Research on Base Station Siting Method Based on 0-1 Planning Model and Immune Genetic Algorithm

Qirui Zhou *

Department of Intelligent Equipment, Shandong University of Science and Technology University, Taian, China, 271019

* Corresponding Author Email: sdkjZhouqr@163.com

Abstract. With the rapid development of 5G technology, the high bandwidth required for communication shows a growing trend. However, the coverage area of the original base station gradually decreases, resulting in the expansion of the weak coverage area, in order to guarantee the quality and reliability of the communication network, there is an urgent need to establish new base stations in the weak coverage area. In this paper, a 0-1 planning model is developed with base stations and weak coverage points as the core elements. In this model, we aim to minimize the cost, and also consider the distance limitation and coverage demand, in order to ensure the premise of service demand, through the immunogenetic algorithm to achieve the optimization of the base station site selection. Ultimately, we have visualized it with the help of MATLAB to fully present the effectiveness and practical application value of this base station siting scheme.

Keywords: Base Station Siting, Multi-Objective Programming, Immunogenetic Algorithm.

1. Introduction

Mobile communication technology is rapidly developing, and the scale of operation is expanding. To solve complex network communication problems, base station siting planning is required for areas with weak communication coverage. With the advent of the 5G era, the communication bandwidth is increasing, but the coverage of base stations is decreasing, resulting in the need for more base stations in the same area. In addition, the types of base stations and antennas are becoming more and more diverse, making the planning of communication networks, especially base station siting, more complex. Therefore, it is important to propose a reasonable base station siting scheme to optimize the communication network. Many scholars have also made corresponding studies. Bian Qiang proposed a base station siting planning method based on improved K-means algorithm in hilly environment; designed a base station siting method based on improved K-means algorithm and used the maximum coverage of the planning area as the judging index of the base station siting result, and the coverage rate was improved to some extent [1]. Juan Liu proposed a hybrid optimization algorithm of particle swarm Drosophila for the optimization of base station location, constructed a new individual update method, and introduced a genetic evolution mechanism in the update process to better maintain the diversity of the population. It has a high performance of optimization search [2]. Jin Weizheng proposed an artificial fish swarm algorithm with variable step size, which was finally applied to the simulation of base station planning for electric power wireless private network with better performance [3], Tang Liqing proposed a whale optimization improvement algorithm, which is able to obtain a more desirable optimization solution and has a faster convergence speed [4], Shan Shuang proposed a mathematical planning model based on 0-1 planning to solve the 5G base station siting problem, and the simulated annealing method was used to simulate the planning model to solve the 5G base station location problem, and the simulated annealing method was applied to the planning model. Simulated annealing method to solve the planning model [5], this paper proposes a 0-1 planning model based on the base station siting problem and uses the immune-genetic algorithm to solve the model, can meet the business needs while providing the lowest cost siting scheme. The problem background and data for this problem are taken from the 2022 mathorcup Collegiate Mathematical Modeling Challenge D problem.

2. Planning modeling

Given a 2500 x 2500 area containing weak coverage points, two types of base stations, macro and micro base stations, have different coverage and cost. The requirement is to select the location and type of the new base station so that the total number of services covering the weak coverage points reaches 90% of the total number of services. To cope with the huge amount of data and computational complexity, we preprocess the data and build a 0-1 planning model [6], while minimizing the cost and achieving full coverage of the weak coverage areas to ensure that at least 90% of the service volume is covered. Distance constraints from existing sites and full coverage of weak coverage areas are considered. The objective function is optimized iteratively using an immunogenetic algorithm, and a visual simulation using MATLAB is performed to verify the effectiveness of site selection.

2.1. Determination of the objective function

This model is a 0-1 planning model with the optimization objective of cost minimization, whose mathematical expression is:

$$\text{Min} \sum_{I=1}^{N} d_i s_i + \sum_{I=1}^{N} v_i t_i \tag{1}$$

Where N is the number of weak coverage points pre-processed from the data above, d is the cost of considering the use of macro base stations, v is the cost of considering the use of micro base stations, and s.t is whether or not to choose d.v. This minimizes the cost on the basis of considering the type and number of base stations.

2.2. Determination of model constraints

2.2.1 Type of base station

Assuming the base station selection for a weak coverage point that has been traversed, the only choices available in the selection of the base station type are to select a macro base station, a micro base station, or not to establish a base station here. There are these three possibilities and only one can be chosen from them, so the first constraint we establish is the base station type.

