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Article

Optimal Deployment of Heterogeneous Nodes to Enhance Network Invulnerability

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Abstract: Wireless sensor networks (WSN) can be used in many fields. In wireless sensor networks, sensor nodes transmit data in multi hop mode. The large number of hops required by data transmission will lead to unbalanced energy consumption and large data transmission delay of the whole network, which greatly affects the invulnerability of the network. Therefore, an optimal deployment of heterogeneous nodes (ODHN) algorithm is proposed to enhance the invulnerability of the wireless sensor networks. The algorithm combines the advantages of DEEC (design of distributed energy efficient clustering) clustering algorithm and BAS (beetle antenna search) optimization algorithm to find the globally optimal deployment locations of heterogeneous nodes. Then, establish a shortcut to communicate with sink nodes through heterogeneous nodes. Besides, considering the practical deployment operation, we set the threshold of the mobile location of heterogeneous nodes, which greatly simplifies the deployment difficulty. Simulation results show that compared with traditional routing protocols, the proposed algorithm can make the network load more evenly, and effectively improve energy-utilization and the fault tolerance of the whole network, which can greatly improve the invulnerability of the wireless sensor networks.

Keywords: Wireless sensor networks; invulnerability; small world characteristic; heterogeneous node; deployment

1 Introduction

Wireless sensor network (WSN) has been regarded as an important part of the Internet of Things (IoT), informatization, intelligence, and the Internet of Everything are closely related to it [1]. WSN comprises a massive number of arbitrarily placed sensor nodes that are linked wirelessly to monitor the physical parameters from the target region [2]. WSN are used in many fields because of their low cost and easy deployment [3]. These sensors are battery-driven and resource-restrained devices that consume most of the energy in sensing or collecting the data and transmitting it [4]. The node failure is considered as one of the main issues in the WSN which creates higher packet drop, delay, and energy consumption during the communication [5]. Therefore, studying the invulnerability of wireless sensor networks has important theoretical value to solve the bottleneck of large-scale application of wireless sensor networks [6]. Network invulnerability measures the ability of the system to provide reliable services in a sustainable and stable manner [7].

Small world network has both short average path length and high clustering coefficient. In sensor networks, the small average path length means that nodes only need less hops and energy when transmitting data to sink nodes [8]. The large clustering coefficient means that the propagation range of local information in the network is relatively wide and the connection between local nodes is relatively close, which makes the data in the network redundant to a certain extent. Therefore, a larger clustering coefficient can improve the fault tolerance and prolong the life cycle of the network.

In wireless sensor networks, cluster heads consume more energy because they have to collect and forward the information perceived by nodes in the cluster. Cluster heads which close to sink nodes consume more energy because they undertake more forwarding tasks. In order to solve the problem of excessive and fast network energy consumption caused by unbalanced load, heterogeneous nodes are introduced which can communicate directly with sink nodes in the network, and the energy of the heterogeneous nodes can be supplemented. Heterogeneous sensor networks with small world characteristic are constructed by using the super link formed between heterogeneous nodes and sink as a shortcut. The addition of heterogeneous nodes and the construction of super links can balance the network load and enhance the invulnerability of the network.

2 Related Works

In recent years, the small world characteristic has been widely concerned by researchers. The small world characteristic shows how everyone in the real world connects with others. Milgram conducted a series of mail delivery experiments in 1967 [9]. The experimental results show that there are about six intermediate transmissions on average before reaching the final receiver. This work quantifies the famous concept of "six degrees of separation" between any individual on earth for the first time.

In 1998, Watts and Strogatz propose a network model, which shows that rewiring several links in a regular ring grid graph (the end point of the rewiring link is randomly selected from the graph) can greatly reduce the average path length between any two nodes in the graph, while still maintaining a high degree of clustering in adjacent nodes [10]. In 2003, Helmy et al. introduce the idea of small world network into the research of wireless networks. They study the relationship between wireless sensor networks and small world networks, and build a wireless sensor network with small world characteristic by introducing logical links. The results show that the average path length between network nodes is greatly reduced by the method of random edging of links [11]. Fu enhances the invulnerability of wireless sensor networks and prolongs the network life through super lines and super nodes, which also uses the small world feature [12]. Jiang proposes a method to build a small world in wireless networks. Different from the previous deployment of wired lines as shortcuts, he uses a mobile router node called data mule. Data mule moves and transmits data between nodes without direct communication, and imitates shortcuts in the small world [13]. Guidoni proposes a tree method based on the concept of small world to design heterogeneous sensor networks. The proposed model introduces an adjustable search space to find heterogeneous sensors and create shortcuts between them. When a shortcut is added to create a connection topology between heterogeneous sensors, the data communication delay is significantly reduced [14]. Pandey introduces probability model to develop cognitive small world. The probability model introduced by the link takes advantage of the characteristics of the network and nodes, such as the number of hops and the geographical distance from the sensor node to the receiver. In addition, a new data transmission scheme is proposed, which uses the residual energy of sensor nodes to change the energy consumption of the link [15]. Sreejith models the sensor network as a small world network by introducing directional sensor nodes, so as to find a route with the smallest path length. This method can find a path with the least hops from the source node to the sink node, so as to transmit data in the shortest time and reduce the network energy consumption [16]. In Sun's paper, a small-world network model is introduced for water quality sensor networks. The energy consumption of the relay nodes near the heterogeneous node is too much, so the energy threshold and non-uniform clustering are constructed to improve the lifecycle of the network. Simulation results show that, compared with the low-energy adaptive clustering hierarchy routing algorithm and the best sink location clustering heterogeneous network routing algorithm, the proposed improved routing model can effectively enhance the energy-utilization. The lifecycle of the network can be extended and the data transmission amount can be greatly increased [17]. In Wang's paper, according to the event level and the node energy of the sensor networks, the nodes' types are defined, which can help to determine the cluster node. Then, an event driven routing protocol (EDRP) is proposed, which considers the event information and the remaining energy of the whole network. EDRP can effectively prolong the life cycle and greatly increase the amount of data transmission of the network [18]. In Çavdar's paper, they propose a novel approach for finding the optimal number of anchor nodes and an optimal placement strategy in a large-scale WSN, based on the output of Grey Wolf Optimization (GWO) and Particle Swarm Optimization (PSO) methods [19]. A large number of research results show that the introduction of small world characteristic into wireless sensor networks can not only effectively reduce the average path length of the network, but also significantly reduce the occurrence probability of isolated clusters in the network. It can greatly improve the overall coverage effect and life cycle of wireless sensor networks. To sum up, most of the previous studies adopt the strategy of random deployment of heterogeneous nodes, however it is obvious that random deployment is not the best. Therefore, for deploying heterogeneous nodes in wireless sensor networks to establish long-range connections, the core problem is how to deploy heterogeneous nodes to achieve global optimization. In order to solve these problems, a heterogeneous node deployment routing optimization algorithm is proposed based on small world characteristic. The algorithm combines the advantages of DEEC clustering algorithm and BAS optimization algorithm.

