2023 IEEE 3rd International Conference on Power, Electronics and Computer Applications (ICPECA) | 978-1-6654-7278-4/23/$31.00 ©2023 IEEE | DOI: 10.1109/ICPECA56706.2023.10076217

Research on Wireless Sensor Networks Coverage Based on Fruit Fly Optimization Algorithm

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***Abstract*—In the coverage of wireless sensor networks, there are some problems in the coverage rate, node energy loss, etc., so this paper proposes a coverage optimization method of WSN based on Fruit Fly Optimization Algorithm. FOA network model is established and analyzed based on fruit flies optimization algorithm of wireless sensor network coverage optimization process, the Smell value of individual fruit fly is introduced. Find out the individual fruit fly with the highest Smell value in population of fruit flies and its corresponding density, group of fruit flies to the fruit flies the coordinates of individual mobile location, complete iteration, so as to improve coverage; In addition, the aspect of energy is improved by setting an energy value for each node in the area to be measured. Energy is consumed in the process of moving, covering and calculating each iteration. With the increase of iteration rounds, when one node energy is lower than a certain threshold, it will stop iterating and the remaining energy will be retained. In this way, the energy loss of the node is avoided on the basis of ensuring the coverage, the number of dead nodes is reduced, the lifetime of the wireless sensor network is prolonged, and the comprehensive performance of WSN is improved.**

Keywords—WSN, Fruit Fly Optimization Algorithm, coverage optimization, node energy

I. Introduction

The Internet of Things is one of the hottest research hotspots in the field of science and technology [1]. As one of its core support technologies, WSN (Wireless Sensor Networks) is an emerging direction of technological development, which has realized the information acquisition, transmission and processing, as well as the target system control of the integration of intelligent management, making it become increasingly mature. Wireless Sensor Network technology has many advantages, such as convenient distribution of nodes and flexible networking. Therefore, WSN has been widely used in a variety of fields [2], and still has great potential for improvement and development, which is a very promising technology in contemporary times.

In the research of Wireless Sensor Networks, network coverage has always been a research hotspot [3]. By randomly distributing a large number of nodes in a large area, WSN enables the devices within this range to be networked. Therefore, full network coverage is required in the area to be monitored, and the number of sensing nodes required is calculated according to the sensing range of each node and the number of nodes that are required in the monitoring area [4]. However, the stability, power and other performances of each node are different [2], which is easy to produce blind areas of network coverage, and may also lead to redundancy of sensor nodes, resulting in the reduction of sensor node performance and energy loss. Regional coverage rate is the main criterion for network coverage evaluation. By optimizing the algorithm, using sensor nodes as few as possible can ensure regional coverage, so as to realize network coverage and alleviate the problem of sensor node redundancy [3], which is the reason for the study of network coverage. To achieve the highest coverage of wireless sensor networks through limited nodes is also a hot issue analyzed by relevant scholars [5].

To solve this problem, domestic and foreign scholars have proposed a variety of algorithms to achieve network coverage. For example: Sparrow Search Algorithm (SSA) , using iterative optimization through individual sparrow searching for food and anti-predation, is characterized by high accuracy for searching and fast convergence speed. The robustness of it is strong as well[2]; Water Wave Optimization (WWO) simulates the propagation and motion mechanism of shallow water waves in nature, and has the advantages of possessing fewer control parameters, simple operation and easy implementation [4]; Particle Swarm Optimization (PSO) [6] was used to model the feature point set, and the area coverage was transformed into the optimized coverage based on the feature point set [5,7]; Genetic algorithms (GA) has unique advantages in solving combinatorial optimization problems, and GA can be applied to solve the problem of selecting the optimal working node set [8]. Artificial Glowworm Swarm Optimization (GSO) [9,10] algorithm has a good application prospect when it comes to the aspect of the optimization process of continuous space and some production scheduling [11]. This paper mainly studies the coverage of WSN based on Fruit Fly Optimization Algorithm (FOA), and on this basis, the Fruit Fly Algorithm is improved and optimized on the problem of processing the residual energy of nodes. Some previous scholars have achieved good results in wireless sensor network coverage through algorithm research [12]. However, the residual energy of nodes has not been considered yet, which may lead to the generation of large quantities of dead nodes. To solve this problem, this paper improves FOA. By monitoring the energy of nodes and retaining the residual energy of nodes through subsequent processes, the generation of dead nodes is reduced, and the loss of node energy is also reduced. The lifetime of wireless network is prolonged as well. On this basis, wireless sensor network coverage will make further breakthroughs in military [13], deployment [14], medical [15] and other fields. Finally, through theoretical analysis and experiments, this paper designed and tested a new algorithm -- the Energy-improved Fruit Fly Optimization Algorithm (E-FOA).