It can be expressed by the following formula:

$$s_i \begin{cases} 1 & option\ d \\ 0 & no\ option\ d \end{cases} \tag{2}$$

$$t_i \begin{cases} 1 & option\ v \\ 0 & no\ option\ v \end{cases} \tag{3}$$

$$s_i + t_i \leq 1 (i = 1,2,3 \cdots\cdots N) \tag{4}$$

The first two formulas are stating when to select the type of that base station, and the last formula is stating that the selectivity can only be unique.

2.2.2 Distance constraints from existing base stations

According to the requirements of the problem, the distance of the new base station and the distance of the existing base station cannot be more than 10, if traversing the entire existing base station data, will inevitably bring a huge computational complexity, so we will be transformed into the constructability of the problem, in layman's terms, if the weak coverage of the point of the Euclidean distance of 10 if there is an existing base station exists, it will be discarded, and in the grid.The way we take the coordinate distance is shown in Figure 1.

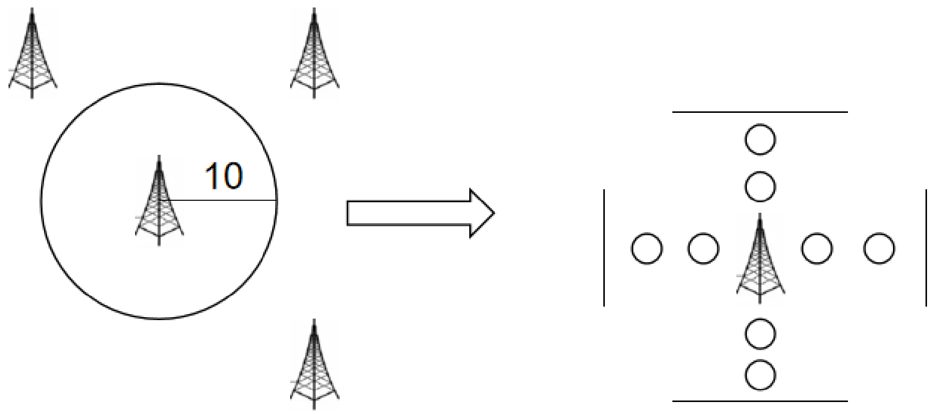

Figure 1. Demonstration of coordinate distances

One O represents the length of five distance units, and based on this figure we can create the following equation to represent the constraint:

$$\sqrt{(x_a - x_i)^2 + (y_a - y_i)^2} \le d \tag{5}$$

$$(x_a, y_a) \in E \tag{6}$$

Assume that the proposed new base station i, whose coordinates are (x_i,y_i), and E is the set of existing base stations, d=10. Determining whether an existing base station exists within a specified distance of the point will determine whether a base station can be established here.

2.2.3 Full coverage constraints

As far as the previous analysis is concerned, we have filtered some of the data based on data preprocessing, which leads to the fact that in the single-objective planning model of this problem it is necessary to ensure that all the weak coverage points are covered so that more than 90% of the business volume can be reached, and in this constraint we construct it based on the type of the base station and the coordinate distance.

The constraint can be expressed by the following equation.

$$\sqrt{(x_b - x_i)^2 + (y_b - y_i)^2} \le M_j(M_1 = 30, M_2 = 10, j = 1,2 \tag{7}$$

$$(x_b, y_b) \in Z \tag{8}$$

$$(x_i, y_i) \in Q \tag{9}$$

Z stands for the set of weak coverage points, Q stands for the set of established base stations, M stands for the type of base station, if 1 is used, then it is a macro base station with a coverage of 30 and if 2 is used, then it is a micro base station with a coverage of 10. If all the weak coverage points are satisfied, then it means that the base station scheme is feasible.

2.3. Summary of single-objective planning models

$$\text{Min} \sum_{I=1}^{N} d_i s_i + \sum_{I=1}^{N} v_i t_i \tag{10}$$

$$s.t.\begin{cases}\sqrt{(x_a-x_i)^2+(y_a-y_i)^2}\le d & (11)\\ (x_a,y_a)\in E & (12)\\ \sqrt{(x_b-x_i)^2+(y_b-y_i)^2}\le M_j(M_1=30,M_2=10,j=1,2) & (13)\\ (x_b,y_b)\in Z & (14)\\ (x_i,y_i)\in Q & (15)\\ s_i\begin{cases}1 & option\ d\\ 0 & no\ option\ d\end{cases} & (16)\\ t_i\begin{cases}1 & option\ v\\ 0 & no\ option\ v\end{cases} & (17)\\ s_i+t_i\le 1(i=1,2,3\cdots\cdots N) & (18)\end{cases}$$

3. Solving of the model

3.1. Algorithmic step

Many immunogenetic algorithms have emerged in recent years [7], Immunogenetic algorithm is used to solve the problem of site selection of base station [8]. Immunogenetic algorithm is based on genetic algorithm and has its own unique antibody concentration regulation mechanism, which suppresses the degradation phenomenon in the late stage of the genetic algorithm by maintaining the diversity of the antibody population. Consider the antigen as the problem to be solved, the antibody as the corresponding solution, and the affinity of the two responds to the feasibility [9].

The first step takes the objective function and constraints to be solved obtained from the model above as input for the antigen of the immunogenetic algorithm.

The second step calculates the initial antibody population P and the initial memory cell population Q (the initial value is the empty set), and for the initial antibody population P generates the initial mature cell set T.

The third step calculates the affinity and the degree of cell differentiation on this basis and calculates the affinity between the antigen and the antibody. The antibody with the highest affinity to the antigen is filtered to be added to the memory antibody population, and the memory cell set with low affinity as well as high density is filtered out.

The selection operation is performed in the fourth step. Individuals are selected for entry into the next generation according to a fitness function based on concentration regulation [10].

The fifth step performs crossover and mutation. On the basis of the fourth step, antibodies are screened for crossover and mutation according to the set crossover and mutation probabilities.

The sixth step updates the population and generates a new generation of population before moving to the third step.

The seventh step satisfies the number of iterations, and the process ends.

The flow of the algorithm is shown in Figure 2.

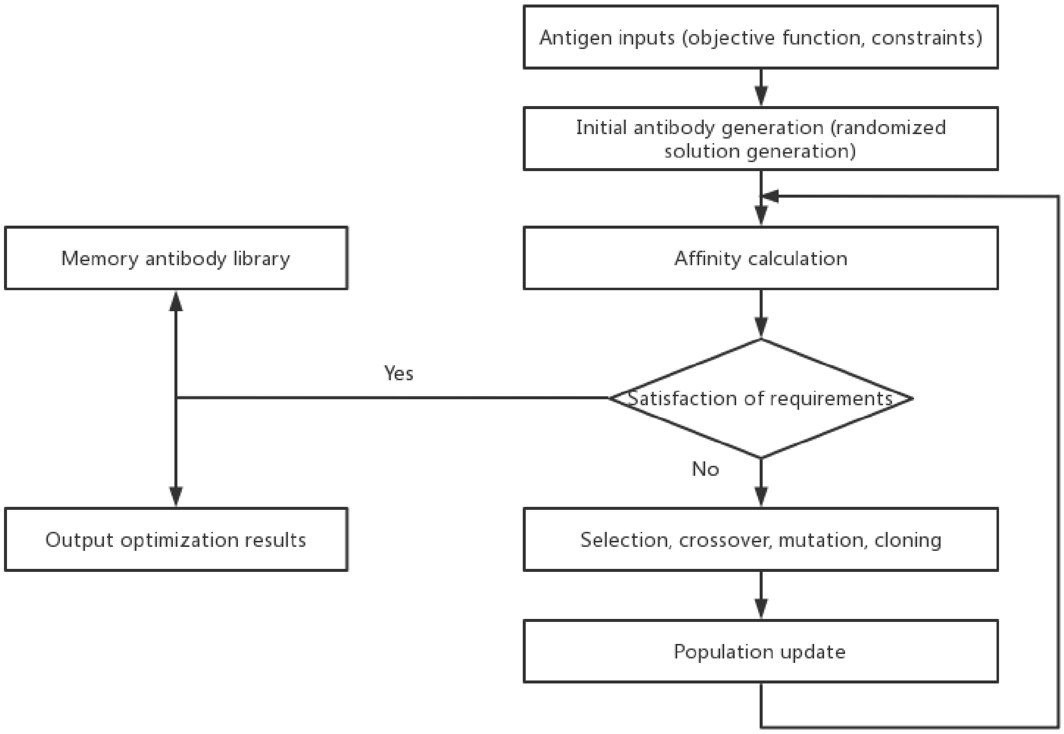

Figure 2. Genetic Algorithm Solving

3.2. Coordinate mapping

The location and coordinates of each base station are represented by a genome, which can represent the location and number of base stations [10]. Assuming that each individual consists of multiple genes, two genes in the genome represent the x-coordinate and y-coordinate of each base station, and the values of x,y are in the range of 0 to 2499. The base station simulation scheme for gene coordinate mapping is shown in Figure 3.