3 Construction of Heterogeneous Network Routing Algorithm

Heterogeneous nodes that can communicate directly with sink nodes are introduced in this paper. Super link which is between heterogeneous nodes and sink is as a shortcut to construct heterogeneous sensor networks with small world characteristic. In heterogeneous sensor networks, the location and number of heterogeneous nodes have a great impact on the performance of the network. In order to effectively reduce the energy consumption of the network and prolong the network life cycle, the primary task of the algorithm is to determine the number and location of heterogeneous nodes.

3.1 Transmission Mode of Super Link in Heterogeneous Network

Ordinary nodes are powered by mobile power, while heterogeneous nodes are powered by solar panels, which means, ordinary nodes have limited energy, while heterogeneous nodes can ignore energy consumption. The data transmission mode of super link in heterogeneous network is shown in Fig. 1. Heterogeneous node h and sink node directly transmit data through super link, while ordinary node v_i transmits data to sink node or heterogeneous node through multi-hop.

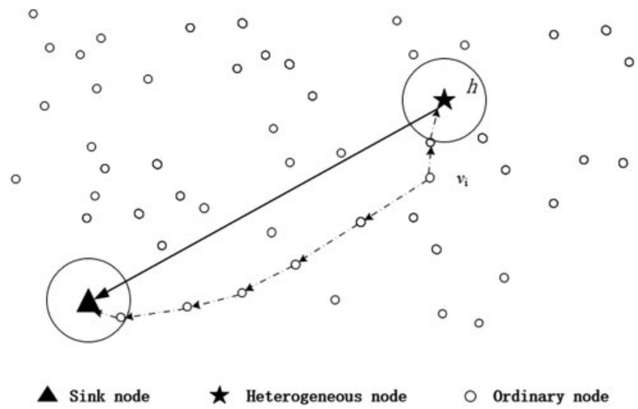
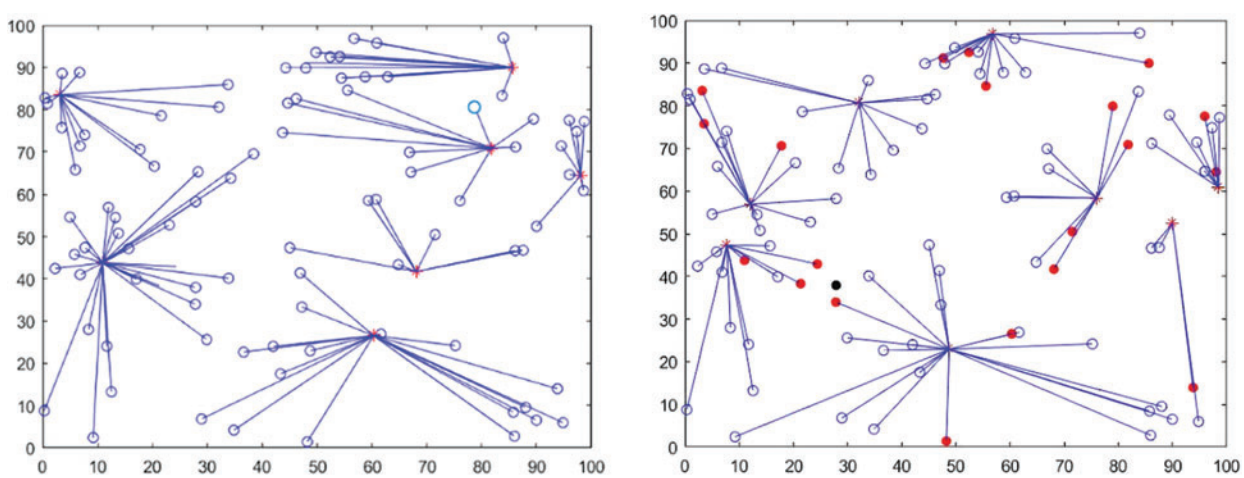


Figure 1: Network model with super link

3.2 Energy Consumption Model of Clustered Sensor Networks

In a wireless sensor network, sensor nodes are powered by mobile power, and the total energy of the whole network is limited. As shown in Fig. 2, 100 sensor nodes are deployed in the monitoring area, and the energy of the nodes is gradually consumed as time passed. The red star point in the figure is the cluster head node, and the circles are the ordinary nodes. After initial deployment, all nodes are blue with sufficient energy, as shown in Fig. 2a. As time passed, due to unbalanced energy consumption, some nodes consume energy very quickly, and their colors gradually change from blue to red, as shown in Fig. 2b. When nodes fail, they are represented in black, as shown in Fig. 2c and Fig. 2d. Therefore, it is very important to overcome the resource constraints and facilitate monitoring through an effective routing algorithm. Clustering wireless sensor networks can reduce the energy consumption and improve the response speed of the network. The introduction of heterogeneous nodes that can communicate directly with sink nodes and the construction of heterogeneous networks with small world characteristic can prolong the network life cycle and enhance the invulnerability of wireless sensor networks.