II. Problem Analysis and Network Model-Establishment

Fruit Fly Optimization Algorithm (FOA) is an optimization method used by many scholars in the world, which is based on the extrapolation of fruit fly foraging behavior. The fruit flies themselves outperform other species in sensory perception, especially in the aspect of smell and vision. The flies' olfactory organs are so good at picking up odors that float in the air that they can detect food sources up to 40 kilometers away. Then, after flying to the place near the exact location of food, they can use their keen vision to find the place their companions gather in, and then they may fly in that direction [16].

A. Node deployment in wireless sensor network based on FOA

Steps are as follows:

1) The size of fruit fly population is Sizepop, the maximum number of iterations is Maxgen, and the population positions X_axis and Y_axis are randomly initialized.

2) According to the location coordinates of the fruit fly population, a random distance and direction are given to each fruit fly so that they can use smell to search for food.

$$\begin{cases} Y_i = X\_axis + H_{i1} \\ X_i = Y\_axis + H_{i2} \end{cases} \quad (1)$$

Here, the random distance H is

$$H = 2 \times step \times rand - step \quad (2)$$

rand is set as a random number, step is 0.3, and the value range of H is [-0.3, 0.3].

3) Calculate the distance Dist between the ith fruit fly and the origin, and then calculate the taste concentration judgment value Si[17]

$$Dist_i = \sqrt{X_i^2 + Y_i^2} \quad (3)$$

$$S_i = \frac{1}{Dist_i} \quad (4)$$

4) The Smell value of individual fruit fly Si can be obtained by substituting the taste concentration judgment value Si into the Fitness function, i.e

$$Smell_i = Function(S_i) \quad (5)$$

5) Identify the individual with the highest Smell value in the fly population and calculate its corresponding Smell value Max (Smell).

6) Find the coordinate position of the individual fruit fly with the highest Smell value, and then the fruit fly population gathers to this position, and update the highest Smell value of the population.

$$\begin{cases} Smellbest = bestSmell \\ X\_axis = X(bestIndex) \\ Y\_axis = Y(bsetIndex) \end{cases} \quad (6)$$

7) Repeat the above steps (2)-(5) for iteration, and judge whether the Smell value is better than the Smell value of the generation last time.[18]

FOA is a small amount of calculation in the wireless sensor network (WSN), with short operation time and the optimization of high precision, but the algorithm does not consider the residual energy of nodes, which will result in significantly lower than the other part can be a large number of mobile nodes remaining energy node, and lead to both the production of large numbers of dead nodes and short cycle of the wireless network.

B. Improvements of the algorithm

(1)Initialization Phase

First, initialize the parameters, including the number of nodes N, sensing radius RS, region side length L, fruit fly population size sizepop, step size S, and discrete granularity data.

In this paper, when the parameters of E-FOA are initialized, each node I is given initial energy E(0, I), energy Ec required for each iteration coverage, energy delta required for moving unit distance, and threshold on the basis of the FOA. After the parameters are determined, the population location is randomly initialized in the area, and the Smell value of the initialized population is calculated.

In this experiment, the Smell value is calculated as follows:

1) Take data as the step size to discretize the points in the region.

