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Area Coverage Optimization of Wireless Sensor Networks Based on Bee Colony

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Abstract. As a kind of self-organizing network with limited energy, wireless sensor network is generally deployed in the area where the environment is bad or the personnel are difficult to reach. The unbalanced energy consumption of nodes will lead to premature network failure, low energy utilization rate of nodes and reduced network coverage rate, which will seriously affect network performance. This paper mainly studies the area coverage optimization of wireless sensor network based on bee colony. In this paper, an artificial bee colony algorithm based on extrapolation is proposed to optimize the network coverage deployment. In order to improve the convergence speed and accuracy of the artificial bee colony algorithm, the extrapolation artificial bee colony algorithm introduces the extrapolation process into the artificial bee colony algorithm and constructs the following bee phase based on the extrapolation process. The simulation results show that the proposed algorithm not only improves the coverage optimization effect, speeds up the convergence speed of the algorithm, but also reduces the travel distance of the nodes, which is suitable for the wireless sensor network optimization with higher requirements for perceptual quality.

1. Introduction

Wireless sensor network is a multi-hop wireless network formed by the self-organization of a large number of sensor nodes. It has the ability of data acquisition, processing, fusion and transmission, and integrates advanced technologies such as microelectronics, embedded, network, wireless communication and distributed information processing. It is a multidisciplinary technology [1]. Wireless sensor network is an emerging technology after the Internet, which has had a huge impact on the way of life and work of human beings. It connects the physical world and the virtual network through sensor nodes, and makes the network everywhere. Wireless sensor network has broadened the way of human interaction with nature, greatly improved human cognitive ability, has

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a broad application prospect and practical value, has aroused the attention of academia and industry, is considered to be one of the most influential technologies in the 21st century. Wireless sensor network can effectively improve the human ability to understand the relevant physical information in the target area through the transmission network, and the next generation network will also provide more direct, effective and reliable information. Wireless sensor network does not need the support of fixed network, can autonomously complete the monitoring task of the corresponding area without human intervention, so that it can work in the harsh or unreachable environment, reduce unnecessary manpower consumption and ensure the safety of the witness. After sensor nodes are deployed in the specified sensing area, through self-organization into a network, sensor nodes (referred to as "nodes" for short) can establish communication paths with their neighbor nodes, maintain communication directly or indirectly with the sink node, and then transmit the perceived relevant information to the sink node. Therefore, the connectivity of the network and the coverage of the nodes to the specified area are the most basic requirements to ensure the network function [2-3].

Optimal node deployment is a challenging problem. This problem has been shown to be NP-hard in many sensor deployment configurations [4]. The node deployment problem can be divided into static deployment and dynamic deployment according to whether the deployment occurs while the network is running. The node structure of traditional wireless sensor network is generally composed of ordinary node and sink node. The ordinary node is responsible for information perception and multi-hop transmission, while the sink node acts as the gateway and the interface with the outside world [5]. With the deepening of the research, scholars have found that even if many strategies are adopted to optimize the performance of traditional wireless sensor network, the improvement degree is still limited. Therefore, some relevant scholars suggest adding some nodes with better performance to make the network more fully meet the application requirements. According to the different components of wireless sensor network nodes, the network can be divided into isomorphic network and heterogeneous network [6].

In this paper, the artificial bee colony algorithm is studied and improved in depth, and a new solution is provided for WSN node deployment. From the deployment level, WSN can provide better service quality when applied in various fields.

2. Wireless Sensor Area Coverage Optimization

2.1. Overview of Network Coverage Related

Wireless sensor network is usually deployed in a designated area to monitor the occurrence of some of these events. To ensure that all the events in the area can be sensed, the coverage of the network to the monitoring area must meet certain requirements, which makes the coverage of the network become one of the important indicators of network service quality [7]. The perception models of perception nodes mainly include Boolean directed perception model, Boolean disk perception model and probability perception model. Factors to be considered in the design of coverage algorithm mainly include coverage type, node deployment mode, network coverage, network coverage ratio, activation strategy and network connectivity [8].