(a) Round 1 (b) Round 1000

Figure 2: (Continued)

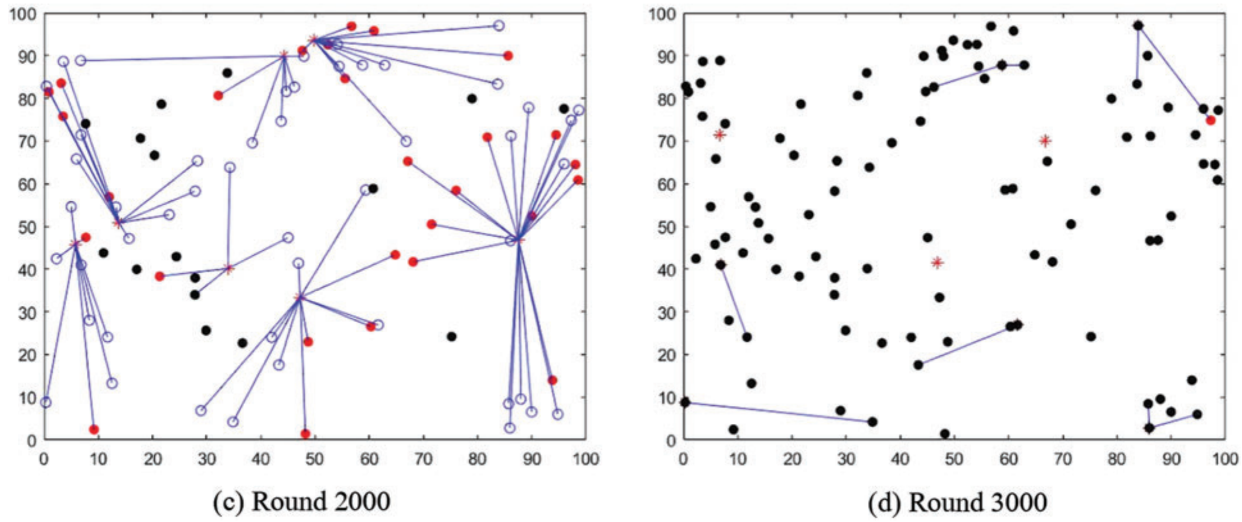


Figure 2: Network energy consumption

3.3 Heterogeneous Node Location Optimization Model

DEEC algorithm is a clustering algorithm to balance the energy of multi-level heterogeneous networks. Its main principle is to select the cluster head according to the ratio of the residual energy of each node to the average energy of the network. Nodes with high initial energy and residual energy are more likely to be selected as cluster heads than nodes with low energy, which can balance the energy and prolong the life cycle of the network [20].

In DEEC algorithm, the calculation method of the probability that a node in the network is selected as the cluster head is shown in Eq. (1).

$$P_i = \frac{P_{opt} N \left(1 + a\right) E_i(r)}{\left(N + \sum_{i=1}^{N} a_i\right) \overline{E}(r)} \tag{1}$$

Where P_{opt} is the proportion of cluster heads from the total nodes, a_i represents the multiple of the initial energy of node i higher than the lowest initial energy E_0, N is the total number of nodes in the network, $E_i(r)$ is the residual energy of node i in round r. $\overline{E}(r)$ represents the average energy of the network, which can be obtained from Eq. (2).

$$\overline{E}(r) = \frac{1}{N} \sum_{i=1}^{N} E_i(r) \tag{2}$$

Due to the different initial energy and energy consumption of each node [21], the probability of becoming a cluster head is different. The relationship between the probability P_i of a node becoming a cluster head and the threshold $T(s_i)$ is shown in Eq. (3).

$$\mathrm{T}\left(s_i\right) = \begin{cases} \dfrac{p_i}{1 - p_i \left(r \, mod \dfrac{1}{p_i}\right)}, & s_i \in G \\ 0, & otherwise \end{cases} \tag{3}$$

where G represents the set of nodes that have not been selected as cluster heads, s_i is the nodes, $i \in [1, n]$.

After the nodes are clustered by DEEC algorithm, the ordinary nodes transmit the data to the cluster head. The cluster head processes the received data centrally, which can not only reduce energy consumption, but also increase the amount of data transmission. The transmission of network nodes will change accordingly with different nodes selected as cluster heads, so as to make the energy consumption more balanced and enhance the invulnerability of the network.

Suppose that the initial position of heterogeneous nodes is $h(u_c, v_c)$. After the nodes are clustered according to the DEEC algorithm, there are n cluster heads whose positions are v_i (x_i, y_i), $i = 1,2, \ldots, N$, and the location of the sink node is (x_m, y_m). Data transmitted by cluster heads can through multi-hop transmission or super link.

When the cluster head transmits data directly to the sink, the node v_i finds the shortest transmission path to transmit the data to the sink node through the greedy algorithm, and sets the distance from the cluster head node v_i to the sink node as d_i^s. When the cluster head v_i transmits data to the sink node through the super link, the node v_i also finds the shortest transmission path from all neighbor cluster heads to the heterogeneous node h through the greedy algorithm, and sets the distance between the node v_i and the heterogeneous node h as d_i^h. When the data is transmitted to the heterogeneous node, the heterogeneous node transmits the data to the sink node through the super link.

The data transmission mode of the cluster heads is determined according to the transmission distance d_i^h and d_i^s. When $d_i^s \geq d_i^h$, the cluster head transmits data to the sink node through the super link; When $d_i^s < d_i^h$, the cluster head transmits data directly to the sink node in multiple hops. For example, for cluster head v_1, the distance to sink node through multi-hop transmission is less than that to heterogeneous node. Therefore, it directly transmits data to sink node through multi-hop, as shown in Fig. 3.

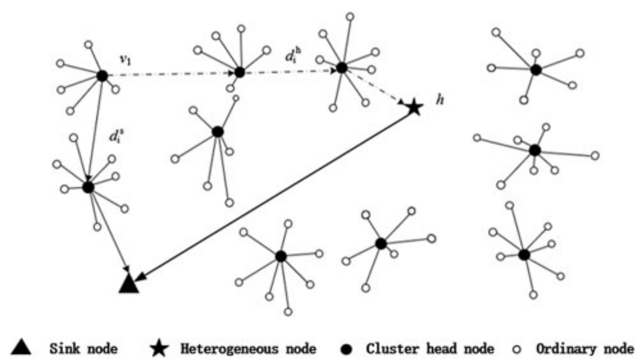


Figure 3: Data transmission mode of cluster head node

It is assumed that S cluster heads directly transmit data to sink node through multi-hop, and H cluster heads transmit data to sink node through super link, where, $H + S = N$. In wireless sensor networks with heterogeneous node, because the energy of heterogeneous node and sink node can be supplemented, the energy consumption of data transmission in the super link needn't to be considered. Therefore, only the distance between cluster head nodes and heterogeneous node needs to be considered.

