

# Mobile Communication Network Site Planning Research Based on Simulated Annealing Algorithm Optimization Model

Ruihan Chen<sup>1</sup>, Xiaowen Yang<sup>1</sup>, Heda Xiang<sup>2</sup>, Ming Dai<sup>1, \*</sup>

<sup>1</sup>School of Mathematics and Computer Science, Guangdong Ocean University, Zhanjiang, China, 524088

<sup>2</sup>School of Electrical Engineering, Shanghai University of Electric Power, Shanghai, China, 200090

\*Corresponding author: vj162774@163.com

**Abstract.** With the development of 5G network, it becomes a hot topic to reasonably plan the siting of communication base stations in the weak coverage area of 5G network. In this paper, we take improving the coverage of service volume and reducing the cost of building base stations in the weak coverage area as the target of siting, and select base station sites among 2500×2500 points in a given area under ideal conditions and actual conditions, respectively, and use the less time-complex clustering method to cluster all weak coverage points. In order to improve the feasibility of the model in practical applications, we try to develop the base station site selection scheme that benefits the most for the 5G construction company by setting up a multi-objective planning model based on multiple constraints. On this basis, the conditions of the multi-objective planning model are changed and optimized to obtain a new multi-objective planning model based on the requirement that the communication coverage of base stations is fan-shaped in real life, and the simulated annealing optimization algorithm based on greedy thinking is used to optimize and solve the listed multi-objective planning model to obtain a new station site plan.

**Keywords:** Multi-objective planning, Genetic algorithm based on Pareto ranking, Simulated annealing optimization algorithm, Matlab.

## 1. Introduction

5G network brings more and more convenience to people's life, and it becomes the direction of social workers to spread 5G network to every household. Since wireless networks depend on the supply of communication base stations, we will plan the sites of mobile communication networks according to the range of base stations that can be covered and the cost of building base stations[1].

In this paper, we plan the sites in a given area, and for this type of site selection problem, we can use 0-1 planning to describe whether to choose a site to build a macro base station or a micro base station. The topic requires achieving 90% coverage of weak coverage points, but we want to improve the feasibility of our model in practical applications, so here we aim at maximizing the coverage of weak coverage points and minimizing the cost of building sites. Establish a multi-objective planning model. Based on this, we add two conditions to build a new multi-objective planning model in order to fit the reality[2].

## 2. Model assumptions and notation

### 2.1. Assumptions

1. Assume that walls, tall buildings and other buildings do not cause interference and shielding to the signal.
2. Assume that the base station signal is not affected by changes in terrain height.
3. Assume that the base station coverage signal is not affected by extreme weather, human interference, etc.
4. Assume that the cost of the base station is constant during the construction of a large number of base stations.
5. Assume that the service volume at weak coverage points remains stable over time.

6. Assume that the base station is built once it is located.
7. Assume that the base station is able to provide signals to its coverage area stably for a long time.

## 2.2 Notations

Important notations used in this paper are listed in Table 1.

**Table 1.** Notations

| Notations        | Symbol Description                                                                                                                    |
|------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| $i, j$           | Weak coverage point number                                                                                                            |
| $X_{ii}$         | Horizontal coordinates of the site                                                                                                    |
| $Y_{ii}$         | Vertical coordinate of the site                                                                                                       |
| $AcerStation_i$  | 0-1 variable to determine if a macro base station is built at point i                                                                 |
| $MicroStation_i$ | 0-1 variable to determine if a microbase station is built at point i                                                                  |
| $A_{ij}$         | 0-1 variable to determine if site j is covered by macro base station i                                                                |
| $M_{ij}$         | 0-1 variable to determine if site j is covered by microbase station i                                                                 |
| $Tra_j$          | j point business volume                                                                                                               |
| $Z_{ij}$         | Coordinate matrix of the distance between base station i and base station j (base stations - including macro and micro base stations) |
| $Dist_{ij}$      | The distance between i and j                                                                                                          |
| $\beta_l$        | The angle corresponding to the main direction of the sector                                                                           |
| $\alpha$         | Relative change angle of the main direction of the sector                                                                             |
| $r_\alpha$       | Radius of coverage corresponding to the relative change angle of the main direction of the sector                                     |
| label            | Base Station Type                                                                                                                     |
| $R_{label}$      | Radius of coverage in the main direction of the corresponding base station type sector                                                |

## 3. Model construction and solving

### 3.1. Multi-objective planning model

The objective function of the problem[3].

$$\max \left( \sum_{j=1}^n Tra_j \sum_{i=1}^n (A_{ij} + M_{ij}) / (A_{ij} + M_{ij}) \right) / \sum_{j=1}^n Tra_j \quad (1)$$

Binding Conditions.

The threshold for the distance between the new site and the existing site is 10.

$$Z_{ij} \leq 10, \quad i, j = 1, 2, \dots, 53249 \quad (2)$$

Only one type of base station can be established at point i, i.e.

$$Acer Station_i + Micro Station_i = 1, \quad i = 1, 2, \dots, 53249 \quad (3)$$

According to Euler's formula, it is known that establishing a macro base station or a micro base station at point i has the limitation of coverage, i.e.

$$\begin{aligned} Dist_{ij} \times A_{ij} &\leq 30 \times AcerStation_i, \quad i, j = 1, 2, \dots, 53249 \\ Dist_{ij} \times M_{ij} &\leq 10 \times MicroStation_i, \quad i, j = 1, 2, \dots, 53249 \end{aligned} \quad (4)$$

The correlations between the four sets of decision variables, namely.

$$\begin{aligned} &AcerStation_i A_{ij}, i, j = 1, 2, \dots, 53249 \\ &MicroStation_i M_{ij}, i, j = 1, 2, \dots, 53249 \end{aligned} \quad (5)$$

$$\begin{aligned} &AcerStation_i = A_{ii}, i = 1, 2, \dots, 53249 \\ &MicroStation_i = M_{ii}, i = 1, 2, \dots, 53249 \end{aligned} \quad (6)$$

In summary, a multi-objective planning model for mobile communication network site planning problem is established.

$$Z = F(X) = \begin{bmatrix} \max \left( \sum_{j=1}^n Tra_j \sum_{i=1}^n (A_{ij} + M_{ij}) / (A_{ij} + M_{ij}) \right) / \sum_{j=1}^n Tra_j \\ \min \left( \sum_{i=1}^n 10 \times Acer Station_i + \sum_{i=1}^n Micro Station_i \right) \end{bmatrix} \quad (7)$$

$$s.t. \varphi(X) = \begin{cases} Z_{ij} \geq 10, i, j = 1, 2, \dots, 53249 \\ Acer Station_i + Micro Station_i \leq 1, i = 1, 2, \dots, 53249 \\ Dist_{ij} \times A_{ij} \leq 30 \times Acer Station_i, i, j = 1, 2, \dots, 53249 \\ Dist_{ij} \times M_{ij} \leq 10 \times Micro Station_i, i, j = 1, 2, \dots, 53249 \\ Acer Station_i \geq A_{ij}, i, j = 1, 2, \dots, 53249 \\ Micro Station_i \geq M_{ij}, i, j = 1, 2, \dots, 53249 \\ Acer Station_i = A_{ii}, i = 1, 2, \dots, 53249 \\ Micro Station_i = M_{ii}, i = 1, 2, \dots, 53249 \\ Acer Station_i, Micro Station_i = 0 \text{ or } 1, i = 1, 2, \dots, 53249 \\ A_{ij}, M_{ij} = 0 \text{ or } 1, i, j = 1, 2, \dots, 53249 \end{cases} \quad (8)$$

### 3.2. Improved multi-objective planning model

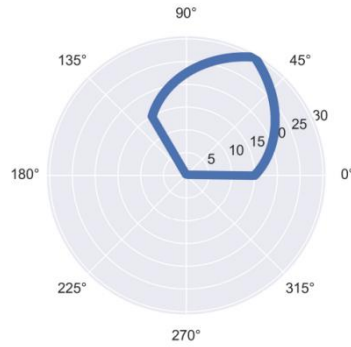
Assuming that the coverage area of the base station is completely circular, the coverage rate of the total service volume of the weak coverage points is as high as 98.4% after the reasonable site planning of 829 macro base stations and 1246 micro base stations. When combined with the actual, i.e., the communication coverage of the base stations is fan-shaped coverage, can the coverage rate of the total service volume of the weak coverage points still reach 90%. Add the following two practical conditions [4].

(1) Each base station is composed of three coverage sectors with linearly decreasing coverage radius from the main direction toward 120°.

(2) The angle between the main directions of any two sectors of each base station must not be less than 45°. Variation of the coverage radius of the base station.

