Construction of node deployment model for wireless sensor network based on fuzzy data fusion

LI ZHONG¹, a
¹Chengdu Polytechnic, Chengdu 610041, China
aemail: zl_cdu@cdut.edu.cn

Abstract: With the goal of increasing the coverage of wireless sensor network nodes and reducing node deployment time, a model of wireless sensor network node deployment based on fuzzy data fusion is designed. According to the wireless sensor network structure, the communication range and communication radius of the node are determined, so as to obtain the coverage of the node. Establishing a wireless sensor network coverage perception model to obtain the perception probability and joint perception probability of the target point. Finally, through fuzzy data fusion and fuzzy fusion rules, the fusion of the target node is realized, and the judgment criterion is obtained, and the deployment of the wireless sensor network node is finally completed under constraints. Experimental results show that this method effectively improves node coverage and reduces node deployment time, indicating that this method is beneficial to enhance the perception quality of wireless sensor networks.

1. Introduction

Wireless Sensor Networks (WSN) is a hot area of academic research in recent years, covering cutting-edge fields such as sensing, communication and electronics. Due to the advantages of self-organization and robustness, WSN are very suitable for obtaining the information of the monitored area by random placement in harsh environments [1-3]. As a result, problems such as monitoring holes and network connectivity caused by random sprinkling of nodes will seriously affect the normal operation of the network. The deployment of sensor nodes reflects the cost and performance of sensor networks, and a good deployment strategy can enhance the perceived quality of sensor networks and reduce costs [4]. Therefore, the deployment strategy of wireless sensor nodes is the first problem to be solved, which is directly related to the optimal allocation of node energy, communication bandwidth, computing processing capacity and other resources of WSN, and affects the perception, monitoring, communication and other quality of service objectives of WSN[5].

In this context, a large number of WSN node deployment methods have been proposed by relevant scholars. In reference [6], a ship WSN node deployment method for ocean monitoring is proposed. Firstly, the sensor distribution algorithm is used to model and analyze the distributed location of sensor network, and the accurate location parameters of wireless sensor are obtained. Secondly, the security node algorithm is introduced to calculate the mutual security of distributed network sensor signals to ensure the stability of the signal. Finally, QDP particle algorithm is introduced to optimize the target signal of sensor network nodes to maximize the effective utilization of deployment nodes. Experimental results show that this method can ensure the stability of network signal in the process of node deployment, but it has the problem of low coverage. Reference [7] introduced the Pareto multi-objective optimization strategy to the deployment of WSN nodes, and designed a multi-objective security optimization deployment plan. Establish a multi-target node
security deployment model, and take the node security connectivity and network coverage as the objective function, taking into account the problem of network security and network coverage quality. The multi-objective particle swarm algorithm is improved through the adaptive adjustment of inertia weight and the update speed of the virtual force algorithm, and the elite archive strategy is used to store non-inferior solutions. The simulation experiment results show that this method can maintain a large node security connectivity, but it has the problem of long deployment time. Reference [8] proposed a method of sensor node deployment based on chaotic optimization of bacterial foraging algorithm. First, the effective coverage of nodes, node idle rate and residual energy balance function are used as optimization factors to construct a comprehensive optimization model of objective function. In the optimization stage, set the flora density function factor, the bacterial wall rebound factor, the trend sequence of chaotic disturbance, the dynamic trend step size, the flora crossover and mutation operator, and the dynamic bacterial migration probability to improve the bacterial foraging algorithm to improve the optimization efficiency. Simulation results show that the improved chaotic bacterial foraging optimization method can effectively optimize the node coverage of WSNs, but this method also has the problem of low node deployment efficiency.

Aiming at the problems of traditional methods, the main goal is to improve the overall coverage of the network, while taking into account deployment efficiency and implementation feasibility, and build a WSN node deployment model based on fuzzy data fusion.