When H cluster heads transmit data to sink through the super link, label the relay cluster head nodes in the transmission path. It is assumed that there are l relay cluster heads with coordinates of

(α_n, β_n), $n = 1, 2, \ldots, l$, transmission distance is shown in Eq. (4).

$$d_i^{\,h} = \begin{array}{l} \sqrt{(x_i-\alpha_1)^2+(y_i-\beta_1)^2}+\sqrt{(\alpha_1-\alpha_2)^2+(\beta_1-\beta_2)^2}+\cdots \\ +\sqrt{(\alpha_{l-1}-\alpha_l)^2+(\beta_{l-1}-\beta_l)^2}+\sqrt{(\alpha_l-u_c)^2+(\beta_l-v_c)^2} \end{array} \tag{4}$$

Similarly, when S cluster heads directly transmit data to sink, label the relay cluster head nodes in the transmission path. It is assumed that the coordinates of j relay cluster head nodes are (γ_n, δ_n), $n = 1, 2, \ldots, j$, transmission distance is shown in Eq. (5).

$$d_i^{\,s} = \begin{array}{l} \sqrt{(x_i-\gamma_1)^2+(y_i-\delta_1)^2}+\sqrt{(\gamma_1-\gamma_2)^2+(\delta_1-\delta_2)^2}+\cdots \\ +\sqrt{\left(\gamma_{j-1}-\gamma_j\right)^2+\left(\delta_{j-1}-\delta_j\right)^2}+\sqrt{\left(\gamma_j-x_m\right)^2+\left(\delta_j-y_m\right)^2} \end{array} \tag{5}$$

Finally, when the heterogeneous node h is at $h\,(u_c, v_c)$, the total distance d of all cluster head nodes transmitting data to sink node is calculated. The calculation of d is shown in Eq. (6).

$$d = \sum_{i=1}^{H} d_i^h + \sum_{i=H+1}^{N} d_i^s \tag{6}$$

Because the initial location $h\,(u_c, v_c)$ of heterogeneous nodes is random, we need to find a globally optimal heterogeneous node location, that is, to minimize the total distance d from all cluster head nodes to sink node.

After clustering by DEEC algorithm, BAS algorithm [22] is introduced. Heterogeneous node is individuals to be searched. The objective function to be optimized is $\mathrm{d} = \sum_{i=1}^{H} d_i^h + \sum_{i=H+1}^{N} d_i^s$, Suppose that the forward direction of the heterogeneous node is random, the objective function d is calculated from the left and right sides. If the total distance d calculated on the left side of the heterogeneous node is less than the right side, the heterogeneous node advances to the left; Otherwise, move forward to the right. Through this principle, heterogeneous node can finally effectively find the global optimal location.

The optimization steps of the algorithm expressed by mathematical model are as follows:

(1) When heterogeneous node is in any position, the direction of progress is random. In dimension D, the heterogeneous node orientation is represented and normalized to the vector.

$$b = \frac{\mathrm{rand}(D, 1)}{|\mathrm{rand}(D, 1)|} \tag{7}$$

(2) The position of the left and right sides of the heterogeneous node (x_{left}, x_{right}) can be expressed by the centroid position x^m and the distance d^m on both sides as:

$$\begin{cases} x_{right} = x^m + d^m \cdot b \\ x_{left} = x^m - d^m \cdot b \end{cases} \tag{8}$$

(3) According to the objective function $\mathrm{d} = \sum_{i=1}^{H} d_i^h + \sum_{i=H+1}^{N} d_i^s$, the total distance d on both sides of heterogeneous node is calculated, which are represented as $d\,(x_{left})$ and $d\,(x_{right})$. In order to simulate the beetle antennae search mechanism, the following location update iterative model is generated:

$$x^m = x^{m-1} + \delta^m \cdot b \cdot sign\left(d\left(x_{left}\right) - d\left(x_{left}\right)\right) \tag{9}$$

In Eq. (9), δ^m is the search step at time m.

(4) The update rule for the front progress length δ of heterogeneous nodes and the distance d on both sides is as follows

$$\begin{cases} d^m = d_e \cdot d^{m-1} + 0.01 \\ \delta^m = \delta_e \cdot \delta^{m-1} \end{cases} \tag{10}$$

In Eq. (10), d_e and δ_e represent the decreasing factors of d and δ, respectively.

Because BAS algorithm has excellent convergence speed and low complexity. It is very suitable for the optimization of heterogeneous node positions.

The simplified deployment diagram is shown in Fig. 4. Heterogeneous node is deployed at the location in the diagram, and heterogeneous node form a super link with sink node (as shown in the bold solid line in the figure). During data transmission, the cluster head nodes which are near the heterogeneous node transmits data to the heterogeneous node (as shown in the dashed line), and then the heterogeneous node transmits data to sink through the super link. Besides, the nodes near sink transmits data to sink (as shown in the thin solid line in the figure).

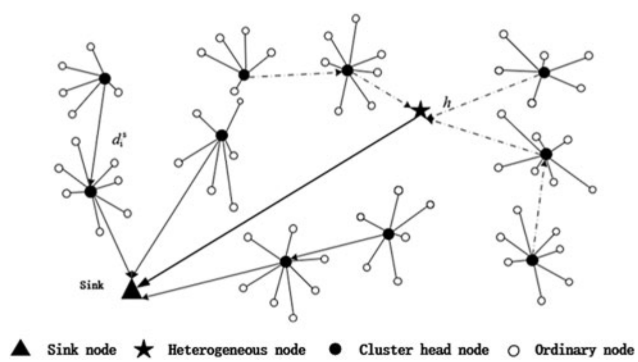


Figure 4: Deployment diagram of heterogeneous node in complex network

Finally, the minimum value $d_{\min}$ of the total distance d of all cluster heads that transmitting data to sink node is found through BAS algorithm. At this time, the location h (u_z, v_z) of heterogeneous node is the optimized location. Because the nodes which are selected as cluster heads are different after each round of clustering, the optimal location of heterogeneous node will change accordingly. Therefore, it is necessary to introduce BAS algorithm once after each round of clustering to find the optimal location of heterogeneous node in a new round and deploy heterogeneous node. The above steps are repeated in each round of DEEC algorithm until the end. The program flow chart of ODHN routing algorithm is shown in Fig. 5.