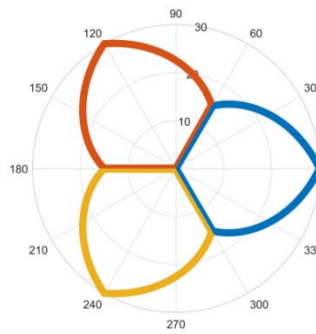
$$r_\alpha = R_{label} \cdot \left( 1 - \frac{\alpha}{120^\circ} \right) \quad (9)$$

$\alpha$  is the relative change angle with respect to the main direction of the sector, and  $r_\alpha$  is the corresponding radius. We visualize the actual coverage range of the base station in one direction. Actual coverage area of base station in one direction is shown in Figure 1.



**Figure 1.** Actual coverage area of base station in one direction

When each sector of the base station is spaced at  $120^\circ$  in the main direction, we visualize its coverage area as shown in Figure 2.



**Figure 2.** Coverage diagram of communication base stations under specific conditions

Based on the above actual situation, we change and optimize the conditions of the multi-objective planning model to obtain the improved multi-objective planning model.

$$Z = F(X) = \begin{cases} \max \left( \sum_{j=1}^n \text{Tra}_j \sum_{i=1}^n (A_{ij} + M_{ij}) / (A_{ij} + M_{ij}) \right) / \sum_{j=1}^n \text{Tra}_j \\ \min \left( \sum_{i=1}^n 10 \times \text{Acer Station}_i + \sum_{i=1}^n \text{Micro Station}_i \right) \end{cases} \quad (10)$$

$$\text{s.t. } \varphi(X) = \begin{cases} Z_{ij} > 10, i, j = 1, 2, \dots, 53249 \\ \text{Acer Station}_i + \text{Micro Station}_i \leq 1, i = 1, 2, \dots, 53249 \\ \text{Dist}_{ij} \times A_{ij} \leq r_\alpha \times \text{Acer Station}_i, \alpha = 1^\circ, 2^\circ, \dots, 60^\circ \\ \text{Dist}_{ij} \times M_{ij} \leq r_\alpha \times \text{Micro Station}_i, \alpha = 1^\circ, 2^\circ, \dots, 60^\circ \\ \beta_I - \beta_J \geq 45^\circ, I, J = 1, 2, 3 \text{ and } I \neq J \\ \text{Acer Station}_i \geq A_{ij}, i, j = 1, 2, \dots, 53249 \\ \text{Micro Station}_i \geq M_{ij}, i, j = 1, 2, \dots, 53249 \\ \text{Acer Station}_i = A_{ii}, i = 1, 2, \dots, 53249 \\ \text{Micro Station}_i = M_{ii}, i = 1, 2, \dots, 53249 \\ \text{Acer Station}_i \text{ Micro Station}_i = 0 \text{ or } 1, i = 1, 2, \dots, 53249 \\ A_{ij}, M_{ij} = 0 \text{ or } 1, i, j = 1, 2, \dots, 53249 \end{cases} \quad (11)$$

### 3.3. Model solving-simulated annealing algorithm to optimize the model

The simulated annealing algorithm consists of two parts, namely the Metropolis algorithm and the annealing process, which correspond to the inner and outer cycles, respectively. The outer loop is the

annealing process, where the solid is brought to a higher temperature (initial temperature  $T(0)$ ), and then the temperature decreases in a certain proportion according to the cooling factor  $\alpha$ , and when the termination temperature  $T_f$  is reached, the cooling ends, i.e., the annealing process ends [5-7].

The Metropolis algorithm is an inner loop, i.e., at each temperature, iterates  $L$  times to find the minimum value of energy at that temperature (i.e., the optimal solution). The figure below shows the change in the energy of the solid at one temperature for  $L$  iterations. At this temperature, the temperature does not change throughout the iteration and the energy changes. When the energy of the previous state  $x(n)$  is greater than the energy of the next state  $x(n+1)$ , the solution for state  $x(n)$  is not as good as the solution for state  $x(n+1)$ , so state  $x(n+1)$  is accepted. When the energy of the next state is higher than that of the previous state, the acceptance probability  $P$ , is used to determine whether to accept it[8].