2. WSN node deployment model

2.1. WSN structure

The WSN is generally composed of three nodes with different structures and functions, which are ordinary sensor points, sink nodes and task management nodes. Among them, ordinary sensor nodes are nodes that are widely deployed in the monitoring area and are responsible for collecting the information of the monitored area [9]. The data collected from the monitoring area cannot be processed and stored on ordinary sensor nodes and then obtained. This requires the use of aggregation, which can collect data on ordinary sensor nodes. The data on the sensor node is transmitted to the local aggregation node through routing in the sensor network, and then transmitted to the task management node with powerful processing and storage capabilities and far away from the monitoring area through mobile wireless networks such as GPRS [10].

The structure of WSN nodes will vary due to different application environments and application requirements, but they can basically be divided into four major functional units, namely sensing unit, processing unit, wireless communication unit and energy supply unit [11]. Among them, the sensing unit is responsible for collecting relevant variables in the monitoring area, and converting these variables into numbers and passing them to the processing unit; the processing unit is the core of the entire node, responsible for managing all hardware resources on the node, and processing data; the wireless communication unit is responsible for the reception and transmission of data in the network; the energy supply unit provides electrical energy for the entire node to ensure the normal operation of the node.

2.2. Node coverage determination

In order to solve the problem of WSN node deployment, the communication range and communication radius of the node must first be determined. The node communication range refers to the area covered by the node's broadcast information, and only the neighboring nodes within the node's broadcast coverage can receive the node's broadcast information [12]. Similarly, due to the limited resources of the node, the communication range of the node is also very limited. The node communication range can also be idealized as a plane circle with radius $r$, then $r$ is the communication radius. The size of the communication radius has an important influence on the connectivity of the network. The larger the communication radius of the node, the more likely the connectivity of the network will be
strengthened. In addition, there is also a certain connection between the monitoring radius $r_a$ of the node and the communication radius $r_i$ of the node. If the node monitoring radius is greater than or equal to the node communication radius, when the network monitoring area reaches full coverage, the nodes in the network cannot reach connectivity [13]. When the communication radius $r_i$ is greater than or equal to twice the monitoring radius $r_a$, and the monitoring area reaches full coverage, the network must be a connected network, otherwise it cannot be determined that the network must be a connected network.

Node coverage is an important indicator to measure the monitoring range of a network. It is the proportion of the total area covered by all nodes in the network to the total area of the monitored area. The larger the ratio is, the better the coverage effect is. The specific calculation formula is as follows:

$$S = \frac{(c_s \times r_a) + (1 + r_i / r)}{S_n}$$  \hspace{1cm} (1)$$

Among them, $n$ represents the number of nodes in the network; $c_s$ represents the coverage area of the $k$ node in the network; and represents the proportion of the total area of the monitored area. Because the coverage of nodes in the network will overlap, it is necessary to calculate the union of the coverage areas of all nodes.

2.3. Coverage perception model of WSN

Set in the WSN two-dimensional plane deployment area, $N$ network nodes with the same sensing radius $r_s$ and communication radius $r_i$ are randomly deployed in the area. Suppose the node set is $K = \{k_1, k_2, ... , k_n\}$, and the position coordinates of node $k_i$ are denoted as $(x_{ik}, y_{ik})$. During the initial deployment, an appropriate WSN key distribution scheme is adopted for key distribution, so that there is a shared key between neighboring nodes to establish a secure connection.

Discretize the deployment area to form $m \times n$ target point set $G = \{g_1, g_2, ..., g_{m \times n}\}$, where the position coordinate of target point $g_i$ is denoted as $(x_{ig}, y_{ig})$, then the Euclidean distance between target point $g_i$ and node $k_i$ is:

$$D(g_i, k_i) = \sqrt{(x_{ik} - x_{ig})^2 + (y_{ik} - y_{ig})^2}$$  \hspace{1cm} (2)$$

Then the perception probability of node $k_i$ to target point $g_i$ is:

$$p(k_i, g_i) = \begin{cases} 1 & D(g_i, k_i) \leq r_i \\ 0 & \text{other} \end{cases}$$  \hspace{1cm} (3)$$

According to formula (3), if the distance from target point $g_i$ to node $k_i$ is less than or equal to the node's sensing radius, namely $D(g_i, k_i) \leq r_i$, the sensing probability of node $k_i$ to target point $g_i$ is 1, and the target point can be covered by the node; Otherwise, the perception probability of node $k_i$ to target point $g_i$ is 0, that is, the target point is not covered by the node.