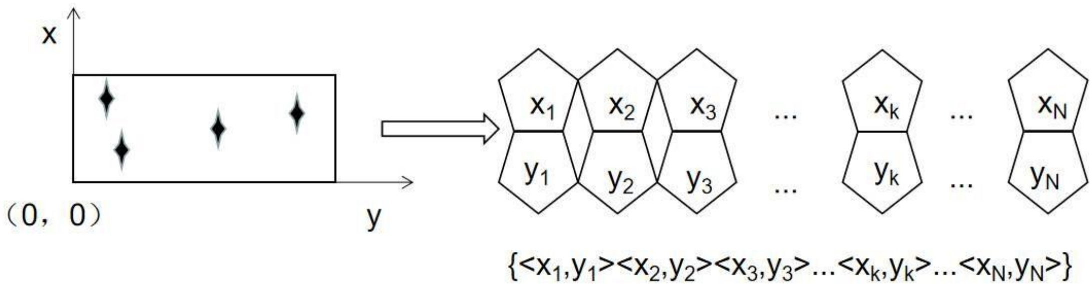

Figure 3. Mapping of gene coordinates

3.3. Initialization of Antibody Population P and Memory Population Q

Random initialization produces a population that is as close as possible to the optimal solution, set the random number $a(0 < a < 2499)$,the lower limit of the number of base stations N1 and the upper limit of the base stations N0, and set the initialization probability to be:

$$p_0 = \left(\frac{N0-N1}{2a}\right) \tag{19}$$

Only when the random number produced is less than this probability, a suitable location is found to set up a base station from the weak coverage area.

3.4. Affinity Calculation and Screening for Redundant Antibodies

The formula to express the affinity of antigen and antibody is as follows:

$$f_i = \frac{n_2}{N+1} \tag{20}$$

where n_2 is the number of antibodies j in antibody i dominating P. Once the number of individuals in the memory antibody M exceeds a given certain threshold, the excess antibodies are screened out according to the neighbor crowding algorithm. Since the method mainly relies on the surrounding neighboring antibodies rather than on the method of discriminating class domains to determine the class to which they belong, the neighborhood crowding algorithm is more suitable than other methods for the set of samples to be divided in which there is a large number of intersections or overlaps of class domains.

Step 1 is to sort the antibodies in ascending order when the number of individuals in the memorized antibody M exceeds a given threshold T

Step 2 Filtering based on the Euclidean distance between two antibodies$\mathrm{d_i} = \|\mathrm{x_{i+1}} - \mathrm{x_i}\|, 0 < \mathrm{i} < 2499$

Step 3 is to calculates the two antibodies with the shortest Euclidean distance and removes antibody $\mathrm{x_j}$ if $\mathrm{d_{i-1}}$ is small, and conversely removes antibody $\mathrm{x_{j+1}}$

Step 4 is to repeats the process until the number of individuals in the memorized antibody M equals the threshold.

3.5. Antibody concentration adjustment

In order to maintain the diversity of antibodies, the concentration is regulated according to the theory of uniqueness network regulation. Antibody coding indicates how well a base station is selected, so the variability between two antibodies is expressed as the difference in how well a candidate base station is selected. The concentration of an antibody is the ratio of the number of antibodies in a population to the size of the population. Define the concentration-adjusted selection probability as follows:

$$P(Ab) = \frac{E_p(Ab)}{1+c_j \times ln(1+D_j)} \tag{21}$$

$E_p(Ab)$ is the antibody selection entropy, D_j is the antibody Ab_j concentration, and D_j is the antibody concentration Ab_j regulation parameter. It can be seen that the smaller the selection entropy of the antibody, the higher the corresponding concentration of the antibody, and therefore the smaller the selection probability.

3.6. Crossover, mutation, cloning

Cyclic crossover is used to keep the genes of the parents in the offspring, preventing the loss of the optimal solution that has been obtained. Mutation can add new elements to the population, and the mutation operation is applied only to the offspring, with the aim of preventing too much variation in the population as well as reducing the probability of generating an optimal solution. Sorting is performed during the selection of the optimal solution, and the values obtained are calculated to update the population. Antibodies with high adaptation are screened and the cloned antibodies are subjected to Gaussian mutation using the cloning technique with the following equation.

$$p_t = p_n + \alpha \times N(0,1) \tag{22}$$

$$\alpha = \frac{\mathrm{e^{-f}}}{\beta} \tag{23}$$

Where p_t is the antibody produced by mutation and p_n is the unmutated antibody; α is the mutation rate of each individual, N (0, 1) indicates that it obeys a normal distribution, f is the degree of adaptation of each individual to the existing environment, and β is the parameter value.