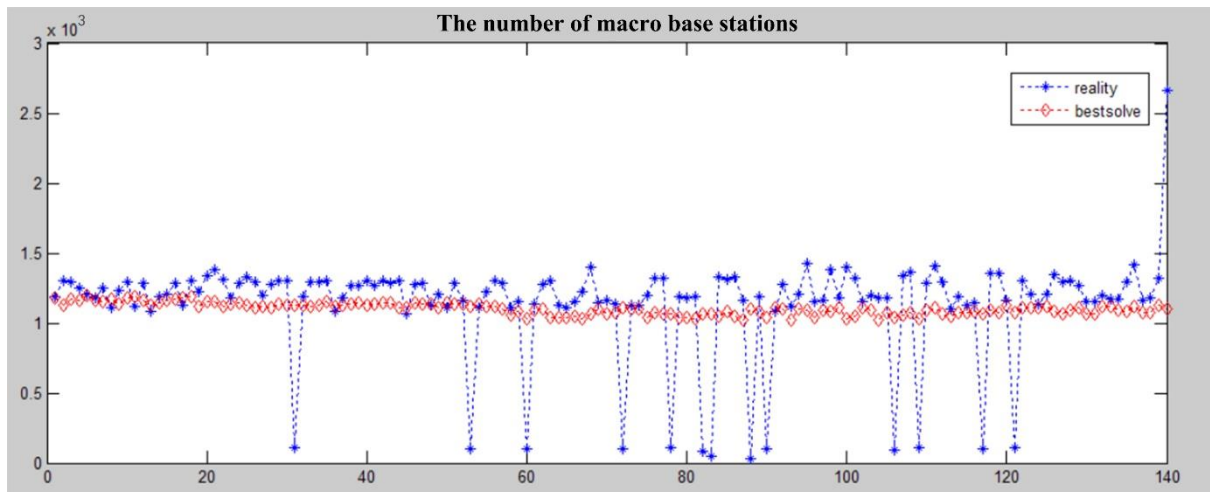
Suppose the previous state is  $x(n)$ , and the system changes state to  $x(n+1)$  according to a certain indicator (gradient descent, energy of the previous section), accordingly, the energy of the system changes from  $E(n)$  to  $E(n+1)$ , define the acceptance probability  $P$  for the system to change from  $x(n)$  to  $x(n+1)$  as.

$$P = \begin{cases} 1 & , E(n+1) < E(n) \\ e^{-\frac{E(n+1)-E(n)}{\tau}} & , E(n+1) \geq E(n) \end{cases} \quad (12)$$

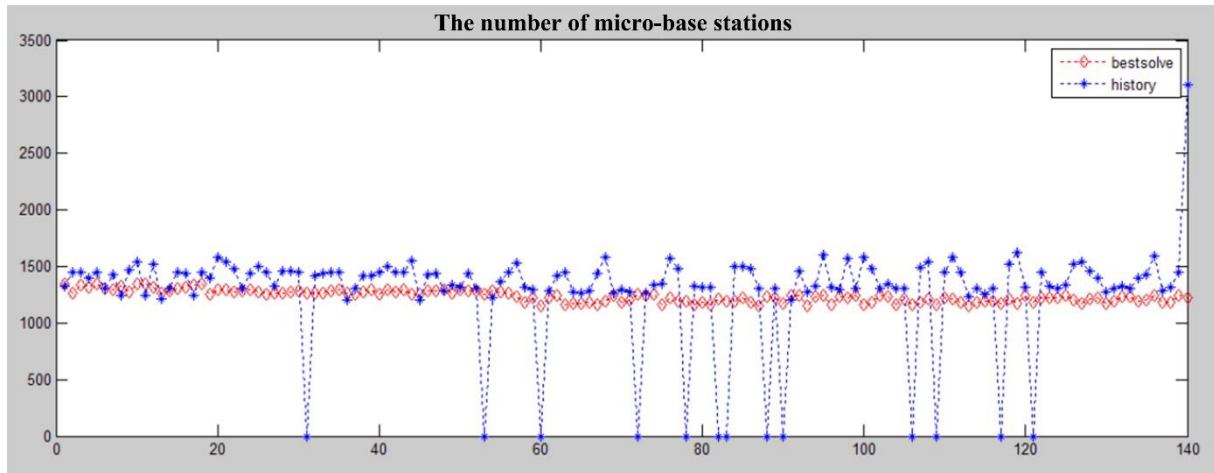
As can be seen from the above equation, if the energy decreases, the transfer occurs immediately, if the energy increases, it means that the system deviates further from the position of the global optimum, at this point the simulated annealing algorithm does not discard it immediately, but carries out a probabilistic operation: first generate a uniformly distributed random number  $\theta$  in the interval  $(0,1)$ , if  $\theta \leq P$ , then such transfer is accepted, and vice versa, the transfer is rejected and goes to the next step, and the cycle repeats. The amount of energy change and  $T$  determine the magnitude of the probability  $P$ , so the value of  $P$  is dynamically changing, the longer the simulated annealing time, the smaller  $P$  relatively, until the temperature  $T$  tends to  $\theta$ , the end of the algorithm[9].