At this point, the joint perception probability of target point $g_i$ is obtained, which is the union of the coverage ratios of node set $K = \{k_1, k_2, ..., k_n\}$ to target point $g_i$:

$$K(g_i) = \sum_{i=1}^{n} \sum_{j=1}^{n} (I_i^j - I_2^j)$$  \hspace{1cm} (4)$$

Only if the target point is covered by any node in the node set, the joint perception probability of the target point is 1, otherwise the joint perception probability is 0.
Assuming that the coverage area of all target points is $\Delta m \times \Delta n$, if the target point is covered, the joint perception probability of the target point is 1, and the coverage area is $\Delta m \times \Delta n$; otherwise, it is 0, and the coverage area of the target point can be expressed as $e \times (\Delta m \times \Delta n)$. After a node is deployed, the ratio of the area covered by the node to the total area of the deployment area is called the node coverage, and its calculation formula is:

$$F = \frac{e_{k_i}}{\sum_{i=1}^{n} e_{w_i} g_i}$$

(5)

Among them, $e_{w_i}$ represents the total area of the deployment area; $e_i$ represents the total area covered by the node.

2.4. Implementation of sensor network node deployment based on fuzzy data fusion

Uncertain coverage is a key issue in WSN. The current methods for studying uncertain coverage are mainly based on mathematical statistics and probability theory. However, in practical applications, the credibility of node detection is related to the distance of the detection target, the characteristics of the detection target and the surrounding environmental conditions, and the value of the credibility varies between 0 and 1 [14]. The sensing ability of sensing nodes has no obvious precise boundary, and the sensing ability changes with time, which shows the fuzzy characteristics of sensor sensing ability, and fuzzy theory has unique advantages in dealing with uncertain problems and targets with fuzzy characteristics [15]. Therefore, the deployment of sensor network nodes is realized through fuzzy data fusion.

In WSN, data fusion system is mainly detection level fusion in numerical fusion, which is composed of data fusion node and detection node. Each detection node detects separately, and transmits the detection results to the data fusion node. Finally, the fusion node makes the final decision. Assuming that there are $l$ fuzzy nodes in a data fusion unit, the set of influencing factors of fuzzy node $l$ on the target node is $O_l$, and the weight set of the influencing result is $J_l$. According to the fuzzy fusion rules, the network fusion result of the target node is:

$$C_{o,l} = \begin{cases} O_l, & P_1 > P_2 \\ J_l, & P_1 < P_2 \end{cases}$$

(6)

According to formula (6), the result evaluation set of the network on the target node can be obtained as:

$$H = P_1 \times P_2$$

(7)

Then the perception index of the WSN to the target node is:

$$b(H) = |H|$$

(8)

According to the detection result of the WSN on the target node, according to the fuzzy theory, the judgment criterion is as follows:

$$\varphi(H) = \begin{cases} 1 & b(H) \geq t \\ 0 & b(H) < t \end{cases}$$

(9)

Among them, $t$ represents the decision threshold of the fusion node.

Restricted by certain factors, the location of the target node greatly affects the detection of the target node by the WSN. Therefore, the information related to the target can be fully utilized to design the wireless sensor node deployment algorithm, which greatly improves the deployment of network nodes. effectiveness. For those target nodes whose distribution is related to location, use the prior probability of the target distribution in the detection area and the factors that influence the detection result of the environment where the target node is located. Combining the fuzzy perception model and the data fusion model, a node deployment method based on fuzzy data fusion is proposed. The specific
5

Implementation steps of the method are as follows:

Step 1: According to the distribution probability of the target node in the detection area and environmental influence factors, divide the detection area into \( (v_1, v_2, ..., v_n) \);

