Optimal Planning of Base Station Location and Sector Direction Based on Simulated Annealing algorithm

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Abstract:- Nowdays, the base stations and antennas become more and more complicated, which makes the choice of base station location of communication network more and more complicated, and needs to solve the weak coverage problem of the existing network. In this paper, data preprocessing is firstly carried out, base station distance threshold is selected as the constraint condition, base station site model is established, site selection is carried out, and three sector main direction angles of each base station are determined according to the sector direction and coverage traffic constraints between the selected base stations. The simulated annealing algorithm based on 0-1 planning was used to solve the 2500×2500 candidate region iteratively, and finally the optimal coordinates and the optimal principal direction angle of the new macro base station and micro base station were obtained.

Keywords:- *Site planning ; Simulated annealing algorithm ; 0-1 planning ; Sector angle optimization*

I. INTRODCUTION

The Times are moving on and the communication network becomes more and more complex. Mobile communication network site planning is the key to promote the quality of mobile communication network. In order to improve the weak coverage area in the network planning scheme, it is necessary to deploy and plan the base station. The design of the deployment base station needs to consider various factors comprehensively to meet the network design objectives while minimizing the cost[1.].

II. PROBLEM BACKGROUND

In the actual project, there are mainly two kinds of base stations, namely macro base station (coverage area 30, cost 100,000 yuan) and micro base station (coverage area 10, cost 10,000 yuan)[2.]. In this paper, macro base station and micro base station are referred to as A-BS and B-BS respectively. The mimimum distance between the new station and the existing station is 10. Each base station has three main directions, each main direction have the maximum coverage, in the main direction around 60 degrees where the coverage of the main direction of half of the coverage can be covered. Above 60 degrees, the sector cannot be overwritten. The angle between the main directions cannot be less than 45 degrees. In this paper, the optimization algorithm is used to plan the base station site and the main direction angle of the sector, so that the total traffic of the covered weak coverage points can reach the maximum and the total cost of the base station construction can be minimized. The location distribution diagram is shown in Figure 1:

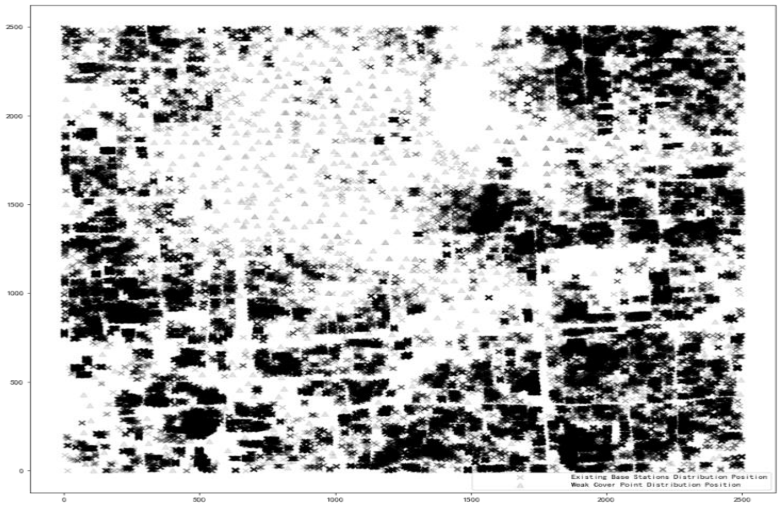

Fig. 1: Distribution of base stations

III. MODEL ESTABLISHMENT AND SOLUTION

A. Define variable

For the location planning of base stations, this paper defines the decision variables a_{ij} and b_{ij} as two 0-1 variables:

$$a_{ij}=\begin{cases}1 \ Establish\ a\ macro\ base\ station\ at\ (i,j)\\0\ no\end{cases}$$
$$b_{ij}=\begin{cases}1 \ Establish\ a\ micro\ base\ station\ at\ (i,j)\\0\ no\end{cases}$$
(1)

For the main direction angle of the new base station, variable θ_{lij} $(l=1,2,3)$ is introduced to represent the polar angle of the three main directions of the new base station.