From the objective function of the multi-objective planning model, we can see that the total number of independent variables is 3, which refer to the amount of weak coverage point traffic, the number of macro base stations, and the number of micro base stations, respectively. In solving the model, we use the principle of simulated annealing algorithm to get the final result.

MATLAB gives a set of optimal solutions for 140 historical data, where the number of macro base stations and the number of micro base stations are shown in Figure 3, and the line graphs shown in Figure 4, respectively.



**Figure 3.** Simulated annealing algorithm simulates the number of macro base stations folded graph

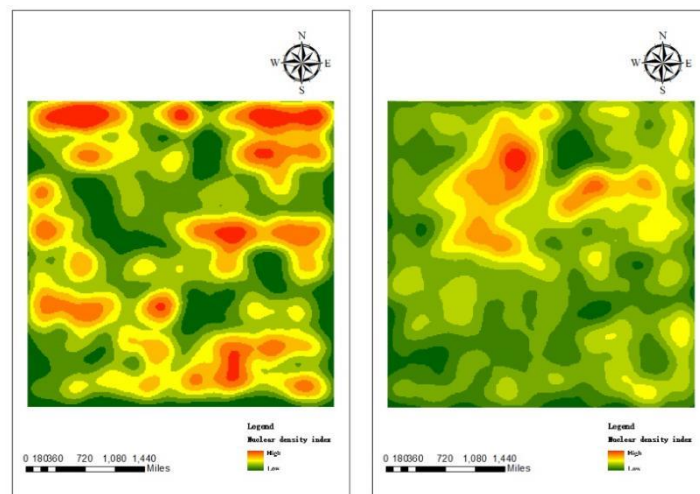


**Figure 4.** Simulated annealing algorithm simulates a line graph of the number of micro-base stations

The simulated annealing algorithm calculates the number of macro base stations to be 1136, the number of micro base stations to be 1384, the cost to be 12774, and the coverage rate to be 90.84%.

To sum up: the new base stations can cover 90% of the total service volume of weak coverage points.

Finally, we visualize the distribution of macro and micro base stations, and use ArcGIS software to analyze the kernel density of the distribution of macro and micro base stations respectively, and derive the heat map of base stations, as shown in Figure 5.



**Figure 5.** Heat map of the distribution of macro-communication base stations (left) and micro-communication base stations (right)

## 4. Conclusion

The multi-objective planning model established can be closely related to the reality, and the proposed problem is solved from the perspective of the 5G construction company [10], which makes the model closer to the reality and more general and generalizable; the model is solved using a multi-objective genetic algorithm based on Pareto sorting, which is relatively new, and the solved results are more relevant to the reality and objective and accurate ; solving the problem in two rows using a simulated annealing algorithm based on greedy thinking and probability, the results are closer to the requirements.

## References

- [1] Cen Zhongdi. Solution of multi-objective planning based on genetic algorithm [J]. Journal of Zhejiang Wanli College, 2001(02):6-8.
- [2] Wang Xiaohua, Yang Na. Parameter optimization estimation model based on genetic algorithm [J]. Electronic World, 2012(24):118-119.
- [3] Li Jia-Xin. A study on multi-target microgrid optimization scheduling based on legacy algorithm [J]. China Equipment Engineering, 2022(03):137-139.
- [4] Fan ZK, Ren QH, Zhang GW. Directional modulation based on multi-objective genetic simulated annealing algorithm [J]. Journal of Air Force Engineering University (Natural Science Edition), 2021, 22(02): 48-53.
- [5] Sun L, Liang YQ. An improved clustering algorithm incorporating mesh partitioning and DBSCAN [J/OL]. Computer Engineering and Applications:1-9 [2022-04-18].
- [6] Chen Xiaohui, Xi Qinggang. Research and implementation of DBSCAN-based adaptive clustering algorithm [J]. Journal of Huaiyin Normal College (Natural Science Edition), 2021, 20(03): 228-234.
- [7] Shi Shoukui, Sun Zhaoliang. Mathematical modeling algorithms and applications [M]. Beijing: National Defense Industry Press, 2017.
- [8] Jiang Qiyuan, Mathematical Modeling (2nd ed.), Beijing: Higher Education Press, 2003
- [9] Lv F, Tian Yue, Li Yun. 5G base station planning and control from the perspective of application scenario analysis [C]// Spatial Governance for High-Quality Development - Proceedings of the 2020 China Urban Planning Annual Conference (13 Planning Implementation and Management). 2021: 604- 609.
- [10] Xu Ting. Analysis of the problems of 5G base station planning and construction [J]. China New Communication, 2021, 23(02):33-34.