Step 2: For the detection block \( v_i \), where \( 0 < i \leq 1 \), determine the fuzzy perception model of the sensing node in the detection block, and calculate the fuzzy perception radius of the detection block according to the fuzzy perception model, the optimal distance between each node and the threshold;

Step 3: According to the coverage requirements of the detection block and the fuzzy perception radius of the sensing node, calculate the node deployment density \( \rho_i \) and node redundancy \( \zeta_i \) of the detection block;

Step 4: Randomly throw \( N_i \) perceptual nodes in the detection block;

Step 5: For the detection block, randomly wake up \( N_i \) sensing nodes, set their flag bit flag=0, and the remaining nodes enter the sleep state;

Step 6: In the detection block \( N_i \), randomly select a sensing node in an awake state, make its flag=1, select the sensing node with the closest distance, and calculate the distance \( d \) between the two nodes;

Step 7: If the node distance \( d \) satisfies:

\[
D - t \leq d \leq D + t \tag{10}
\]

Set the node's flag bit flag=1, and proceed to step 10 operation, otherwise proceed to step 8 operation;

Step 8: If the node distance \( d \) satisfies \( d \leq D + t \), the resultant force between the sensing nodes is repulsive force, and the node moves away by one unit, then go to step 7, otherwise, go to step 9;

Step 9: If the node distance \( d \) satisfies \( d > D + t \), the resultant force between the nodes is perceived as gravitational force, the node moves closer by one unit, and then step 7;

Step 10: Select the node closest to the adjustment node and marked as 0, repeat step 7 to step 9, until all nodes are adjusted, and the detection block is deployed;

Step 11: Repeat step 6 to step 10 to adjust the sensing nodes in all detection blocks until all the detection blocks are adjusted and all detection area nodes are deployed;

Step 12: The network enters the dynamic adjustment stage. Once the node dies, select the sleeping node closest to the dead node, move to the location of the dead node and wake up, until all nodes die, and the life of the network ends.

According to the above steps, the effective deployment of all WSN nodes is completed.

3. Experiments

In order to verify the performance of the WSN node deployment model based on fuzzy data fusion, experimental analysis is carried out. First, set up the experimental environment. In the set experimental environment, starting from two aspects of node coverage and deployment time, compare the deployment performance of different methods.

3.1 Simulation experiment environment and parameter setting

Use Matlab2011 to simulate the proposed method, and compare the related methods in the same simulation environment. The comparison methods are the deployment method of ship WSN nodes for marine monitoring (Method 2) and the multi-objective security optimization deployment method of WSN nodes (Method 3). The above methods are compared with the method in this paper (Method 1).

The simulated monitoring area is a rectangular area with a side length of 100m×100m, in which 225 wireless sensor nodes are randomly scattered. The nodes are normally distributed in the monitoring area, and the initial coverage rate is 21%. The specific parameters are shown in the following table 1:
Perform performance tests on different methods according to the above parameters, and the test results are as follows.

3.2 Result analysis
Firstly, the node coverage test is carried out, and the maximum optimization times is set to 50 times. In order to verify the effectiveness of the proposed method, the node coverage under different methods will be tested under the same initial random deployment state, and the results are shown in Figure 1.

![Comparison results of node coverage of different methods](image)

Figure 1 Comparison results of node coverage of different methods

Analysis of Figure 1 shows that the method proposed in this paper has obvious advantages in node coverage compared with traditional methods. The method in this paper effectively improves the influence of interference between clusters in the deployment process. At the same time, it also has a good effect on the virtual force cancellation phenomenon caused by too many nodes and too dense, thus improving the coverage of WSN nodes.

The deployment time is used as an experimental indicator to further verify the deployment effect of the method in this paper. The specific results are shown in Figure 2.
Figure 2 Comparison of deployment time of different methods

Analysis of Figure 2 shows that the deployment time of this method for WSN is always lower than that of methods 2 and 3, indicating that this method will consume less time in node deployment and effectively improve the problem of low deployment efficiency of traditional methods. The method in this paper has high application value.