B. Data preprocessing

For existing base stations, the distance between all base stations within the range of 50 is calculated, and the distance value obtained is approximately replaced by the distance between any two new base stations, and the distance between all base stations is sorted in ascending order. The smallest of the top 90% data is taken as the threshold between the B-BS and the B-BS; the smallest of the top 80% data is taken as the threshold between the A-BS and the B-BS; the smallest of the top 70% data is taken as the threshold between the A-BS and the A-BS. Finally, the threshold of B-BS and B-BS is set as 13, the threshold of A-BS and B-BS is 26, and the threshold of A-BS and A-BS is 40.

- The distance threshold between the existing network base station and the new base station is bigger than or equal to 10, that is:

$$\sqrt{(i_k-i_c)^2+(j_k-j_c)^2}\geqslant 10 \Leftrightarrow \begin{cases}|P_a-P_c|\geqslant 10\\|P_b-P_c|\geqslant 10\end{cases} k=a,b \quad (2)$$

Where, P_a is the coordinates that the A-BS may choose, P_b is the coordinates that the B-BS may choose, and P_c is the coordinates of the existing base station.

- The distance threshold between the new A-BS and the new B-BS is bigger than or equal to 26, that is:

$$for\ \forall\,(i_a,j_a)\in A,(i_b,j_b)\in B$$
$$\sqrt{(i_a-i_b)^2+(j_a-j_b)^2}\geqslant 26 \Leftrightarrow |P_a-P_b|\geqslant 26 \quad (3)$$

- The distance threshold between the new A-BS and the new A-BS is bigger than or equal to 40, that is:

$$for\ \forall\,(i_a,j_a)\in A,(i_a',j_a')\in A$$
$$\sqrt{(i_a-i_a')^2+(j_a-j_a')^2}\geqslant 40 \Leftrightarrow |P_a-P_a'|\geqslant 40 \quad (4)$$

- The distance threshold between the new B-BS and the new B-BS is bigger than or equal to 13, that is:

$$for\ \forall\,(i_b,j_b)\in B,(i_b',j_b')\in B$$
$$\sqrt{(i_b-i_b')^2+(j_b-j_b')^2}\geqslant 13 \Leftrightarrow |P_b-P_b'|\geqslant 13 \quad (5)$$

It is specified T as the region 2500×2500 coordinate set, C is the coordinate set of the existing base station, D is the coordinate set of the new A-BS and M is the coordinate set of the new B-BS. Therefore, the data filtering flow chart is shown in Figure 2:

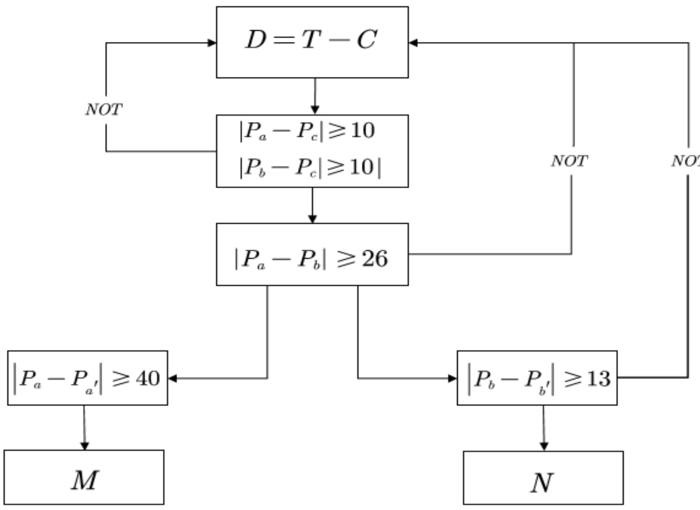

Fig. 2: Data screening flow chart

After screening, M and N are the coordinate sets that may be built are obtained of A-BSs and B-BSs.

C. New base station coverage

Each base station has three sectors, each sector has a main direction, and the coverage is linearly reduced[3.]. The coverage area (when the coverage area is the largest) is shown in Figure 3:

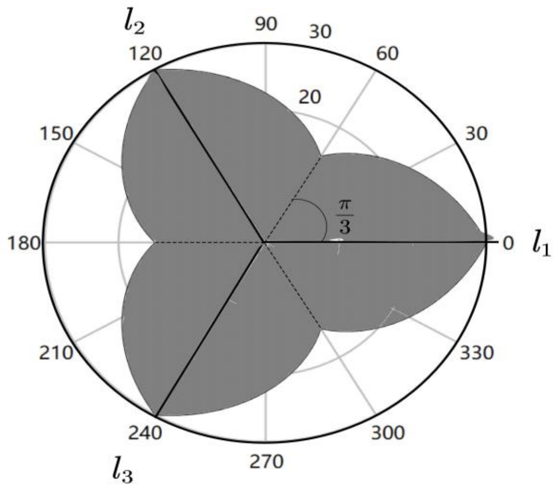

Fig. 3: Three sectors coverage diagram of base station

Among them, l_1, l_2 and l_3 are the three main directions, the pairwise between the three can not be less than 45 degree, and the shadow part is the coverage of the base station. The product, dotted line is the boundary dividing the three regions. And polar coordinates are introduced to establish the model.

The coordinates of the new base station are poles and the x are poles.The boundary curve equation under polar coordinates is given as:

$$\rho_{ij}(\theta) = k \cdot \theta + \lambda \qquad \theta \in \left[-\frac{\pi}{3}, \frac{\pi}{3}\right] \tag{6}$$

Where, ρ_{ij} is the covering pole diameter of the new base station and θ is the covering pole angle of the new base station.

Taking A-BS (coverage area 30) as an example, when the main direction is aligned with the axis, the curve passes three points:

$$(30, 0), \left(15, \frac{\pi}{3}\right), \left(15, -\frac{\pi}{3}\right)$$

Substituting into the equation:

$$\begin{cases} When\ \theta \in \left[0, \frac{\pi}{3}\right],\ k = -\frac{45}{\pi}, \lambda = 30 \\ When\ \theta \in \left[-\frac{\pi}{3}, 0\right), k = \frac{45}{\pi},\ \lambda = 30 \end{cases}$$

Therefore, the equation of the boundary curve of the A-BS with respect to the polar angle θ is :

$$\rho_{ij}(\theta) = \begin{cases} -\frac{45}{\pi} \cdot \theta + 30, \theta \in \left[0, \frac{\pi}{3}\right] \\ \frac{45}{\pi} \cdot \theta + 30, \theta \in \left[-\frac{\pi}{3}, 0\right) \end{cases} \tag{7}$$

Similarly, the equation of the boundary curve of the B-BS point about the polar angle is as follows:

$$\rho_{ij}(\theta) = \begin{cases} -\frac{45}{\pi} \cdot \theta + 10, \theta \in \left[0, \frac{\pi}{3}\right] \\ \frac{45}{\pi} \cdot \theta + 10, \theta \in \left[-\frac{\pi}{3}, 0\right) \end{cases} \tag{8}$$

Let the coordinates of the new base station is (i_k, j_k), the coordinates of the weak coverage point is (x_d, y_d), its polar angle is θ, and the distance between two points is ρ_d.As shown in Figure 4:

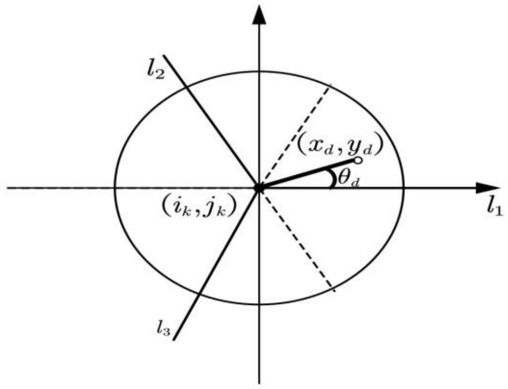

Fig. 4: Schematic diagram of polar coordinates system

From the coordinates of the weak coverage point and the coordinates of the new base station, the polar angle of the weak coverage point is obtained:

$$\begin{cases} \rho_d = \sqrt{(x_d - i_k)^2 + (y_d - j_k)^2} \\ x_d - i_k = \rho_d \cos\theta_d \\ y_d - j_k = \rho_d \sin\theta_d \\ \tan\theta_d = \frac{y_d - j_d}{x_d - i_d}, x_d - i_d \neq 0 \end{cases}$$

Let $\theta'_d = \theta_d - \theta_{lij}$, where $\theta_d, \theta_{lij} \in [-\pi, \pi], \theta'_d \in \left[-\frac{\pi}{3}, \frac{\pi}{3}\right]$,when $|\theta'_d|$ is the minimum value , by substituting θ'_d into the boundary equation of the A-BS and the B-BS, the covering pole diameter ρ_{ij} corresponding to the pole angle of the point can be obtained, and the comparison between ρ_{ij} and ρ_d shows whether the point is covered. Therefore, the set of weak coverage points P_d and the total traffic Σt_d contained in the A-BS and B-BS are：

$$P_d \in \{(x_d, y_d) | \rho_d \leqslant \rho_{ij}\}$$
$$\alpha_{ij} + \beta_{ij} = \Sigma t_d$$

Where, respectively, α_{ij} and β_{ij} represent the total service volume of weak coverage points within the coverage range of A-BSs and B-BSs, and t_d represents the service volume at the points P_d.

D. Construct objective function

The coordinates of A-BS and B-BS selected by the data, according to the coverage area of A-BS and B-BS, find the weak coverage point within the coverage area, and calculate the total cost of new base station and the percentage of total business volume of new base station in the total business of weak coverage points:

$$\begin{cases} Z = 10 \sum_{(i,j) \in M} a_{ij} + \sum_{(i,j) \in N} b_{ij} \\ \eta = \dfrac{\sum_{(i,j) \in M} a_{ij}\alpha_{ij} + \sum_{(i,j) \in N} b_{ij}\beta_{ij}}{\Sigma t_d} \times 100\% \end{cases} \tag{9}$$

Where, Z represents the total cost of building a new base station, which η is the percentage of total business volume of new base station in the total business of weak coverage points.

To sum up, the construction objective function E is as follows:

$$\min E = \Sigma t_d \cdot \frac{10 \sum_{(i,j) \in M} a_{ij} + \sum_{(i,j) \in N} b_{ij}}{\sum_{(i,j) \in M} a_{ij}\alpha_{ij} + \sum_{(i,j) \in N} b_{ij}\beta_{ij}}$$

$$s.t. \begin{cases} a_{ij}, b_{ij} = 0 \ or \ 1 \\ a_{ij} + b_{ij} \leqslant 1 \\ \theta_{lij} \in [-\pi, \pi] \quad l = 1,2,3 \\ |\theta_{1ij} - \theta_{2ij}| \geqslant \dfrac{\pi}{4} \\ |\theta_{1ij} - \theta_{2ij}| \geqslant \dfrac{\pi}{4} \\ |\theta_{2ij} - \theta_{3ij}| \geqslant \dfrac{\pi}{4} \end{cases} \tag{10}$$

IV. MODEL SOLVING

Starting from a high initial temperature, the simulated annealing algorithm randomly searches for the global optimal solution of the objective function in the solution space with the decrease of temperature and the change of state, that is, the local optimal solution tends to the global optimal[4.]. The objective function can be regarded as an energy function. In order to obtain the global minimum of the objective function, an initial model must be assumed as the initial energy value, and then the objective function moves in the decreasing direction with appropriate cooling speed, and the search parameters converge. In this algorithm, the receiving probability of jumping from state A to state B satisfies the Metropolis criterion[5.]:

$$P = \begin{cases} 1 & E(n+1) < E(n) \\ \exp\left(\dfrac{E(n+1) - E(n)}{T}\right) & E(n+1) \geqslant E(n) \end{cases} \tag{11}$$

The simulated annealing algorithm is used to locate the base station, and the whole process is an optimization process. The process of the algorithm is shown in Figure 5.