2) Determine whether the discrete grid points are in the coverage area of the nodes. If the grid point is in the coverage area[19], change the coverage state of this grid point to covered.

3) After judging each node, calculate the proportion of the number of covered grid points to the number of all grid points, that is, the coverage rate of node network.

(2) Iterative Optimization Phase

In this phase, on the basis of the traditional algorithm, the computational energy consumption, coverage energy consumption and mobile energy consumption consumed by the node in the iteration are considered. Before the node moves, the ratio between the energy consumption of this node and the total energy consumption of all nodes is judged to be higher than the threshold. If the ratio is lower than the threshold, the node will not move in this iteration. Thus, the premature death of nodes can be prevented and the life cycle of wireless network can be prolonged.

In this paper, the energy cost of nodes is mainly considered as follows.

1) In each iteration, the node needs to recalculate the Smell value of the moving destination. Therefore, each node needs to deduct the computational energy consumption with a fixed value of beta after iteration.

2) The node always works with a certain coverage radius, so the node has energy overhead at every time. The specific cost is

$$\text{Ecover (i) =j* Ec} \tag{7}$$

Here, Ec is the energy required to meet the coverage in each round, and j is the number of iterations.

3) The node will have energy cost in the process of moving, and the specific cost is the distance mov_dist(I,j) that the ith node needs to move in the JTH iteration multiplied by the energy consumption delta of movement per unit distance, that is

$$\text{E\_mov(j,i) = delta * mov\_dist(j,i)} \tag{8}$$

4) In the process of iteration j+1, when the ratio of energy E(j, I) of node I to the sum of energy E(j,:) of all nodes is lower than a certain threshold, I will not move in iteration j+1.

5) After k rounds of iteration, the remaining energy of node I is

$$\text{E(k,i)= E(0,i)-j*beta-j*Ec -sum(E\_mov(j,i))} \tag{9}$$

After calculating the node energy in each iteration, the network lifetime is the minimum remaining energy of all nodes divided by Ec, that is

$$\text{T\_life=min(E(j,i)) / Ec} \tag{10}$$

In order to comprehensively consider the coverage rate and network lifetime, this paper proposes a comprehensive index P(Performance).

$$\text{P =Smell*T\_life} \tag{11}$$

Smell is the network coverage of nodes, and T_life is the network lifetime of nodes.

In order to have a clear description of the E-FOA, Fig.1 shows the flow chart of the algorithm.

III. EXPERIMENTS AND RESULTS G

In order to verify the filtering iteration through the residual energy of nodes, this paper uses MATLABR2021a (The word Matrix is combined with the word Laboratory, and then the software Matlab is created. This software is mainly oriented to the high-tech computing environment of scientific computing. It integrates significant functions like numerical analysis, matrix operating and modeling, simulation. It can offer a perfect solution for scientific research and engineering design, since these fields need efficient numerical calculation essentially.) to conduct simulation and comparative experiments on the FOA algorithm and the E-FOA algorithm based on the residual energy of nodes. The experimental performances of the coverage, network lifetime and comprehensive indexes of the two algorithms are respectively discussed under the same initial conditions. And the specific performance comparison of the two under different initial energy distribution of nodes. The parameter settings of the algorithm are listed in Table I.

TABLE I INITIAL PARAMETERS OF PROPOSED MODEL

Parameter	Description	Value
L	Regional Side Length	50
n	Number of Nodes	35
rs	Radius of Perception	5
data	Measures of Dispersion	0.4
maxgen	Upper Limit of Iterations	600
sizepop	Population Size	20
s	Step Size	0.3
E0	Node Initial Energy	20
delta	Energy Consumption per Unit Distance	200*0.001
beta	Node calculates the Smell value of the Energy Consumed	4*0.001
Ec	Energy Required for Node Coverage at Each Iteration	20*0.001
threshold	Energy Determination Threshold	0.285

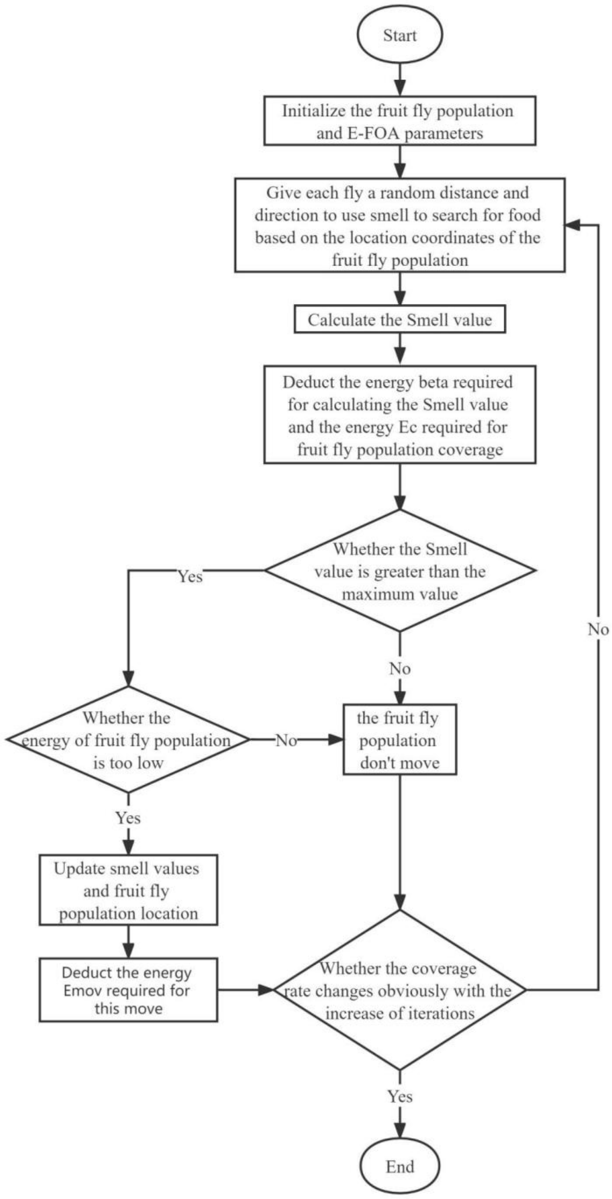

Fig 1. The Flow Chart of the Algorithm

On the purpose of better comparing the Performance of the two algorithms, a new concept of comprehensive Performance P is introduced as one of the evaluation criteria of the algorithm Performance, and the comprehensive Performance is defined as follows:

$$P = \text{Smellbest} * \text{T\_life} \tag{12}$$

Here: Smellbest represents the current best coverage rate, and T_life is introduced to represent the current network life time.

In the simulation experiment, 35 nodes were randomly distributed in a two-dimensional square area of 50*50, and the nodes are randomly deployed in the sensor area. In this paper, four groups of experiments were carried out for different energy consumption. The values of sigma were 0.5, 1.0, 1.5 and 2.0 respectively. The following four figures are examples of random deployment of a node with different sigma values, as shown in Figure 2, Figure 3, Figure 4 and Figure 5.

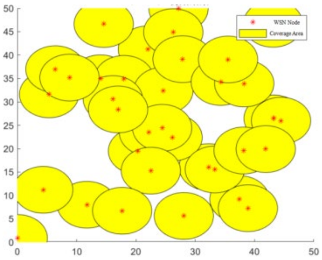

Fig 2. Random deployment of nodes when sigma = 0.5

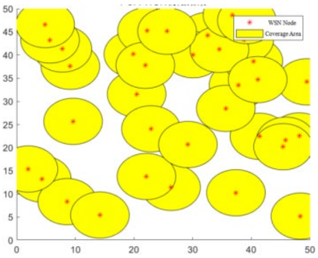

Fig 3. Random deployment of nodes when sigma = 1.0

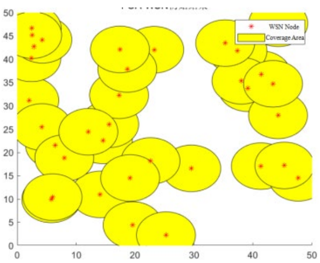

Fig 4. Random deployment of nodes when sigma = 1.5

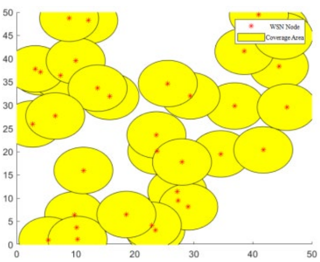

Fig 5. Random deployment of nodes when sigma = 2.0

Here, the red '*' indicates the node position, and the yellow area indicates the coverage area of the current node.

After the initial node deployment coordinates are obtained, the nodes are deployed using the FOA algorithm and the E-FOA algorithm. Fig 6-9 shows the final deployment results of the two algorithms. The figures clearly show that these two algorithms can both deploy nodes well and obtain high coverage.

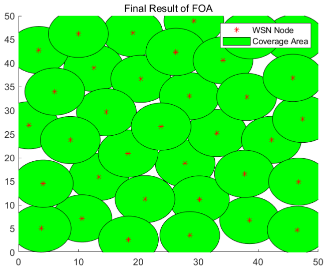

Fig 6. Final Result of FOA when sigma=0.5

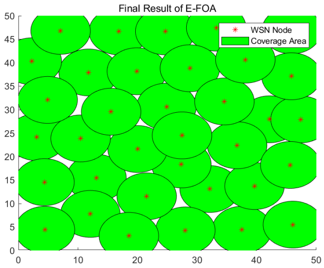

Fig 7. Final Result of E-FOA when sigma=0.5

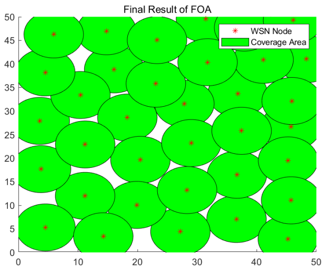

Fig 8. Final Result of FOA when sigma=1.0

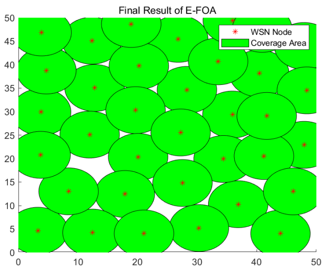

Fig 9. Final Result of FOA when sigma=1.0

Here, the red '*' indicates the node position, and the green area indicates the coverage area of the current node.

In the following, this paper will specifically compare the performance of FOA and E-FOA under different sigma values through three indicators: Rate of Coverage, Comprehensive Performance and Network Life, and compare and analyze the overall operation of the two algorithms.

A. Rate of Coverage

Firstly, the coverage of the algorithm is taken as one of the performance indexes. Figure 10-13 shows the coverage changes of the two algorithms with different sigma values (blue curve is FOA algorithm, red curve is E-FOA algorithm, X-axis is iteration number, Y-axis is coverage). Fig.10 shows that when sigma is 0.5, the FOA algorithm has carried out a total of 497 iterations, and the optimal coverage reaches 91.925%. However, the E-FOA algorithm reached 92.593% coverage after 555 iterations. The coverage of E-FOA is also 0.332% higher than that of FOA algorithm. Fig.11 shows that when sigma is 1.0, the FOA algorithm has carried out 398 iterations in total, and the optimal coverage reaches 91.308%. However, the E-FOA algorithm achieved 91.490% coverage after 513 iterations. The coverage of E-FOA is also 0.182% higher than that of FOA algorithm. As can be seen from Fig.12, when sigma is 1.5, the FOA algorithm has carried out 394 iterations in total, and the optimal coverage reaches 89.336%. The E-FOA algorithm achieves 89.865% coverage after 575 iterations. The coverage of E-FOA is also 0.529% higher than that of FOA algorithm. Fig.13 shows that when sigma is 2.0, the FOA algorithm has carried out 256 iterations in total, and the optimal coverage reaches 91.030%. However, the E-FOA algorithm achieved 91.547% coverage after 575 iterations. The coverage of E-FOA is also 0.517% higher than that of FOA algorithm. At the same time, the second half we observe the red curve can be found in the coverage tends to be stable nodes can still work after a period of time, and as stated earlier, the node stops working doesn't mean death, but the node energy down to a certain ratio will stop working, and it also convenient for us in the deployment work carried out on the network after the completion of maintenance work. Moreover, as the value of sigma decreases, the initial energy sizes of different nodes are closer to each other, and the difference between the iteration times of the two algorithms before and after the improvement gradually decreases.

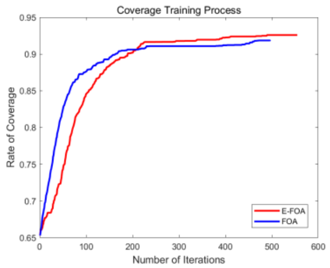

Fig 10. The coverage changes of the two algorithms when sigma =0.5

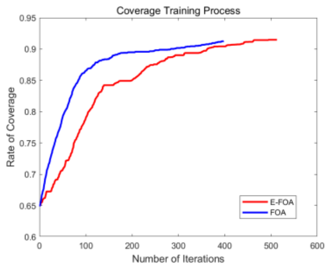

Fig 11. The coverage changes of the two algorithms when sigma =1.0

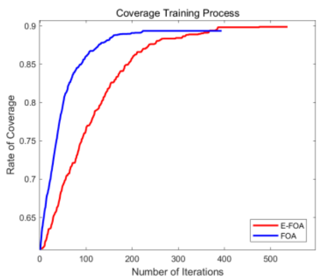

Fig 12. The coverage changes of the two algorithms when sigma =1.5

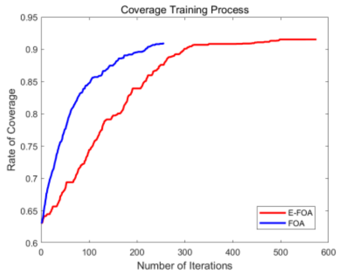

Fig 13. The coverage changes of the two algorithms when sigma =2.0

B. Network Life

Secondly, this paper takes the network life time as one of the indicators to measure the two.

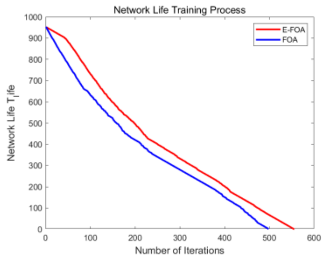

Fig 14. The network life time changes of the two algorithms when sigma =0.5

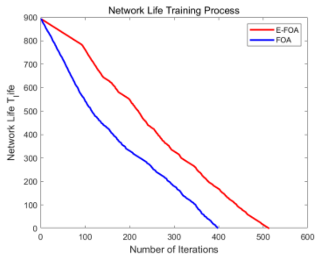

Fig 15. The network life time changes of the two algorithms when sigma =1.0

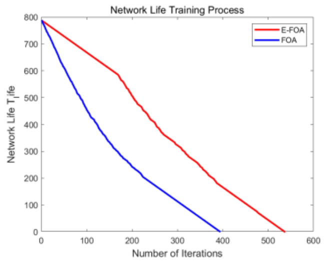

Fig 16. The network life time changes of the two algorithms when sigma =1.5

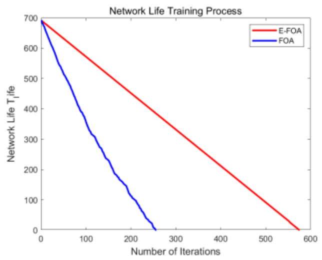

Fig 17. The network life time changes of the two algorithms when sigma =2.0

Figure 14-17 shows the changes of network lifetime of the two algorithms with the number of iterations (blue curve is FOA algorithm, red curve is E-FOA algorithm, X-axis is the number of iterations, Y-axis is the network lifetime). The figure clearly indicates that when under the same initial conditions, the reduction speed of network lifetime of E-FOA algorithm is much lower than that of FOA algorithm. This also exactly verifies the expectation of the improved algorithm in this paper, which is to make considerable reduction on the energy consumption of nodes and effectively extend the network lifetime[20].

C. Comprehensive Performance

Finally, the comprehensive performance P is introduced as the performance evaluation index of the algorithm. Figure 18-21 shows the changes of the comprehensive performance P of the two algorithms with the number of iterations (blue curve is FOA algorithm, red curve is E-FOA algorithm, X-axis refers to the number of iterations, Y-axis refers to the comprehensive performance). Table II shows the maximum value of the comprehensive performance P of the two algorithms under four sigma values. As can be seen from the figure, the overall performance of E-FOA algorithm is better than that of FOA algorithm, which is also consistent with the expected situation.

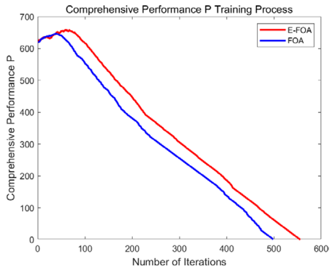

Fig 18. The change of the comprehensive performance P of the two algorithms when sigma =0.5

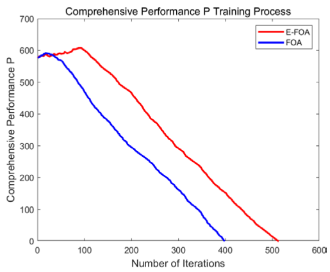

Fig 19. The change of the comprehensive performance P of the two algorithms when sigma =1.0

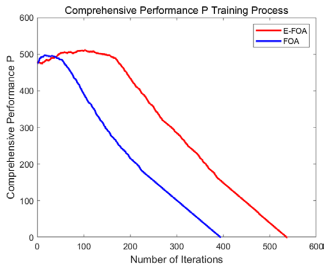

Fig 20. The change of the comprehensive performance P of the two algorithms when sigma =1.5

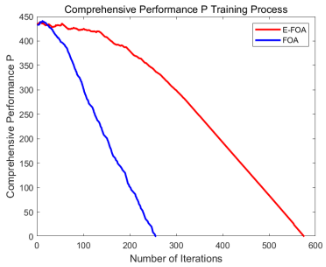

Fig 21. The change of the comprehensive performance P of the two algorithms when sigma =2.0

TABLE II THE MAXIMUM VALUE OF THE COMPREHENSIVE PERFORMANCE P OF FOA AND E-FOA AT DIFFERENT VALUES OF SIGMA

sigma	FOA	E-FOA
0.5	647.2061	658.335
1.0	591.858	608.7829
1.5	496.8489	511.488
2.0	441.1158	438.882

IV. CONCLUSION

In this paper, the FOA is improved in terms of energy, so that the algorithm can monitor the energy of each node, stop the iteration when the node energy is low, reduce the loss of node energy, and reduce the number of dead nodes. Through this improved method, the coverage of wireless sensor network is optimized. After the iteration of the optimization algorithm, the coverage rate of the final nodes is nearly the same as that of the unimproved algorithm, that means the nodes can still be evenly distributed in the monitoring area, basically realizing the full coverage of the network. In the whole iteration process, through the energy monitoring of a single node, the node can be timely stopped moving, the remaining energy of the node can be retained, the energy consumption of the node is reduced, and the network life is prolonged. Considering the network life time and coverage, the comprehensive performance of WSNS under the improved FOA is significantly improved. Therefore, this algorithm has certain advantages compared with other improved algorithms.However, sometimes the increase of the coverage rate may be erratic, and the final coverage rate is not always as high as expected, which still needs improvements in the future.

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