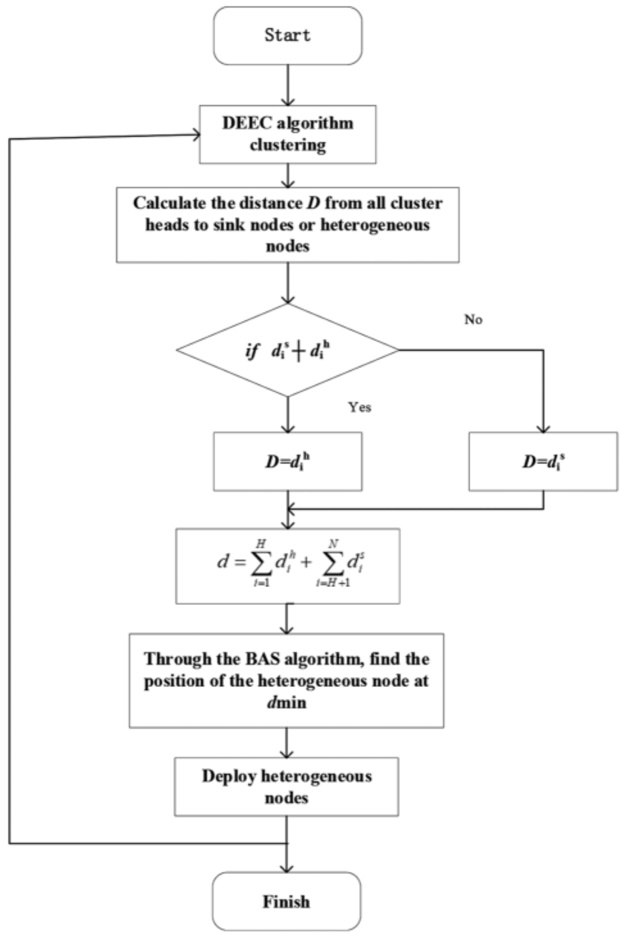


Figure 5: ODHN Program flow chart

3.4 Optimization Model of Heterogeneous Node Number

The cost should be considered when building heterogeneous sensor networks. The number of heterogeneous nodes can't be too many, but must meet the network performance requirements. In order to solve this problem, BAS algorithm is introduced after each round of clustering to find the optimal deployment location of heterogeneous nodes, so as to realize the location updating of heterogeneous node. Different from traditional methods of building a small world by fixed multiple heterogeneous nodes in WSN, a heterogeneous network is proposed according to the ODHN algorithm. Therefore, only one heterogeneous node can achieve good results, which not only saves the cost, but also optimizes the network structure.

4 ODHN Algorithm for Setting Moving Threshold

The movement of heterogeneous node will consume a lot of energy. In practical applications, real-time deployment can't be realized according to the optimal location of heterogeneous node after each round of clustering. Through experiments, the distribution of the optimal locations is concentrated in several regions. Most of the optimal positions are distributed in the area far from the sink node. This is because the area farther away from the sink node has more load, and heterogeneous node can be deployed there to balance the load. As shown in Fig. 6, the sink node is a red pentagram located at (50,50), and the optimal locations are small circular points, which are concentrated in the upper left and lower right regions. In this way, heterogeneous node can share part of the load in the network, make the network load more balanced, and greatly improve the transmission efficiency and life cycle.

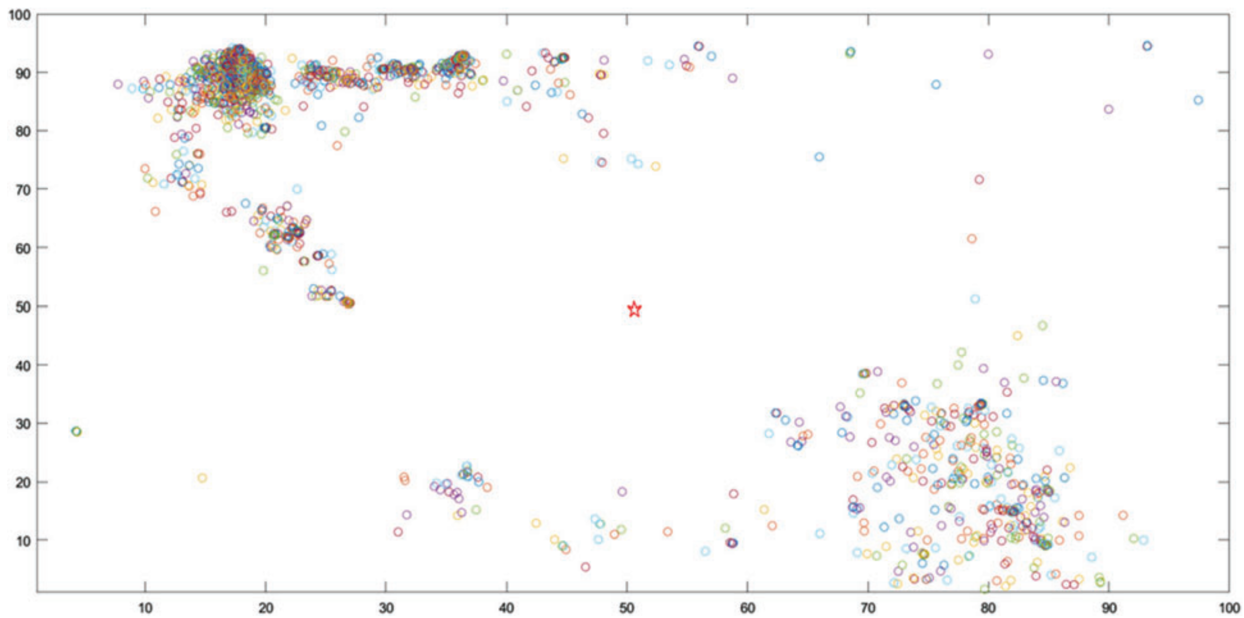


Figure 6: Optimal location distribution of heterogeneous nodes

Therefore, mobility threshold of heterogeneous node is set (ODHN-SMT algorithm). If the distance of the optimal locations is less than the threshold, the heterogeneous node will not move. On the contrary, heterogeneous node move to the optimal location of current round. As shown in Fig. 7, the distance between the heterogeneous node Y_2 in the second round and the heterogeneous node Y_1 in the first round is less than the threshold, so the heterogeneous node does not move. The position Y_2 is equal to the position of Y_1. The distance between Y_3 and Y_2 is greater than the threshold, so the heterogeneous node moves to the position Y_3.

