Study of 0-1 backpack planning based on simulated annealing algorithm and greedy algorithm for base station coverage and clustering problems

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Abstract. For the base station siting and planning problem in the communication industry, we first establish a 0-1 backpack dynamic planning model, and then use the simulated annealing algorithm and greedy algorithm to continuously optimize the base station sitting under different requirements. Moreover, the coverage area of the considered base stations is closer to the actual one (i.e., three sectoral areas). In this regard, we first establish the polar coordinate system to study the relationship between the change of the main direction angle of a single base station and the coverage area and then use the hierarchical clustering algorithm to classify the main direction angles of the three areas into three categories based on the distribution of weak coverage points around the stations and find the three best main direction angles of a single base station. And the greedy algorithm is used to solve the problem from local to overall so that each base station can cover the weakest coverage points as much as possible, and finally get a more ideal result that the total weak coverage rate of all base stations reaches 79.8%.

Keywords: 0-1 backpack problem, Greedy algorithm, Simulated annealing algorithm.

1. Introduction

With the rapid development of mobile communication technology scale, the scale of mobile communication operations is also getting bigger and bigger, which leads to bringing more and more complex communication networks and the planning difficulty also rises. Meanwhile, with the rapid development of 5G, the bandwidth of communication is getting larger and larger, but the coverage area of base stations is getting smaller and smaller, so the number of base stations needed to cover the same area becomes more and more, and the types of base stations and antennas also increase, so the problem of base station planning becomes more complicated, so it is particularly important to select several sites from the optional candidate sites to achieve the maximum coverage of the area.

2. Model Establishment and Solution

2.1. Model Establishment

In this paper, the base station siting problem is categorized as a 0-1 backpack planning problem. For this problem, a total of n base stations needs to be selected, and the service volume of the base station j is w_j, assuming that the service volume of the base station is non-negative and the maximum total service volume is W.

So that 90% of the total service volume of the weak coverage points is covered by the planned base stations. In which we need to select the locations where base stations can be built according to the constraints and plan whether to choose to build macro base stations or micro base stations for these base stations, introducing the 0-1 variables p_i, q_i. When $p_i = 0$, the base station will not be built. When $p_i = 1$, the base station will be built. When $q_i = 0$, the micro base station is chosen to be built. When $q_i = 1$, the macro base station is chosen to be built.

We choose the idea of the value density greedy method to solve this kind of backpack problem.

Let the total weight of the backpack be the maximum total service *W*. Each coordinate that meets the constraint is called a proposed site, and there is a discussion on whether each proposed site should be built as a micro-base station or a macro-base station. If a micro base station is built, the value density of the proposed site is $v_i/10$, where v_i denotes the number of services that can be performed by the micro-base station. If a macro base station is built, the value density of the proposed site is $v_i/30$, where v_i denotes the service volume that can be accomplished by the macro base station. Each time we choose the proposed site with the highest value density to build. Until the constraint *W* is greater than ninety percent of the total service volume is satisfied.

On this basis, we establish the 0-1 integer planning model with the largest business volume, and the decision variables in the model as well as the objective function and constraints are as follows.

Objective function: Total service volume of new base stations

$$\max W = \sum_{i=1}^{n} w_i p_i q_i \tag{1}$$

Decision variables: choice of whether to build a base station, choice of the type of base station construction

Constraints:

(1) The Euclidean distance between the new base station and the weak coverage point is less than 30 of the coverage range of the macro base station or 10 of the coverage range of the micro base station

(2) The threshold for the distance between the new station site and the existing station site is 10

(3) The selection of the base station is only selected and unselected, as 0 or 1

(4) The construction type of base station is an only a micro base station or macro base station, like 0 or 1

$$s.t.\begin{cases} \sum_{i=1}^{n} w_i p_i q_i \geq 6350607 \\ \sqrt{(x-x_0)^2-(y-y_0)^2} \geq 10, (x, y\ is\ the\ base\ station\ to\ be\ determined) \\ p_i, q_i = 0,1 \\ \sqrt{(x-x_0)^2-(y-y_0)^2} \leq 30, (x, y\ is\ macro\ base\ station) \\ \sqrt{(x-x_0)^2-(y-y_0)^2} \leq 10, (x, y\ is\ micro\ base\ station) \end{cases} \tag{2}$$

2.2. Simulated annealing algorithm for solving dynamic programming models

We choose the simulated annealing algorithm as the solution method based on greedy thinking. The simulated annealing algorithm has two levels of loops; loop one, iterative iteration to generate new solutions, which are generated by random perturbation at any temperature in the process of cooling down and calculate the change of the objective function value to decide whether it is accepted or not. Loop two, slow cooling repeats the iterative process, slowly decreasing the temperature after the completion of iteration at a fixed temperature, so that the algorithm may eventually converge to the global optimal solution.

Since the initial temperature of the algorithm is relatively high, through the iterative process of loop one, the new solution that makes E increase may also be accepted with some probability at the beginning, thus being able to jump out of the local minima. And, although the acceptance function is already very small at low temperatures, the possibility of accepting worse solutions is still not excluded, so we record the best feasible solution (historical optimal solution) encountered during the annealing process as well and let it be output together with the last accepted solution before terminating the algorithm to prevent missing the optimal solution.

In the present application, the annealing process is controlled by a set of initial parameters, i.e., the cooling schedule, which is centered on trying to bring the system to quasi-equilibrium so that the algorithm approaches the optimal solution in a finite time.

Selection of parameters:

(1) Initial solution x_0 and initial value T_0

Based on the preliminary analysis of the global optimal solution and the search range, combined with the size of the problem, we choose the initial solution x_0 is the service volume covered by any proposed base station, and the initial value T_0 is 90.

(2) control parameters T_i and its decay function

Because of the special nature of this problem, we construct a special decay function to "cool down" the program. The common attenuation function is $T_{i+1} = \alpha T_i, i = 0,1,2,\cdots$, where α can take the value of 0.95.

(3) Markov chain length

It is known that the Markov chain length should be chosen such that a quasi-equilibrium state is reached at each value of the control parameters, which for the simple case can be directly given as L_i=100n, where n is the scale. Here we take n=5 and L_i=500.

(4) Acceptance function

$$p(i \Rightarrow j) = \begin{cases} 1, f(i) \le f(j) \\ exp\left(\frac{f(i)-f(j)}{kL_i}\right), else \end{cases} \tag{3}$$

When the high-temperature case of L_i is relatively large, the denominator on the index is relatively large and this is a negative index at this time, so the probability of acceptance is close to one, i.e., a new solution x_j that is worse than the current solution x_i may also be accepted, thus providing the possibility of jumping out of the local optimal solution.

(5) Stopping conditions

$$T_i < T_f = 0.01 \tag{4}$$

At high temperature sufficient wide-area search has been performed to find the region where the best solution may exist, while at low temperature in a sufficient local search, it is likely to find the global optimal solution, so a sufficiently small number was set for T_f.

We finally calculated the number of macro base stations to be built as 894, and micro base stations as 978. The percentage of new base stations business to total business is 90.56741%. All new base station locations are shown in Figure 1.

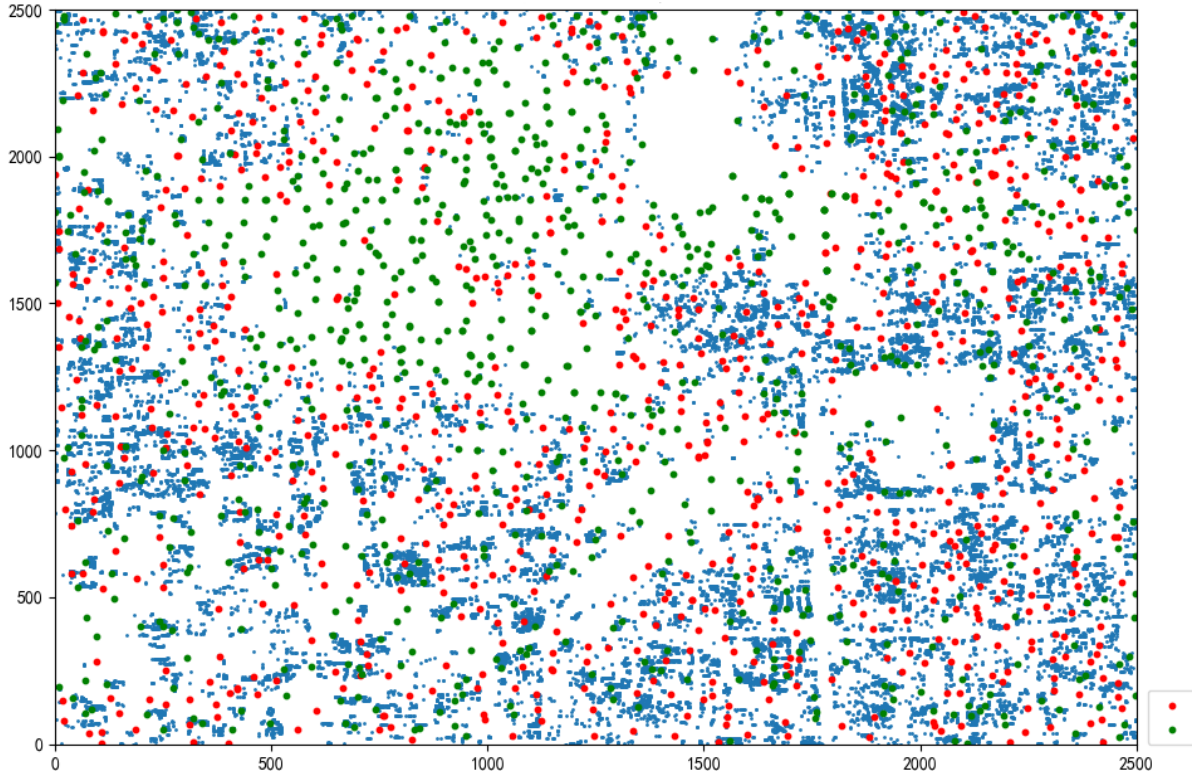


Figure 1. Distribution of new base stations

2.3. Optimization of the coverage area

We consider more closely the reality, where the coverage area is changed from the original circular range to three sectors that will change direction, so we decide to build the planning with angle as the independent variable and use the greedy algorithm to solve it.

2.3.1. Establish the polar coordinate system

The coverage area of each base station is not exactly circular, but each base station has 3 sectors of coverage area, where each sector points in one direction. And each sector has the maximum coverage in the main direction (30 for macro base stations and 10 for micro base stations) and can be covered within 60 degrees to the left and right of the main direction, and the coverage area is gradually reduced linearly, and at 60 degrees, the coverage area is half of the coverage area in the main direction. Beyond 60 degrees, it cannot be covered by this sector, thus we intend to analyze the coverage of the base station at different angle changes, for which we establish the polar coordinate system.

We establish the polar coordinate system horizontal axis is 0°, and because the angle change of the main direction of the sector area is 0°-360°, and the angle between any two main directions should be greater than 45°, so we assume that the radius of the unit circle is R, the angle between the main direction and the horizontal axis is θ, to get the radius formula is

$$R = k\theta + t \text{ (both k and t are linear parameters)} \tag{5}$$

And because the coverage area of the base station is only 1/2 of the coverage area in the main direction when the main direction is extended by 60 degrees, it is obtained that

$$R = \frac{\pi}{2}k + t, \frac{R}{2} = \frac{\pi}{6}k + t \tag{6}$$

It can be solved that $k = 3R/2\pi$, $t = R/4$.

2.3.2. Coverage Analysis

By obtaining the coverage variation law of each sector of the base station earlier, we then analyze a single macro base station as an example and solve for the variation of the angle of the main direction and the number of coverage points under the coverage constraint of this macro base station, and the visualization analysis is shown in Figure 2.

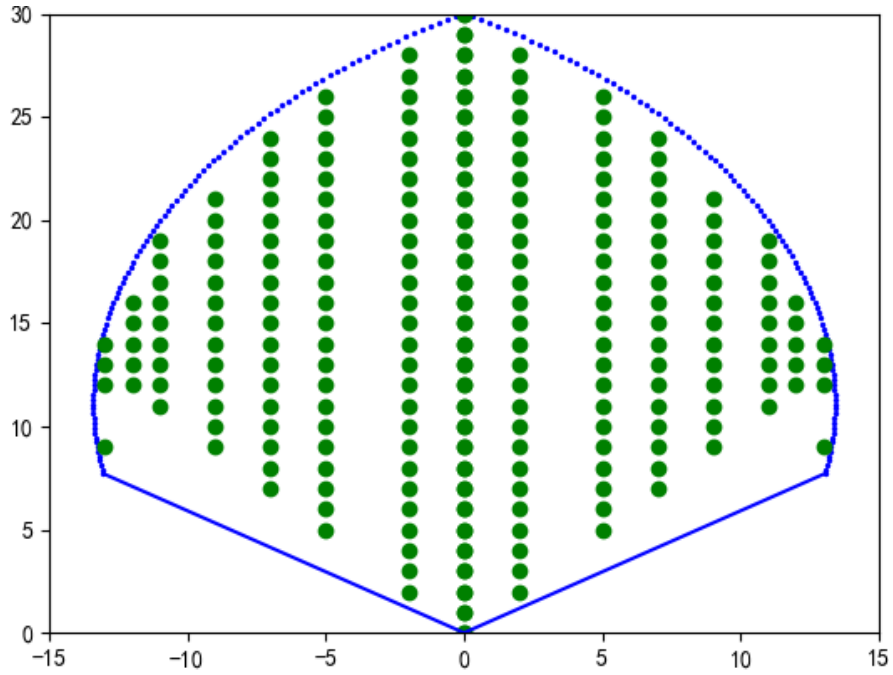


Figure 2. Coverage of macro base stations

2.3.3. Main direction cluster

After analyzing the coverage of individual base stations, we then decided to use the systematic (hierarchical) clustering method and the greedy algorithm to obtain the degrees of the three main directions of each base station based on the distribution of weak coverage points around each base station in turn. Systematic clustering is a method to divide each sample into several classes. The basic idea is to first consider each sample into one class, then specify the distance between classes, select the pair with the smallest distance to merge into a new class, calculate the distance between the new class and other classes, and then merge the two classes with the closest distance, thus reducing one class at a time until all samples are combined into one class.

The number of samples is assumed to be n (in this case, the three main directional angle samples of each base station) and the number of clusters is k (here, the parameter variables that can be set and will be set continuously until the optimal solution is found). For the variable clustering analysis, it is only necessary to replace the distance with the similarity coefficient p, and then the variables with larger similarity coefficient p are clustered separately.

In the initial state, the systematic clustering method treats each sample as a cluster, i.e., $k=n$. The two most similar samples are then merged into one cluster to obtain $k=n$-1; the two most similar clusters are again found in the remaining n-1 clusters and merged into one cluster to obtain $k=n$-2, and so on until k=1.

Finally, we get the angle between a single base station and the corresponding weak coverage point and the category it belongs to (here it is divided into three categories corresponding to the three sector-main directions) and solves for the angles of the three-sector coverage centerlines of the first base station: 174.326°, -238.137°, and -39.325°, respectively.

2.3.3. Greedy algorithm solution

Subsequently, the weak signal points covered by the first station were removed, and the remaining base stations beyond the first one was solved using the greedy algorithm and clustered again to obtain the three best-fit angles, and the process was repeated until the end.

3. Results

After a suitable planning solution, we get a more ideal result that meets the requirements. Finally, we calculated that the number of macro base stations to be built is 894, the number of micro base stations is 978, and the ratio of new base station services to total services is 90.56741%.

When the conditions become more realistic and demanding, the coverage of the base station changes significantly. We adopt the idea from the local optimum to the overall optimum, and use the greedy algorithm to make each base station cover as many weak coverages points as possible by adjusting the angle of the three main directions in turn, and removing these weak coverage points for each coverage. The final result of the coverage rate is 79.8%.

References

[1] Zheng Ling. Research on Innovative 4G Mobile Communication Network Planning Countermeasures [D]. Fuzhou University, 2017.

[2] Zhang H, Su XM, Yu SB, Tian Shoudong, Xiao Q, Wang YQ, Yin XT, Hu WP. A method and device for siting 5G base stations [P]. Shanghai: CN113395704A, 2021 - 09 - 14.

[3] Shi Jian. Research on 5G-oriented mobile communication technology and its optimization [D]. Tianjin University, 2017.

[4] Wang Jiahong, Wu Xiaojing, Cui Hanke. Optimization method for site selection of base station construction for wireless networks by weighing cost and signal strength [P]. Fujian Province: CN110366187A, 2019 - 10 - 22.

[5] Chen Dawei, Xin Lifeng, Wu Zebin, Han Bing, Wang Yanjiao, Qin Jian. Base station site selection and urban weak coverage determination method [P]. Beijing: CN113015176A, 2021 - 06 - 22.

[6] Liu Yaxi. Research on coverage calculation and optimization methods for mobile communication networks [D]. University of Science and Technology Beijing, 2021. doi: 10.26945/d.cnki.gbjku.2021.000123.

[7] Jiang Jiaqing. Communication base station siting and ground network setting [J]. