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# Optimization of 3D WSN coverage based on equilibrium optimization algorithm

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***Abstract:*** Coverage optimization is one of the basic problems in wireless sensor networks. Coverage reflects the service quality provided by wireless sensor networks. Swarm intelligence algorithm is an optimization method inspired by natural organisms. Node coverage optimization is also an optimization problem. Swarm intelligence algorithm can solve the coverage problem of wireless sensor networks. Therefore, this paper focuses on the application of swarm intelligence algorithm in coverage optimization of wireless sensor networks, and proposes a coverage optimization strategy based on swarm intelligence algorithm: coverage optimization of three-dimensional wireless sensor networks based on equilibrium optimization algorithm. In this algorithm, the principle is to control the volume and mass balance model, the particle concentration update according to the equilibrium candidate solution, and finally reach the equilibrium state, which mainly consists of three stages: population initialization, equilibrium pool and concentration update. In the simulation, the equilibrium optimization algorithm has higher effective coverage than the particle swarm optimization algorithm.

## 1. Introduction

With the rapid development of wireless network communication technology, wireless sensor network comes into being. Wireless sensor network is a distributed sensor network. It can monitor, sense and collect all kinds of information about the environment or monitoring objects in real time. The information will be sent to the terminal. It is this wireless sensor network that integrates the logical information world with the objective physical world and changes the way human interacts with nature. [1].

If the deployment nodes of wireless sensor networks are deployed in a randomly selected way, the coverage area cannot be as large as possible under the condition of cost control. At the same time, with the development of The Times, the deployment location of wireless sensor network has been not confined to two-dimensional space, but more applications in three-dimensional space. It also shows that the coverage control technology of wireless sensor networks directly determines the detection performance level of wireless sensor networks. In either case, the goal is to cover as much area as possible while keeping costs under control. Reduces network power consumption and optimizes network connection performance.

## 2. Algorithm description

### 2.1 Algorithm Background

Swarm intelligence algorithm is inspired by the creatures in nature. They can show such intelligent characteristics as autonomy, learning, adaptability and reactivity. The core idea of swarm intelligent optimization algorithm is to realize a certain result through the concept of group, which is composed of simple individuals. This is an optimization problem. Swarm intelligence algorithm has been introduced into coverage optimization of wireless sensor networks by many scholars and has achieved good results. In the existing literature, there are genetic algorithm optimization of wireless sensor network coverage [2], and particle swarm optimization. In this paper, multi-population intelligent optimization algorithm is studied. Finally, according to a new heuristic algorithm -- equilibrium optimization algorithm proposed by Faramarzia et al in 2019, the optimal coverage method is found by controlling the concentration update of particles in the volum-mass balance model according to the equilibrium candidate solution.

Equilibrium Optimizer algorithm (EO) is a physical heuristic optimization algorithm of hybrid dynamic mass balance with strong controlled volume proposed by Faramarzia et al in 2019 [3]. Mass balance equation reflects the physical process of controlling mass entry, departure and generation in the volume, which is generally described by first-order differential equation:

$$V\frac{dC}{dt} = QC_{eq} - QC + G \tag{1}$$

In the formula, V is the control volume; C is the concentration in the control volume; Q is the capacity flow rate of the inflow or outflow control volume; $C_{eq}$ represents the concentration inside the control volume under massless generation (i.e. equilibrium state); G is the mass generation rate inside the control volume [4].

Through the differential equation described by formula (1), it can be obtained:

$$C = C_{eq} + (C_0 - C_{eq})F + G(1-F)/\boldsymbol{\lambda} V \tag{2}$$

$$F = \exp(-\lambda(t - t_0)) \tag{3}$$

In the formula, F is the coefficient of exponential term; $\boldsymbol{\lambda}$ for turnover; $C_0$ is the initial concentration of the control volume at time $t_0$.

### 2.2 Algorithm Optimization

Like most intelligent algorithms, the standard EO algorithm generates the initial population in a random manner:

$$\vec{C_i} = LB + R_1 \cdot (UB - LB) \tag{4}$$

In this formula, $\vec{C_i}$ represents the i-th self-care initial position in the initial population, M is the population size, $R_i$ is the random vector of [0,1], i= 1,2...... M.

UB and LB are the upper and lower bounds of the exploration space respectively.

After the population is initialized, the particles lack the basis to reach the equilibrium state. Therefore, the fitness value of each particle in the population is calculated, and four candidate solutions $\overrightarrow{C_{eq_1}} \sim \overrightarrow{C_{eq_4}}$ are obtained according to the fitness value, and then the average candidate solution $\overrightarrow{C_{eq\_ave}}$ is obtained from these candidate solutions. Five candidate solutions together form the equilibrium pool $\vec{C_p}$. Finally, a candidate solution is randomly selected in the equilibrium pool to provide the basis for judging the equilibrium state of the population and participate in the updating process of particle concentration.

$$\overrightarrow{C_p} = \vec{C}_{eq_1} \sim \vec{C}_{eq_4}, \vec{C}_{eq_{ave}} \tag{5}$$

$$\vec{C}_{eq} = Rand(\vec{C}_P) \tag{6}$$

In formula (5), $\overrightarrow{C_{eq}}$ represents the candidate solution randomly selected from the equilibrium pool with the same probability.

Next, update the concentration. Concentration updating is the embodiment of particle optimization from the current position to another position. Its specific form is as follows:

$$\vec{C} = \overrightarrow{C_{eq}} + (\vec{C} - \vec{C}_{eq})\vec{F} + \frac{\vec{G}}{\vec{\lambda} V}(1 - \vec{F}) \tag{7}$$

In formula (7), $\vec{C}$ represents the current particle, $\vec{\lambda}$ is the random vector between [0,1], V is the unit volume, $\vec{F}$ is the exponential term mainly used to balance exploration and development, $\vec{G}$ is the generation rate used to improve the development capacity.

Meanwhile, the new definition of $\vec{F}$ is:

$$\vec{F} = a_1 sign(\vec{r} - 0.5)[e^{-\vec{\lambda}t} - 1] \tag{8}$$

$$t = (1 - \frac{Iter}{Max\_Iter})^{a_2 \frac{Iter}{Max\_Iter}} \tag{9}$$

Finally, the solution is updated according to formula (1). The specific iteration diagram of equilibrium optimization algorithm is shown as follows (Figure 1).

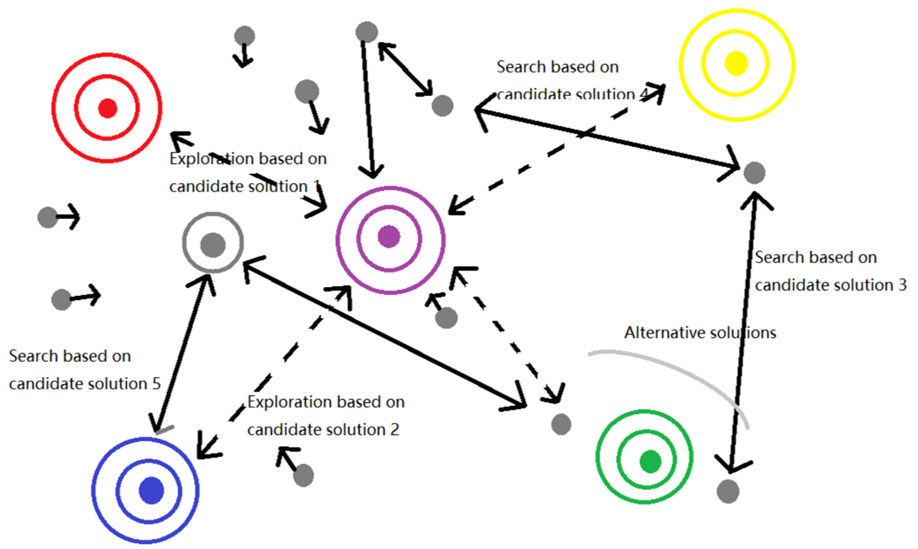


Figure 1: Schematic diagram of EO algorithm optimization principle.

## 2.3 Algorithm Performance Comparison

There are many kinds of intelligent optimization algorithms. There are also many applicable algorithms that can optimize coverage problems in wireless sensor networks. The balanced optimization algorithm proposed in this paper is more sensitive and can achieve better coverage with fewer iterations.

Now compare EO with GWO, PSO, SSA, and GSA, setting up 23 experimental functions. The population size was set to 60, the maximum number of iterations was set to 600, and each algorithm performed 35 independent operations. Experimental efficiency comparison (Figure 2) and parameter space of experimental function F1 (Figure 3) are shown in the Figure 2 and 3:

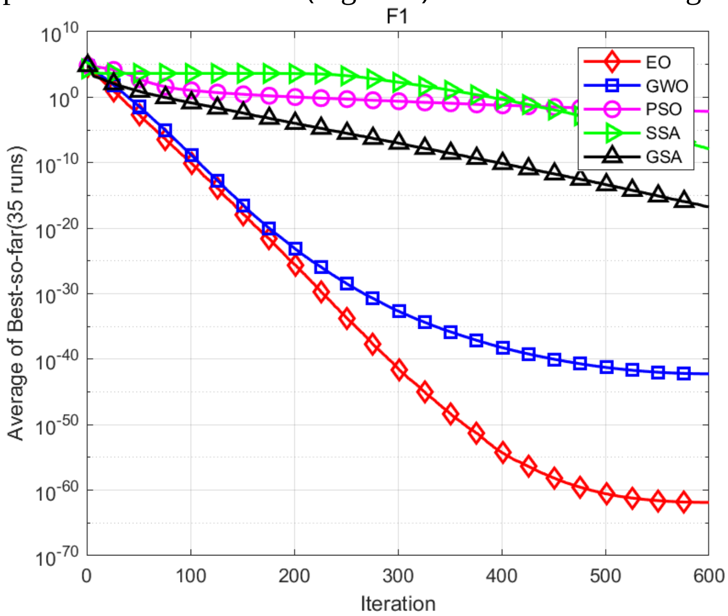


Figure 2: Efficiency comparison of five intelligent algorithms under experimental function F1.

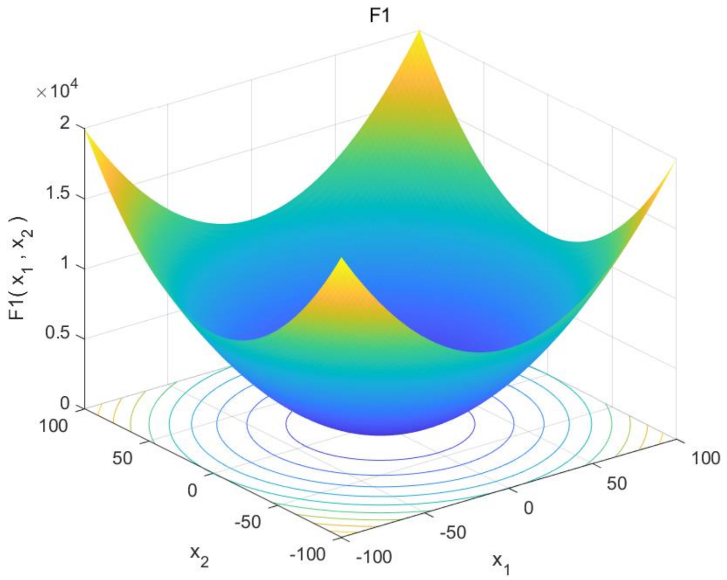


Figure 3: Parameter space under experimental function F1.

Among the 23 experimental functions, F3 (single-peak function/30-dimensional), F8 (multi-peak function/30-dimensional), F18 and F19 (fixed-dimension multi-peak function / 2-dimensional) are selected as examples. The population size is set to 60, the maximum number of iterations is set to 600, and each algorithm operates independently for 35 times. The results are shown as follows: (Figure 4)

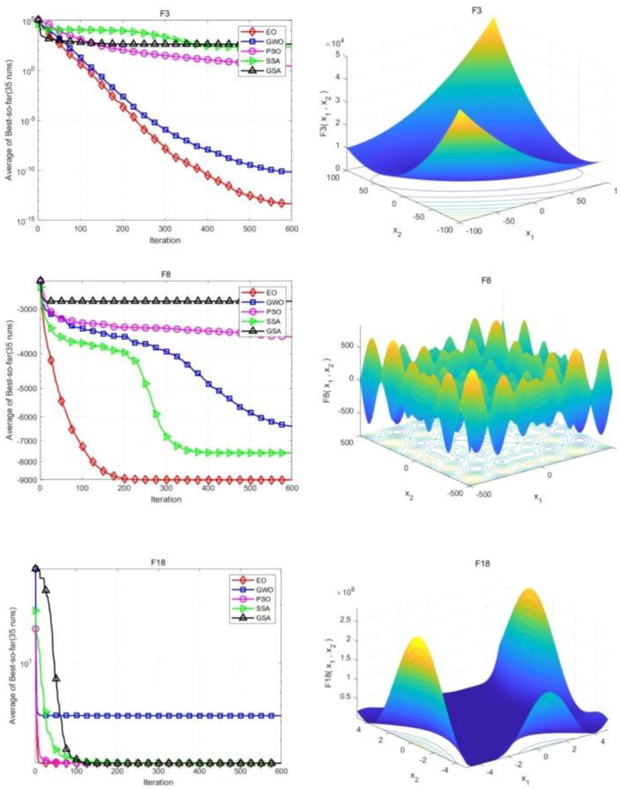


Figure 4: Running results under typical experimental functions.

As can be seen from the above experimental results, compared with GWO, PSO, SSA and GSA, the coverage optimization scheme of 3D wireless sensor network proposed in this paper has a great improvement in coverage efficiency, and the required number of iterations is also significantly reduced.

## 3. Application of balanced optimization algorithm in coverage model of wireless sensor network

### 3.1 Wireless sensor model

In this paper, the wireless sensor is designed as the most ideal perception model. Refers to a spherical region in a space with the sensor node as the center of the circle and r as the radius. In a three-dimensional space, if a coordinate point is covered by the radiation range of the wireless sensor, the perception probability of this area is denoted as 1, and if it is not covered, it is denoted as 0.

Then the coordinate of a wireless sensor is $(x_i, y_i, z_i)$. The perception probability of whether any point (x,y,z) in the three-dimensional space is covered by the wireless sensor is defined as follows:

$$p = \begin{cases} 1 \ \ if\ d \leq r \\ 0 \ \ else \end{cases} \tag{10}$$

In formula (10), d is the Euclidean distance between the sensor and a target point.

$$d = \sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2} \tag{11}$$

Based on the above ideal situation, a wireless sensor model with multiple nodes in three-dimensional space is established.

## 3.2 Analysis of simulation experiment

In order to verify the effectiveness of the equilibrium optimization algorithm, MATLAB simulation experiment is carried out in this paper. Simulation in the monitoring area of 50m × 50m × 50m three-dimensional space, the number of sensor nodes N = 30, its sensing radius is $R_S = 10m$, communication radius $R_c = 20m$, iteration 500 times. The initial coverage results are shown below. (Figure 5)

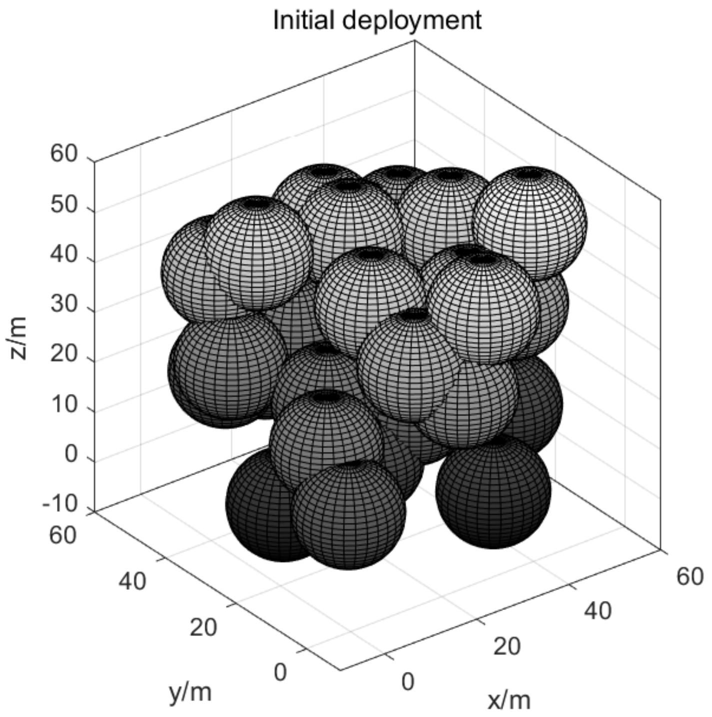


Figure 5: Schematic diagram of initial deployment of wireless sensor network.

In the random initial model, the initial coordinates of the wireless sensor are shown in the following table 1.

Table 1: Initial coordinates of randomly generated wireless sensors.

| X | Y | Z | X | Y | Z | X | Y | Z |
|---|---|---|---|---|---|---|---|---|
| 29.62 | 0.91 | 43.69 | 34.72 | 4.65 | 3.84 | 48.39 | 49.39 | 32.17 |
| 34.21 | 11.14 | 38.97 | 18.05 | 5.56 | 34.41 | 46.257 | 14.63 | 32.82 |
| 2.56 | 10.28 | 21.38 | 7.65 | 47.65 | 37.48 | 34.40 | 35.67 | 11.95 |
| 28.52 | 37.82 | 41.88 | 4.07 | 24.55 | 2.90 | 29.25 | 45.71 | 40.90 |
| 5.22 | 41.01 | 23.30 | 29.93 | 12.91 | 26.63 | 10.68 | 49.68 | 15.76 |
| 49.87 | 21.06 | 8.30 | 27.43 | 17.83 | 16.95 | 18.71 | 18.59 | 40.43 |
| 18.66 | 48.65 | 15.26 | 15.26 | 26.46 | 19.05 | 39.34 | 24.56 | 20.36 |
| 18.28 | 19.17 | 9.67 | 47.69 | 11.29 | 49.64 | 24.10 | 47.30 | 21.12 |
| 38.76 | 49.76 | 32.82 | 36.19 | 42.11 | 8.26 | 11.33 | 41.73 | 42.62 |
| 44.46 | 29.56 | 42.23 | 0.11 | 0.90 | 13.52 | 25.02 | 1.074 | 28.78 |

After 500 iterations, the wireless sensor is distributed more evenly and can cover more areas under limited sensor nodes. From the initial position, each wireless sensor is updated as an individual (also known as a node). Under the condition of balancing the concentration of each region in the space, the current solution is judged to be the optimal solution and the next iteration is carried out. When the result of the next iteration is more optimized, the original optimal solution is replaced. Finally, we can get the coverage diagram of wireless sensor network optimized based on equilibrium optimization algorithm, as shown in Figure 6:

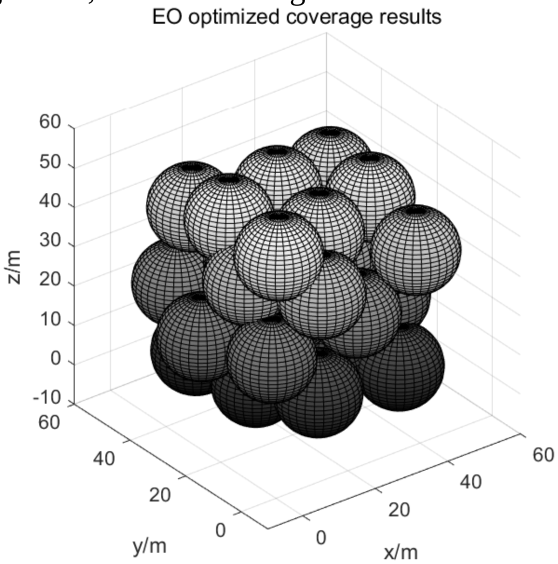


Figure 6: Schematic diagram of EO optimization coverage results.

The coordinates of the optimized wireless sensor are shown in the following table 2.

Table 2: Wireless sensor coordinates optimized based on equilibrium optimization algorithm

| X | Y | Z | X | Y | Z | X | Y | Z |
|---|---|---|---|---|---|---|---|---|
| 15.53 | 30.13 | 30.80 | 33.55 | 23.14 | 30.74 | 18.53 | 20.34 | 21.80 |
| 10.47 | 20.98 | 6.27 | 30.49 | 42.64 | 29.59 | 5.76 | 9.12 | 19.47 |
| 38.54 | 5.78 | 7.53 | 27.74 | 17.89 | 6.57 | 5.76 | 43.42 | 22.99 |
| 43.50 | 37.21 | 40.68 | 43.35 | 25.20 | 5.64 | 23.15 | 14.54 | 42.79 |
| 15.64 | 4.14 | 34.58 | 42.44 | 15.84 | 19.62 | 27.68 | 7.04 | 24.20 |
| 18.62 | 41.83 | 20.93 | 6.53 | 18.84 | 34.43 | 10.15 | 43.73 | 40.55 |
| 40.78 | 19.27 | 43.39 | 16.35 | 6.21 | 8.32 | 44.31 | 34.81 | 21.90 |
| 0.02 | 27.03 | 18.74 | 42.42 | 42.82 | 8.30 | 26.11 | 33.64 | 43.62 |
| 24.85 | 42.26 | 6.52 | 41.17 | 3.18 | 37.18 | 7.02 | 8.20 | 45.44 |
| 30.17 | 30.32 | 14.44 | 8.07 | 39.52 | 6.72 | 8.78 | 28.51 | 44.94 |

According to the computer simulation results, we can see that. Random generated coordinates result in an initial coverage of 0.57. After 500 iterations of optimization, the coverage is optimized to 0.78. The coverage is greatly improved. The coverage optimization curve is shown in Figure 7.

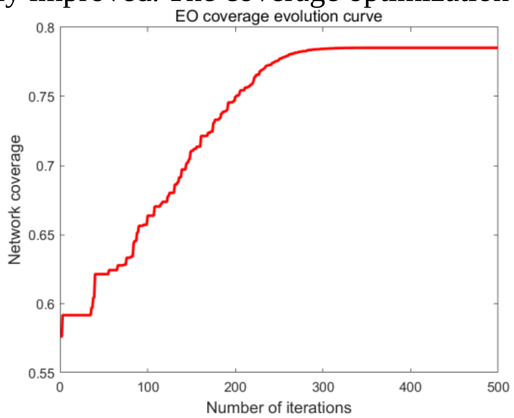


Figure 7: EO optimization coverage curve.

It can be observed from the EO coverage evolution curve diagram that the convergence speed of the equilibrium optimization algorithm is fast. Basically, stable coverage optimization results have been obtained after about 300 iterations. The reduction in the number of iterations also effectively reduces the amount of computation, and reduces the running time, which can improve the coverage faster and more accurately.

### 3.3 Stability analysis

According to literature [5], the equilibrium optimization algorithm has certain stability. Although the implementation of the algorithm needs to generate the initial population in a random way, and the generation of individual positions in the population has a certain randomness, it does not affect the subsequent optimization of position iteration optimization of wireless sensor by the equilibrium optimization algorithm. The optimization results have certain stability, and the coverage rate after optimization must be above 75%. The following six experiments with different node numbers and space sizes are selected for comparison, and the optimized coverage rate is relatively stable. (Figure 8)

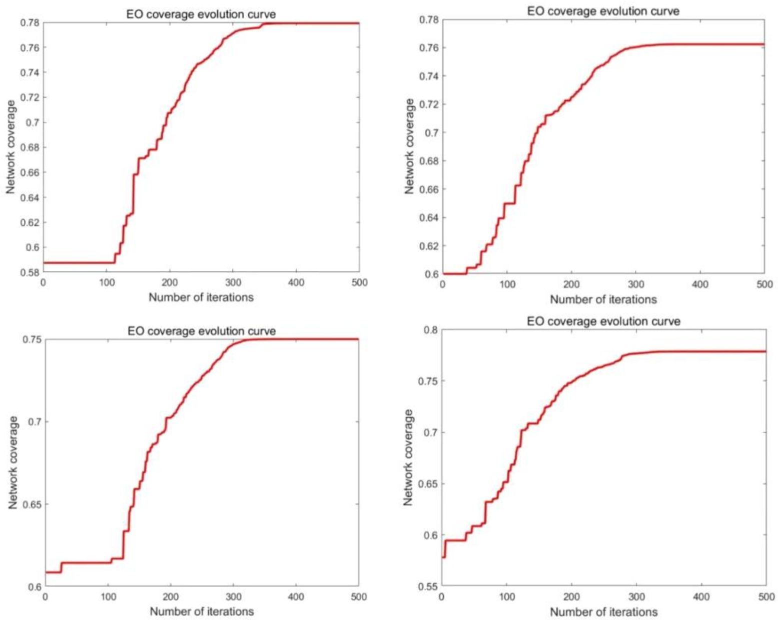


Figure 8: Comparison of the four experiments

By comparing the four groups of experiments in Figure 8, we can see that the algorithm has a faster solving speed and good stability. It can be used to optimize the coverage of wireless sensor network in practical industrial engineering.

## 4. Conclusions

In this paper, a three-dimensional coverage method based on equilibrium optimization algorithm is proposed for node coverage optimization in wireless sensor networks. This algorithm finds the optimal coverage method by controlling the concentration update of particles in the volume-mass equilibrium model according to the equilibrium candidate solution. The convergence speed of this algorithm is faster. By comparing the convergence speed with PSO, GWO, SSA and other algorithms, it can be concluded that the equilibrium optimization algorithm has faster convergence speed and stability, and can adapt to more kinds of single-peak or multi-peak functions. It can be seen from the simulation results that the balanced optimization algorithm can achieve better optimization effect, and the coverage ratio of wireless sensor network is stable above 75%. It is a stable algorithm that is conducive to improving the coverage of WSN.

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