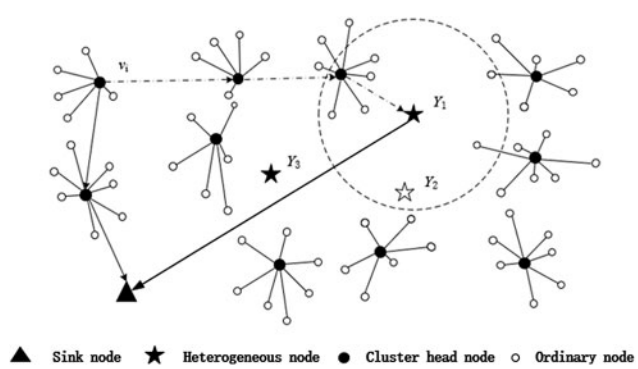


Figure 7: Heterogeneous node mobility diagram

If the threshold is too large, the frequency of heterogeneous node movement will be reduced, which can reduce energy consumption. But it will reduce the accuracy of the heterogeneous node location. Therefore, it will reduce the transmission efficiency and life cycle of the network.

On the contrary, if the threshold is too small, the frequency of heterogeneous node movement will increase and the system energy consumption will increase. But the accuracy of heterogeneous node location will also improve. So, the transmission efficiency and life cycle of the network will be improved.

Therefore, it is necessary to comprehensively consider the overall deployment cost and the invulnerability of the network. It is necessary to set an appropriate threshold. We conducted many experiments. According to the regional range of the optimal location obtained from the experiments, we get the movement threshold as 60 m which is shown in Fig. 8. The threshold setting should ensure that heterogeneous node will be distributed in a better area. After many experiments, we conclude that the threshold should be set to 50% ∼ 60% of the length or width of the experimental area.

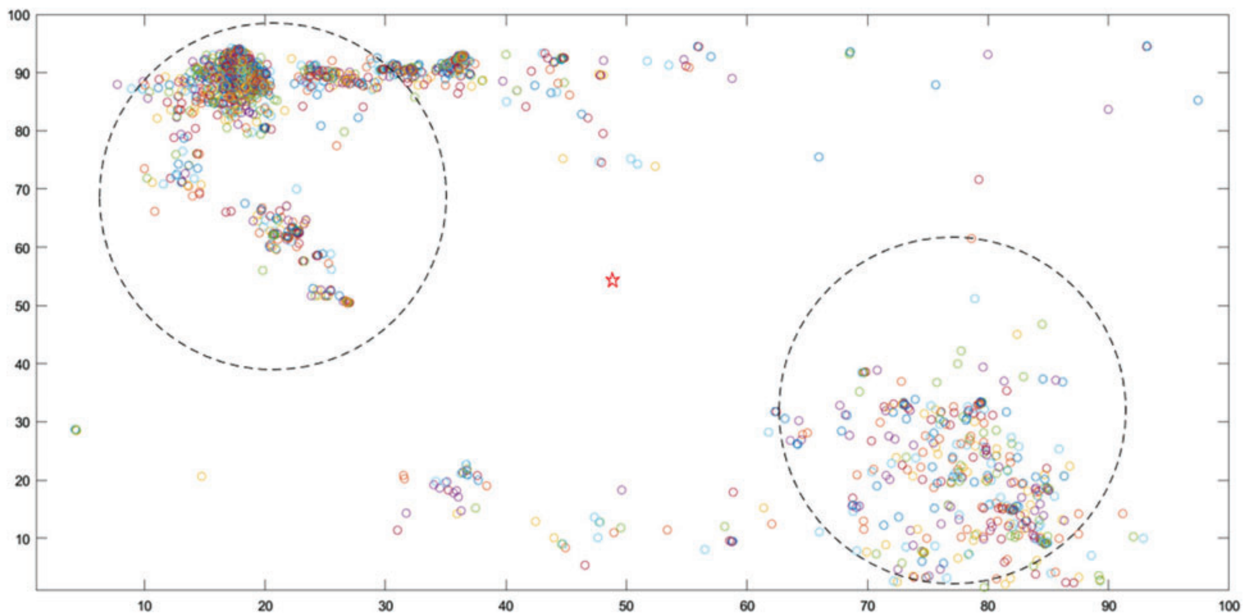


Figure 8: Heterogeneous node mobility threshold range

5 Simulation Results and Analysis

The ultimate goal of the algorithm is to improve the energy efficiency and prolong the life cycle of the network. In the simulation analysis, we compare the network in five aspects: the number of dead nodes (life cycle), the amount of data transmission, energy consumption, the number of cluster heads and load distribution.

We deploy 100 sensor nodes in the monitored area to simulate ODHN algorithm, ODHN-SMT algorithm and DEEC algorithm. Other conditions are set as follows.

1) The energy of ordinary nodes is limited. Sink node is located in the monitoring area, and the energy can be supplemented;
2) Each node has an independent ID number;

3) Each node has the ability to sense and transmit data.

The network simulation parameter settings are shown in Tab. 1.

Table 1: Network simulation parameters

Parameter name	Parameter value
Network area	100 m × 100 m
Number of nodes	100
Sink node coordinates	(50,50)
Number of routing execution rounds	5000
Node initial energy	0.5 J
Energy consumption ERX of transmitting ETX and receiving circuit	5 × 10^−8 J
Energy consumption of power amplifier circuit E_{mp}	1.3 × 10^−13 J

The number of dead nodes can intuitively display the length of the network life cycle. As shown in Fig. 9, the node death speed of ODHN algorithm is much slower than that of DEEC algorithm. The death of all nodes of ODHN algorithm is at round 4602, while in DEEC algorithm is at round 2957. So, the life cycle of ODHN algorithm is 55.6% longer than that of DEEC algorithm. The performance of ODHN-SMT algorithm with a moving threshold of 60 m is almost the same as that of ODHN algorithm without a moving threshold, which is within an acceptable range.