(1) Coverage Type

It mainly includes three kinds: area coverage, target coverage and fence coverage. Target coverage only requires that the network can cover a number of discrete target locations in the region, while regional coverage requires that the sensor network can cover every location in the region. The targets in the target coverage problem can be some location areas in the deployment area, or can represent some special physical targets in the monitoring area (such as missile reflectors in the battlefield). Fence covering refers to the construction of a fence to detect intrusion or find a covering path through the whole area [9].

(2) Node Deployment Mode

Under different application backgrounds and environments, sensor networks have different deployment methods, including deterministic deployment and random deployment. Deterministic deployment is to deploy each node at a specified location, while in random deployment, sensor nodes are randomly distributed in the monitoring area.

(3) Network Coverage

Network coverage refers to the minimum number of times any location in the region is covered by nodes. Repeated coverage of the same position through different nodes can increase the coverage robustness of the network. For example, in the Boolean disk perception model, when the network coverage is k, the network can still guarantee the coverage of the region after the failure of k-1 nodes.

(4) Network Coverage

Coverage ratio refers to the ratio of areas or target locations in the monitoring area that can be covered by the network and meet the coverage requirements. If 80 out of 100 target locations in the area can be covered by the network, then the coverage ratio of the network at this time is 80%. Full coverage is when the coverage ratio is 100%.

(5) Activation Strategy

In order to ensure the effectiveness of the algorithm and improve the life cycle of the network, the algorithm usually needs to make the nodes activate or sleep their functional modules regularly. For example, in regional coverage, when a region can be covered by multiple nodes, only one node needs to be active to perceive covering the corresponding region, while other nodes can sleep to save energy, and then the nodes take turns to work to extend the coverage period of the region.

(6) Network Connectivity

After the sensing node collects the relevant information, the information needs to be transmitted to the sink node in a multi-hop way. In order to ensure the transmission of information, the node and sink must be connected, that is, to ensure the connectivity of the network [10]. As an important aspect of topology control, network coverage and connectivity often need to be considered to ensure the realization of network functions.

2.2. Artificial Swarm Algorithm Optimization Strategy

Artificial bee colony algorithm is simple and easy to implement in structure, has few control parameters, and has low requirement on the form of the target problem. However, this algorithm also has all the disadvantages of most swarm intelligence algorithms, such as strong randomness and slow convergence of candidate formulas [11-12]. The extrapolation method can lead the algorithm to accelerate to a better direction and improve the convergence speed. Therefore, this paper introduces the extrapolation method into the artificial bee colony algorithm, so as to improve the local exploration ability of the artificial bee colony algorithm and accelerate the convergence speed of the algorithm.

(1) New Nectar Search Formula of Scout Bees

When a food source is not renewed after multiple explorations, scouts are lost in the colony. The scout bees generate a new food source through Equation (1) and then transform into hire bees. The new solution generation process of scout bees ensures the diversity of the population and increases the possibility of obtaining the global optimal solution.

$$x_{ij} = x_j^{\min} + r_{ij} \times (x_j^{\max} - x_j^{\min}) \quad (1)$$

(2) The Following Bee Stage Based on Extrapolation

In artificial bee colony algorithm, hiring bees are generally responsible for global exploration, while scouting bees are responsible for population diversity. The main task of following bees is to explore more solutions with good quality, so as to accelerate algorithm convergence and improve the accuracy of solutions. It has been pointed out in many literatures that the global optimization ability of artificial bee colony algorithm is very strong, but the convergence ability is weak because the hired bees and the following bees adopt the same candidate solution generation equation. The process of following bee stage based on extrapolation method is presented below.

Step 1: First generate the candidate solution UI of the original solution XI.

Step 2: Calculate the fitness values FITX and FITU of the original solution and the candidate solution.

Step 3: If FITX = FITU, the number of times the current food source has not been updated limit increases by 1, and then stop the algorithm output result.

Step 4: If FITX < FITU, then:

$$x_{2j} = x_{ij},\ f(x_2) = fit_x,\ x_{1j} = u_{ij},\ f(x_1) = fit_u \quad (2)$$

Step 5: If FITX > FITU, then:

$$x_{1j} = x_{ij},\ f(x_1) = fit_x,\ x_{2j} = u_{ij},\ f(x_2) = fit_u \quad (3)$$

Step 6: Iterate with extrapolation method to obtain x1j and f(x1). It is harder to control the boundary. If the algorithm exceeds the boundary, it is harder to stop at the boundary.