To sum up, this method can not only improve the deployment efficiency of nodes, but also has a larger coverage of nodes, effectively improves the effectiveness and reliability of network node deployment, and has better detection ability for target nodes. The above experiments verify the effectiveness and superiority of this method.

4. Conclusion
In order to solve the problems of low node coverage and long node deployment time in traditional methods, a method for constructing a WSN node deployment model based on fuzzy data fusion is proposed. Through the establishment of a WSN node perception model and fuzzy data fusion model, the corresponding deployment strategy of wireless sensor nodes is proposed. The simulation results show that the method in this paper can reduce the deployment time while meeting the coverage requirements, thereby expanding the network coverage and improving the detection performance of the network. In the future, will optimize the model in this paper on this basis, and try to use other fusion strategies to optimize the three-dimensional deployment algorithm of wireless sensor nodes to make it more efficient.

References
[1] Weizheng L, Xiumei T. Quality analysis of multi-sensor intrusion detection node deployment in homogeneous wireless sensor networks. Journal of supercomputing, 2020, 76(2):1331-1341.
[2] Li Q, Yi Q, Tang R, et al. A Hybrid Optimization from Two Virtual Physical Force Algorithms for Dynamic Node Deployment in WSN Applications. Sensors, 2019, 19(23):5108.
[3] Domga R K, Stanica R, Tchuente M, et al. Sensor deployment in wireless sensor networks with linear topology using virtual node concept. Wireless Networks, 2019, 25(8):4947-4962.
[4] Nasri N, Mnasri S, Val T. 3D node deployment strategies prediction in wireless sensors network. International Journal of Electronics, 2020, 107(5):808-838.
[5] Mishra R, Jha V, Tripathi R K, et al. Corona based node distribution scheme targeting energy balancing in wireless sensor networks for the sensors having limited sensing range. Wireless Networks, 2020, 26(2):879-896.
[6] Zhang X F. Optimizing the deployment method of ship wireless sensor network node for ocean monitoring. Ship Science and Technology, 2019, 41(20):149-151.
[7] Sun Z W, Shen D. Multi Objective Security Optimization Nodes Deployment for Wireless Sensor Network. Chinese Journal of Sensors and Actuators, 2018, 31(12):106-112.
[8] Wang Z D, Cheng E L, Hu Z D. Sensor Node Deployment Strategy of Chaotic Optimization of Bacterial Foraging Algorithm. Chinese Journal of Sensors and Actuators, 2018, 31(01):110-118.

[9] Du R, Xiao M, Fischione C. Optimal Node Deployment and Energy Provision for Wirelessly Powered Sensor Networks. IEEE Journal on Selected Areas in Communications, 2019, 37(2):407-423.

[10] Yu Z, Tang R, Yuan K, et al. Investigation of Parameter Effects on Virtual-Spring-Force Algorithm for Wireless-Sensor-Network Applications. Sensors, 2019, 19(14):3082.

[11] Lin T L, Chang H Y, Wang Y H. A Novel Hybrid Search and Remove Strategy for Power Balance Wireless Charger Deployment in Wireless Rechargeable Sensor Networks. Energies, 2020, 13(10):2661.

[12] Demetri S, Picco G P, Bruzzone L. LaPS: LiDAR-assisted Placement of Wireless Sensor Networks in Forests. ACM Transactions on Sensor Networks, 2019, 15(2):1-40.

[13] Hoyingcharoen P, Teerapabkajorndet W. Expected Probabilistic Detection and Sink Connectivity in Wireless Sensor Networks. IEEE sensors journal, 2019, 19(12):4480-4493.

[14] Awad F H. Optimization of relay node deployment for multisource multipath routing in Wireless Multimedia Sensor Networks using Gaussian distribution. Computer networks, 2018, 145(11):96-106.

[15] Anzani M, Javadi H H S, Modirir V. Key-management scheme for wireless sensor networks based on merging blocks of symmetric design. Wireless Networks, 2018, 24(8):2867-2879.