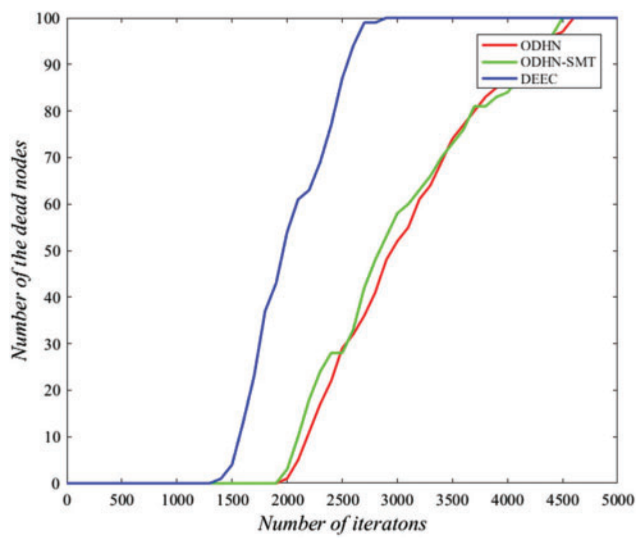


Figure 9: Comparison of network dead nodes

The amount of data transmission determines the accuracy and application way of data analysis. A large amount of data transmission can make the realization of functions more effective. Fig. 10 shows the data transmission volume of ODHN algorithm and DEEC algorithm. 182749 bits is transmitted by ODHN algorithm, which is 1.62 times data transmission volume than that of DEEC algorithm

(69653 bits). The transmission effect of ODHN-SMT algorithm is almost the same as that of ODHN algorithm.

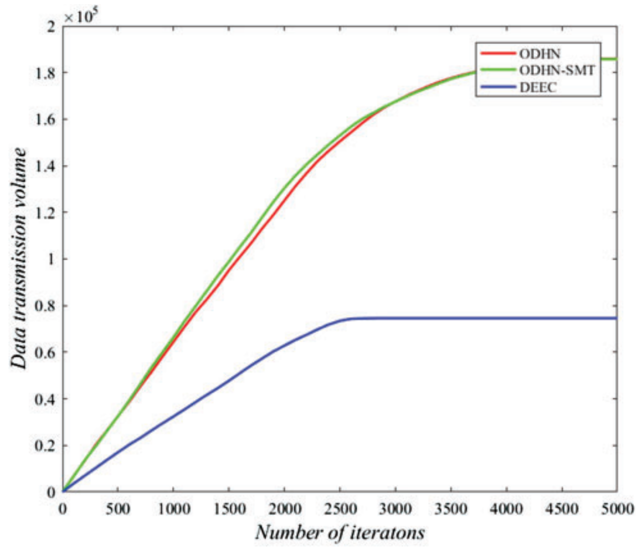


Figure 10: Comparison of network data transmission volume

The energy will gradually decrease over time until the nodes die. Reducing energy consumption can prolong the network life cycle. The comparison of energy consumption between ODHN algorithm and DEEC algorithm is shown in Fig. 11. The energy consumption of ODHN-SMT algorithm and ODHN algorithm is lower than DEEC algorithm by about 36.7%.

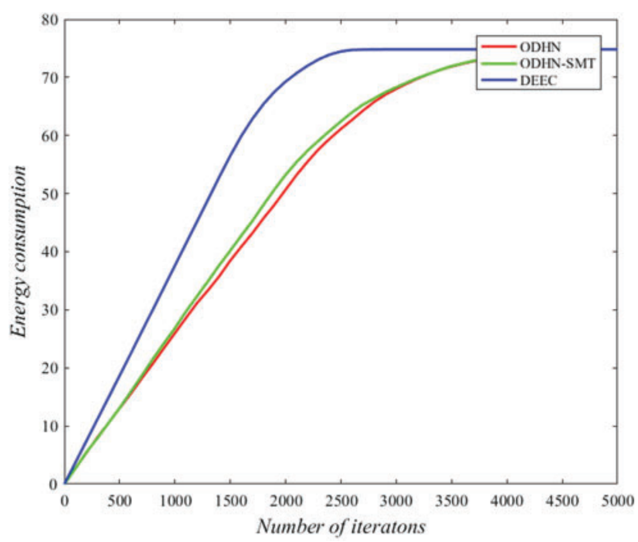


Figure 11: Comparison of network energy consumption

The cluster heads can not only aggregate the data of the member nodes, but also reduce the amount of data transmission and save energy consumption. Moreover, with the different selection of cluster heads, the transmission paths of these nodes will change accordingly, so that the energy is consumed evenly to improve the survival time of nodes. Therefore, the generation of cluster heads is of great significance. The comparison of the number of cluster heads produced by the ODHN algorithm, ODHN-SMT algorithm and DEEC algorithm is shown in Fig. 12. The number of cluster heads produced by the ODHN algorithm and ODHN-SMT algorithm is higher than that of the DEEC algorithm and the cluster heads have a longer survival time.

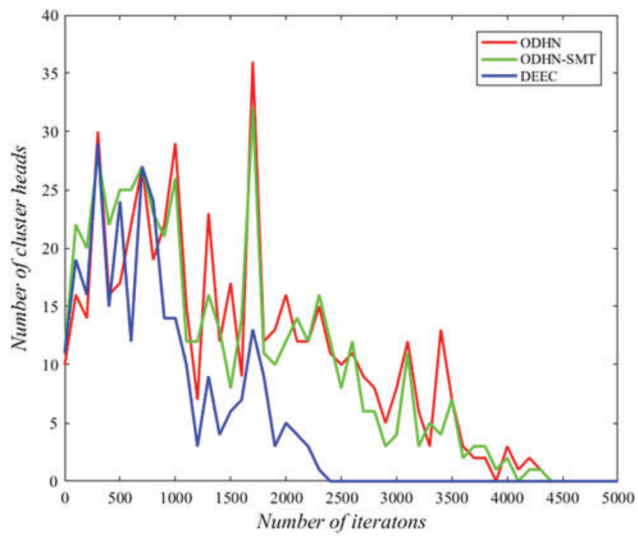


Figure 12: Comparison of network cluster heads

The load balanced degree is determined by the ratio of the number of member nodes in the cluster, the number of cluster heads and the total number of the sensor nodes. The more the number of cluster head nodes, the smaller the value of the balanced degree, which indicates that the network is more balanced. When the network load is balanced, the network operation efficiency is high, and the value of network load balanced degree is small and stable. When the network load is unbalanced, the operation efficiency decreases, and the value of network load balanced degree is large. As shown in Fig. 13, after the 2000 rounds of DEEC algorithm, the network load balanced degree began to soar, and after the 2600 rounds, the network completely failed. In ODHN algorithm and ODHN-SMT algorithm, after 3200 rounds, the network load balanced degree began to soar, and the network completely failed after the 4500 rounds. The essence of optimization scheme is to balance the network load, so as to improve the invulnerability of the network.