Xij =x1j, fitx= f(x1), otherwise the number of times the food source has not been updated limit increases by 1.

(3) Overlay the Optimal Deployment Strategy

In the study, each food source was composed of a set of selected sensor coordinates, and all food sources contained the same number of sensors. The dimension D is the number of sensors contained in the food source. When bees explore food sources to find new food sources, they calculate the coordinates of two sensors to find a new sensor coordinate. If no sensor exists at the generated new sensor coordinate position, select the sensor nearest to the point.

Step 1: Parameters such as population number, dimension, maximum number of cycles MaxITR and food source unupdated times Limit were initialized. The proportion of employee bees and follower bees is 50%, the scout bee is set as 1, and the fitness value is set as the network coverage.

Step 2: Generate the initial random solution to form the initial food source;

Step 3: Calculate the coverage rate of each sensor to each pixel, and then calculate the total coverage rate Rarea(S);

Step 4: Hiring bees. Calculate the candidate values, and reserve the better solution through greedy selection.

Step 5: Calculate the probability that each food source will be selected by the following bees;

Step 6: In the following bee stage, the extrapolated following bee optimization method was adopted.

Step 7: Detection bee stage. When the number of unupdated food source reaches the limit, initialize the food source.

Step 8: The node layout of the food sources in the memory coverage.

Step 9: Increase the number of cycles by 1;

Step 10: If the number of loops is exceeded, return the persah best fit value, and the program ends. Otherwise, go back to Step 4.

In an algorithm iteration, the time complexity of coverage optimization based on the extrapolated artificial bee colony algorithm is $O(\varepsilon \cdot PS \cdot D)$, which is the number of extrapolated iterations. In the study, its average value is 3 times. The time complexity is relative to $O(PS \cdot D)$ of the original artificial bee colony algorithm.

3. Simulation Experiment

3.1. Experimental Environment

All experiments in this paper are simulated under Matlab 2016. The computer configuration is as follows: i5 processor with main frequency of 3.3GHz, memory of 8G, and operating system Windows 10 with 64-bit.

3.2. Experimental Data

In order to verify the optimization effect of the optimized colony coverage optimization algorithm, comparative experiments were conducted with ABC and PSO coverage optimization algorithms. 200 sensor nodes with a sensing radius of 5m were randomly deployed in a square monitoring area with a side length of 100m, among which 70 were static nodes and 30 were mobile nodes. The mesh unit of the grid evaluation method was 4m, and the binary perception model was used.

4. Simulation Experiment Results and Analysis

4.1. Performance Comparison of Different Algorithms

Table 1. Comparison of iteration times and time consuming of different algorithms

	Number of convergent iterations	Computing time(s)
ABC	817	28.59
PSO	609	10.36
OABC	9	5.21