3.7. Display of solution results

According to the immunogenetic algorithm solution, the following results can be obtained: 235 macro base stations and 3891 micro base stations, the weak coverage point map with the above macro base stations and micro base stations through the simulation is shown as follows, where red dots indicate macro base stations, green dots indicate micro base stations, and blue dots indicate weak coverage points.The MATLAB simulation is shown in Figure 4.

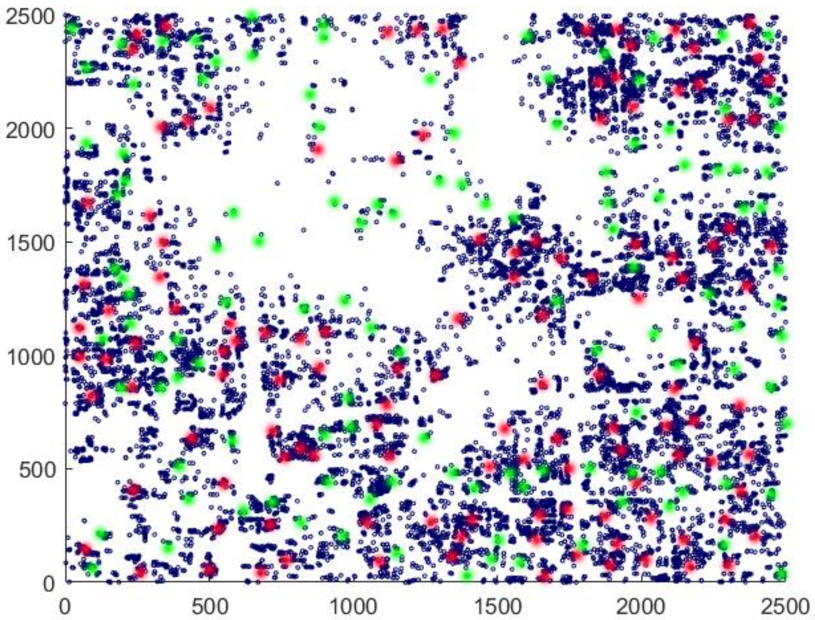

Figure 4. Scatterplot of macro and micro base station simulation

We select the coordinates of macro base stations and micro base stations with horizontal coordinates at (2050-2300) and vertical coordinates at (1650-2150) to show, and the rest are put in the annex, the results are shown in Table.1:

Table.1. Coordinate points for planned construction of macro and micro base stations

Macrocell station x	Macrocell station y	Micro base Station x	Micro base Station y
2207	2122	2158	2061
2217	2066	2133	2056
2190	2057	2151	2024
2134	1969	2102	2023
2222	1824	2129	1911
1971	1513	2121	1824
20-17	1518	2102	1817
2022	1437	2168	1707
2082	1476	1895	1675
2107	1510	1912	1659
2121	1444	1902	1614
2140	1337	1930	1615
2165	1366	1969	160-1
2161	1304	1987	1619

The points of Table 1 are visualized through MATLAB as shown in Figure 5:

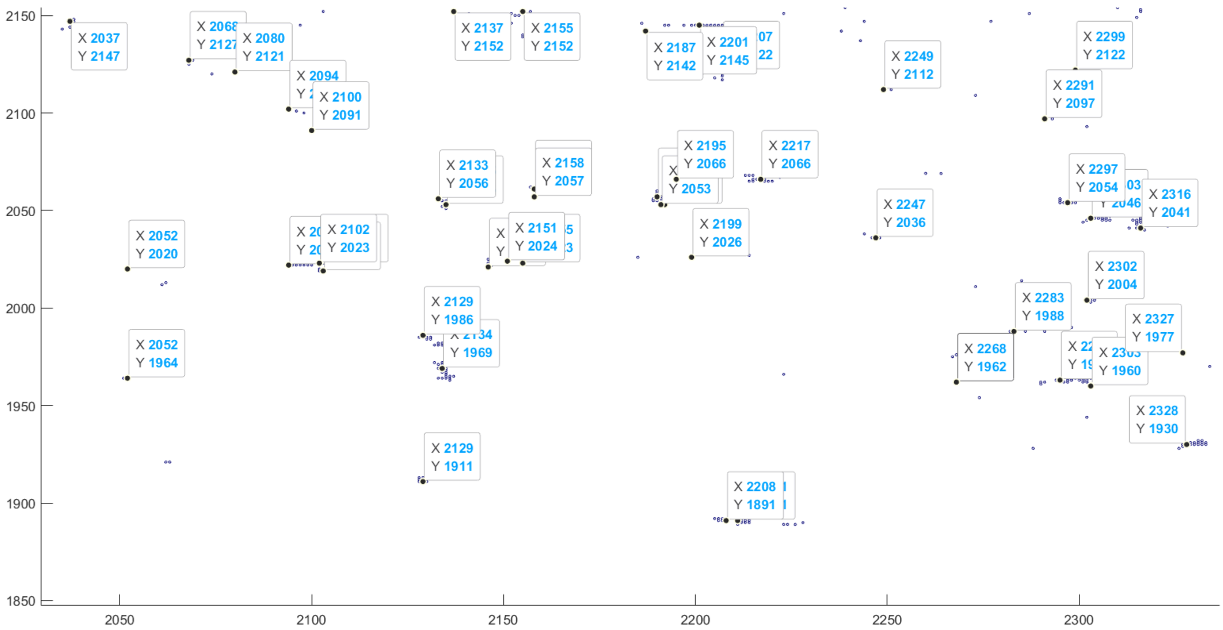

Figure 5. Map of coordinates of selected macro and micro base stations

4. Conclusions

In this paper, for the mobile base station siting problem, a 0-1 planning model based on immune genetic algorithm is proposed, which is able to meet the business requirements while achieving the lowest cost. The model performs well in question D of the 2022 mathorcup challenge, and the results are visualized more objectively. It is worth noting that this paper only considers the idealization of the base station coverage and does not address the real situation where the base station coverage decreases linearly. In the subsequent research, the model can be improved to consider more complex scenarios. In addition, the immune genetic algorithm model proposed in this paper has a wide range of application value in site planning type of problems, such as wireless signal deployment in enterprises and radar station deployment in the military field. Therefore, the model has good generalization significance and is expected to provide effective solutions for the optimization of site selection problems in different fields.

References

[1] BIAN Qiang, XU Donghui, LIU Jiangliang, HE Jingyuan, YANG Haiyu. Research on wireless broadband base station siting algorithm based on hilly area [J]. Journal of Arms and Equipment Engineering, 2023, 44(02): 146-152.

[2] Liu Juan,Yang Chunhua. Particle swarm Drosophila hybrid improvement algorithm in base station site selection optimization problem [J]. Computer and Digital Engineering,2021,49(07):1341-1345+1356.

[3] JIN Weizheng, SONG Chao, LUO Yijun. Site selection planning of base station for electric power wireless private network based on artificial fish swarm algorithm [J]. Journal of Wuhan University (Engineering Edition), 2021, 54(06): 551-556.

[4] TANG Li-Qing, YING Zhongyu, LUO Yun. Base station siting based on whale optimization improvement algorithm [J]. Computer and Modernization,2020, (09): 100-105.

[5] Shan-Shuang. Base station siting optimization problem based on simulated annealing method - Application of simulated annealing method to mathematical planning model for 0-1 planning [J]. Advances in Applied Mathematics, 2023, 12:

[6] FANG Longxiang, YU Xueyu. Network node siting of urban underground logistics system based on 0-1 integer planning algorithm [J]. Journal of Anhui University of Engineering, 2019, 34(05): 53-58.

[7] Xie Xukai, Cheng Songlin. 5G base station site selection planning based on immunogenetic algorithm [J]. Modern Information Technology, 2020, 4(02): 4-6.

[8] Chen Shi. Research on NB-IoT base station siting based on improved artificial immunity algorithm [D]. Nanjing University of Posts and Telecommunications, 2020.

[9] ZHU Si-Feng, LIU Fang, CHAI Qiang-Yi. Immunocomputing-based base station siting optimization for TD-SCDMA networks [J]. Journal of Communication, 2011, 32(01): 106-110+120.

[10] Jiexin Zhang, Yujie Zheng. Intelligent optimization implementation of 3G base station siting [J]. Computer Engineering and Application, 2009, 45(35): 230-232+235.