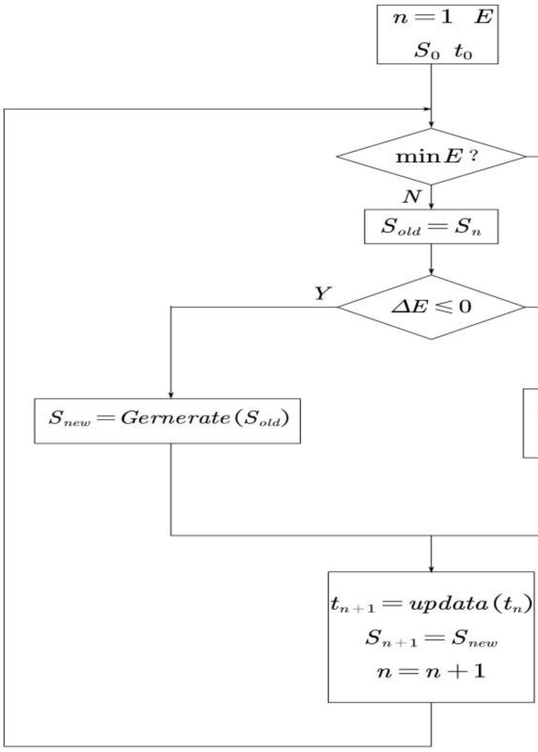

Fig. 5: Flowchart of simulated annealing algorithm

After the site selection of the base station, the three main directions angle of each base station are determined. The direction angle of a sector of a base station is determined based on the movement direction of the maximum coverage traffic of a single sector, and the weak coverage points covered in the specified angle sector are eliminated. Then, with the angle limitation between the first main direction angle as the constraint, the main direction angle of the second sector is determined with the target of the maximum service volume covered by the sector, and so on, the main direction angle of the third sector of the base station is determined iteratively, so that the three main directions of each base station are determined.

V. MODEL RESULTS

After iterative solution, the coordinate location of A-BS and B-BS can be obtained as shown in Table 2 (only some coordinate points and main direction angle of base station are shown) :

Table 2: Location of base station coordinates and direction angle table

Number	x	y	Label	traffic	Angle1	Angle2	Angle3
1	994	1854	0	16954.92325	2.5132752	1.7278767	3.2986737
2	570	650	0	2937.894392	0.6283188	-0.1570797	1.4137173
3	574	2352	0	520.869703	0.6283188	-0.1570797	1.4137173
4	1460	223	0	246	0	-0.7853985	0.7853985
5	704	450	0	21720.05989	4.3982316	3.6128331	5.1836301
6	194	2190	0	69.573175	3.7699128	2.9845143	4.5553113
7	711	828	1	4451	5.6548692	4.8694707	6.4402677
8	818	2020	0	0	3.141594	2.3561955	3.9269925
…	…	…	…	…	…	…	…
1257	1051	1346	0	0	4.3982316	3.6128331	5.1836301
1258	2471	1923	0	0	5.0265504	4.2411519	5.8119489
1259	1484	1224	0	16604.72726	0.6283188	-0.1570797	1.4137173

Note: 1 means A-BS, 0 means B-BS

VI. CONCULSION

On the premise that the coverage of base stations is linearly reduced, the model in this paper calculates the number of base stations in the actual project, removes the sites that do not meet the requirements according to the distance threshold of base stations, and screens out the coordinates of base stations that may be built. By establishing 0-1 site planning model and combining constraint conditions and simulated annealing algorithm, it is obtained that in the 2500×2500 region, 1093 new A-BSs and 669 new B-BSs are built, with a total cost of 115.99 million yuan, and the business volume of new base stations accounted for 86.7% of the total business volume of weak coverage points.

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