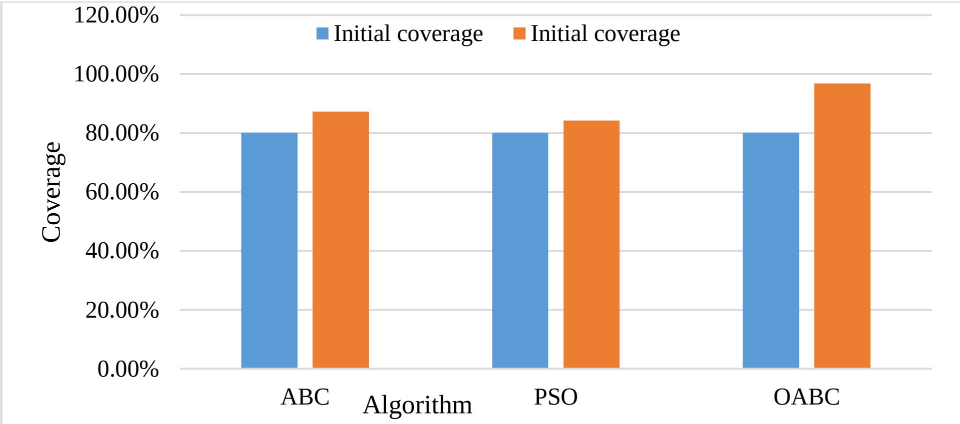

Figure 1. Coverage after optimization of different algorithms

As shown in Table 1 and Figure 1, after 50 independent runs of the three algorithms, the coverage rate of the optimized OABC algorithm reaches 96.76%, which is 9.56% and 12.55% higher than that of ABC and PSO algorithm respectively. The reason is that the OABC coverage optimization algorithm significantly increases the diversity of understanding vectors. Moreover, the new position update formula has a strong global search ability, which improves the robustness and global search ability, while ABC and PSO algorithms fall into the local optimal solution. In terms of convergence speed and calculation time, OABC algorithm is also better than the other two algorithms in an overall way. The number of convergence iterations of OABC is only 9, far lower than the 609 times of PSO and 817 times of ABC. The calculation time of OABC was only 5.21 seconds.

4.2. Node Move Location Selection Policy

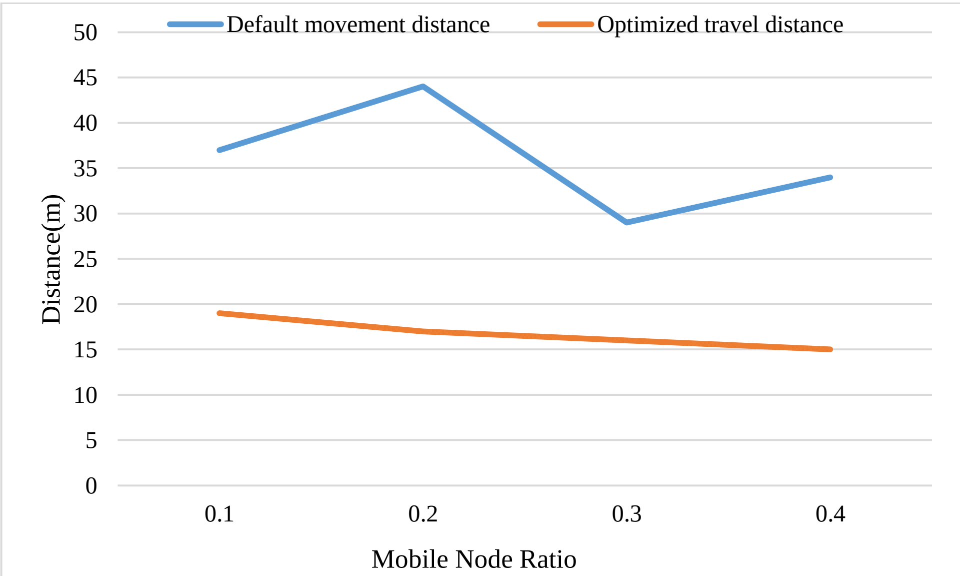

Figure 2. Average moving distance of mobile nodes in different proportions

As shown in Figure2, the average moving distance of nodes was reduced after the strategy was selected to verify the use of node moving position. The total number of nodes was 100, the ratio of mobile nodes was 0.1, 0.2, 0.3, 0.4, and the GCABC parameters were unchanged for 9 iterations. The average travel distance of nodes in different proportions is greatly reduced, which effectively reduces the energy consumption of nodes and prolongs the network life cycle.

5. Conclusion

In regional coverage, perceived quality is an important embodiment of network service quality. At present, researchers mainly use mobile node experiment network dynamic deployment. In order to improve the network performance, this paper deals with the area coverage optimization problem for the randomly deployed and incomplete wireless sensor networks. In this paper, an artificial bee colony algorithm based on extrapolation is proposed for the shortcomings of slow convergence and low precision of artificial bee colony algorithm. In the hiring and scouting stages, the algorithm still uses part of the original artificial bee colony algorithm to maintain the global optimization ability and species diversity of the algorithm itself. In the following stage, the process based on extrapolation strategy is adopted to accelerate the convergence speed and improve the accuracy of the algorithm. Due to my limited ability and energy, the area coverage optimization algorithm studied in this paper is still in the theoretical research stage, which can be further studied in the following directions: this paper assumes that the deployment area of nodes is a two-dimensional plane, without considering the complexity and diversity of nodes deployed in the actual scene. Therefore, the coverage optimization problem can be studied in the three-dimensional situation in the future.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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