Nodes that close to the sink consume more energy because of more transmitting tasks. The cluster head node consumes too much energy because it needs to process and transmit the data uploaded by the member nodes. Because heterogeneous node is added, the cluster heads that near to the heterogeneous node can transmit data to heterogeneous node, and then the heterogeneous node transmit data to sink through super link. Therefore, the excessively fast energy consumption caused by unbalanced network load is solved.

100 sensor nodes are deployed in the monitoring area, as shown in Fig. 14. The red star in the figure is the cluster head node, the blue triangle is the sink node at the coordinates (50,50), the green star is the heterogeneous node at the coordinates (80,80) and the blue circle are the ordinary nodes with sufficient energy. It can be seen from Figs. 14a and 14b that the residual energy of the network is very different whether heterogeneous nodes are added or not.

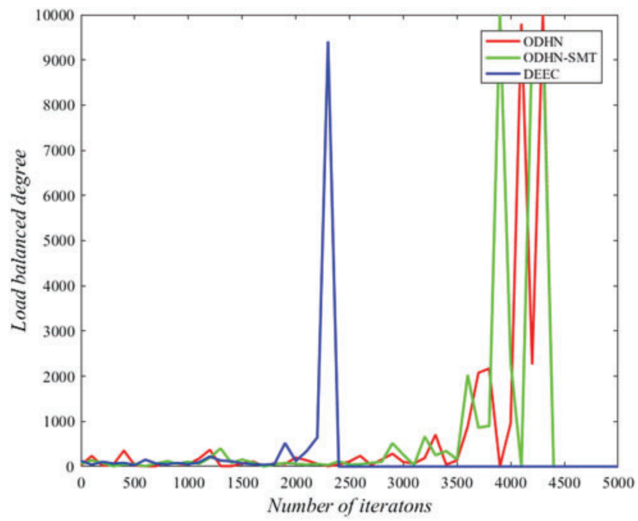


Figure 13: Comparison of network load balanced degree

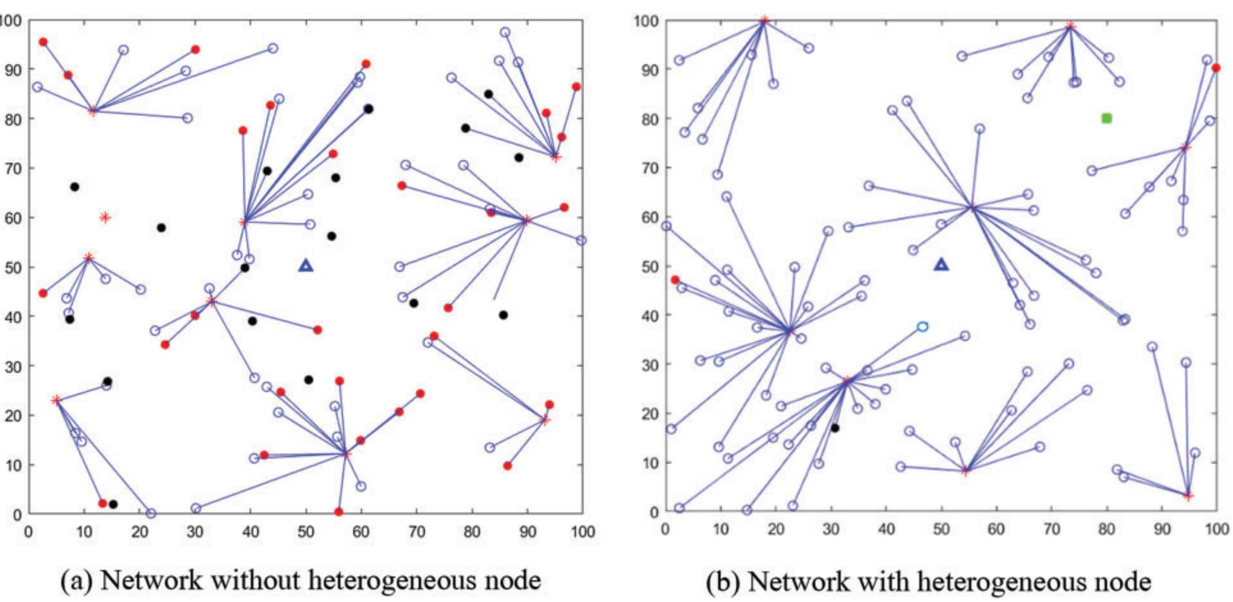


Figure 14: Comparison of network operation

As time passed, due to unbalanced energy consumption, some nodes consume energy more quickly, and their colors gradually change from blue to red. When the nodes die, they are represented in black.

The simulation results show that the network with heterogeneous node can balance the network load, and improve the connectivity between sensor nodes, which can greatly increase the life cycle of the network.

6 Conclusions

An optimal heterogeneous node deployment algorithm (ODHN algorithm) is proposed for clustering heterogeneous wireless sensor networks. By building a heterogeneous network model with small world characteristic, optimal deployment of heterogeneous nodes is studied, which can optimize the routing efficiency and communication efficiency of wireless sensor networks. In ODHN algorithm, cluster heads are selected in a probabilistic manner according to the ratio of the residual energy of each node to the average energy of the network. After each round of clustering, BAS algorithm is introduced to find the optimal deployment location of heterogeneous node, so as to realize the location update of heterogeneous nodes from the first round to the last round. However, in practical application, it is impossible to update the location of heterogeneous node at each round. Therefore, the heterogeneous node mobility threshold is defined, and an ODHN-SMT algorithm is proposed. The simulation results show that the algorithm can greatly prolong the life cycle and improve the invulnerability of the wireless sensor networks.

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