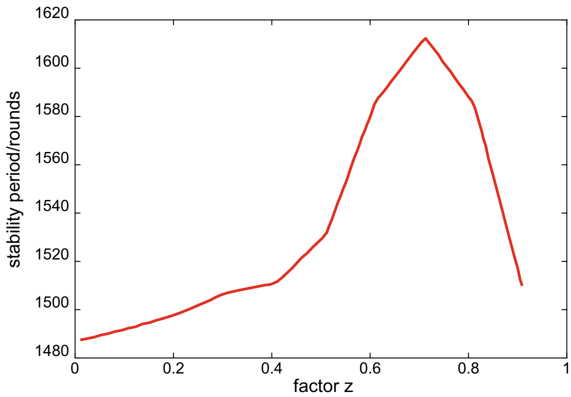
Fig. 1.1 Flowchart of mixed data transmission scheme

parameters are given in Table 1.1. We employ 20% advanced nodes and 20% super nodes. The energy of advanced nodes is 1.5 times more than normal nodes, while the

Table 1.1 Simulation Parameters

Parameters	Values
d_0	87 m
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
E_{elec}	50 nJ/bit
E_{DA}	5 nJ/bit
l	4000 bit

Fig. 1.2 Relationship between the stability period and the parameter z



energy of super nodes is three times more than normal nodes ($m = 0.50, m_0 = 0.50, a = 1.50, b = 3.0$).

We will now discuss the performance of our proposed DEEC and DDEEC methods on the basis of several evaluation indicator. This work uses four different performance indicators to evaluate the performance of our algorithm. The variances of stability period, network life cycle, throughput, and cluster head number are described as follows:

(1) Stability period: This is the death time of the first node.
(2) Network life cycle: Usually designated as the total time for the full operation and functionality of the network to perform dedicated tasks. Take the integer of all nodes to die, that is, the last node in the network to die.
(3) Packets sent to base stations: This is the total number of messages received by base stations over a period of time, during which each node sends a message to the cluster head or base station in each round.
(4) Number of cluster heads: This is the number of cluster heads in each round.

Figure 1.2 illustrates the relationship between the stability period and the parameter z in the proposed DEEC. As can be seen from Fig. 1.2, the parameter z varies with the stability period, when it is near to 0.74, at the same time as the network performance—the stable period reaches the optimal level. In order to simplify follow-up research, we can set the parameter z to 0.74.

Figure 1.3 illustrates the relationship between the network lifetime and the parameter c in the proposed DEEC. As can be seen from Fig. 1.3, the parameter varies with the stability period, when it near to 0.02, at the same time as the network performance—the network lifetime reaches the optimal level. In order to simplify follow-up research, we can set the parameter c to 0.02.

Figure 1.4 illustrates the relationship between the number of active nodes and the number of rounds. As can be seen from Fig. 1.4, the first nodes of DEEC, DDEEC, and the proposed method begin to die at 1095, , and 1493, respectively. This means that this method has a longer stability period than other methods. As can be seen

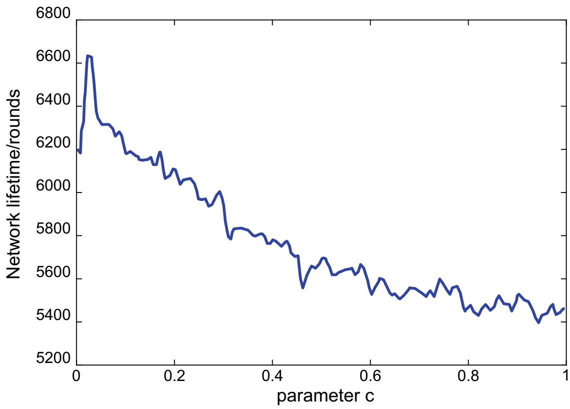


Fig. 1.3 Relationship between the network lifetime and the parameter *c*

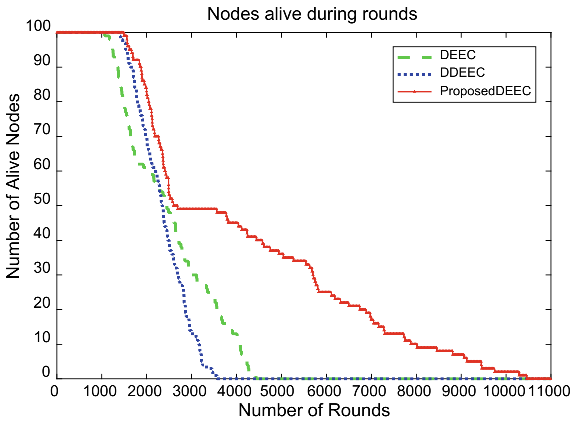


Fig. 1.4 Number of nodes alive

from Fig. 1.4, the last nodes of DEEC, DDEEC, and the algorithm in this paper begin to die in 3569, 4350, and 10,501 rounds, respectively. This means that this method has a longer network life cycle than other methods.

Figure 1.5 illustrates the relationship between the packets sent to the base station and the round. From Fig. 1.5, the packets sent to the base station for DEEC, DDEEC, and the proposed method are 0.75×10^5, 1.2×10^5, and 4.2×10^5. We can see that the packets sent to the base station for the proposed algorithm are still more than the others in the whole network lifetime. This means that the proposed method is more efficient than the others in terms of data transmission. It is necessary for the improvement measures that we adopt the mixed transmission mode in the data transmission phase. These cluster heads will deliver packets to the base station and thereby increase throughput.

Figures 1.6, 1.7, and 1.8 show the relationship between the number of cluster heads generated by DEEC, DDEEC, and the proposed algorithm throughout the network time. As can be seen from Fig. 1.4, the stabilization periods of DEEC, DDEEC, and

Fig. 1.5 Number of messages

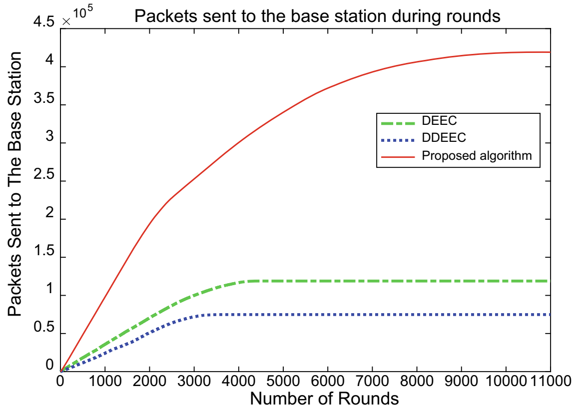


Fig. 1.6 Number of cluster heads of DEEC

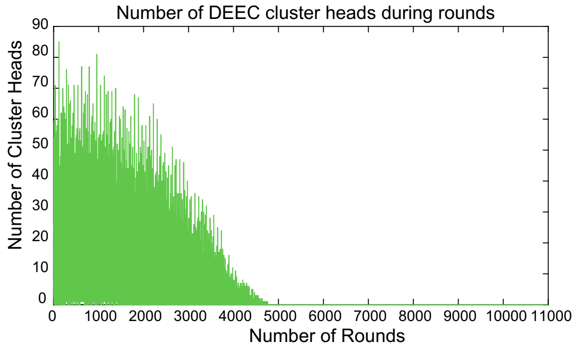
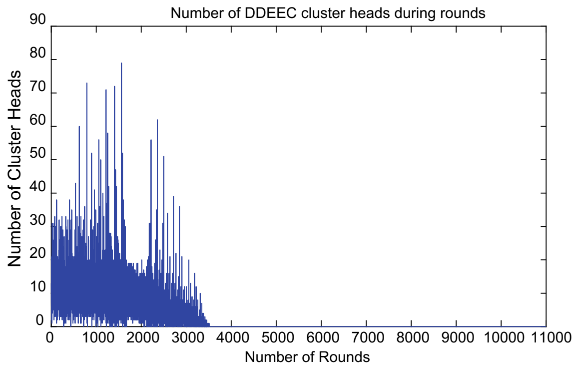


Fig. 1.7 Number of cluster heads of DDEEC



the proposed method are 0-1095, 0-1350, and 0-1493 rounds, respectively. Based on the above stable period, we can see that the number of cluster head DEEC is more balanced, followed by DDEEC and stable period. The method and number of cluster heads are more stable and unstable than other clusters. This means that the energy

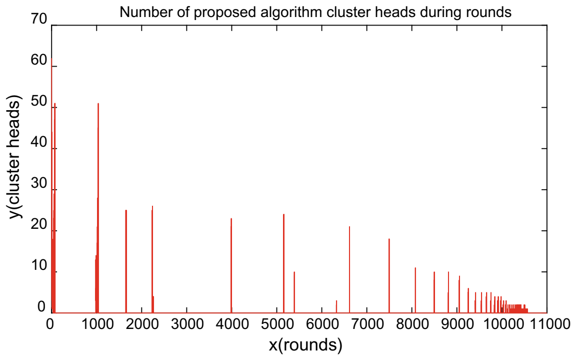


Fig. 1.8 Number of cluster heads of proposed method

consumption of the method is more balanced than that of the method during the unstable period. The reason is that improved clustering techniques, such as adaptive weighted selection probability by adding conditions and positive calculation, save a lot of energy in the protocol. Therefore, we can conclude that the algorithm can save more energy and prolong the network life, and the stability is more effective.

It can be seen from the figure that the algorithm is superior to DEEC and DDEEC in energy efficiency and energy balance. This is because our improved algorithm reduces the fluctuation of cluster heads. It needs to consider the speed of residual energy and energy consumption to improve the probability threshold to select cluster heads, and also uses hybrid transmission mode in the data transmission phase. Therefore, the protocol helps prolong the network lifetime.

From all the figures, we can see that they show that the proposed algorithm is better in terms of energy efficiency and energy balance than DEEC and DDEEC. This is because our improved algorithm reduces the fluctuation of the cluster heads by taking residual energy and the rate of energy consumption into consideration to improve the probability threshold during the period of choosing cluster heads, and also by adopting the mixed transmission mode in the data transmission phase. Thus, the proposed protocol is helpful in extending the network lifetime and stability time.

1.6 Conclusion

An improved, distributed and efficient clustering algorithm for HWSNs was proposed. The probability threshold and cluster head selection probability are improved, and the hybrid data transmission mode is adopted in the data transmission stage, which reduces the energy consumption of nodes. The simulation results show that when compared with DEEC and DDEEC, the algorithm can effectively prolong the stability time and lifetime of the network.

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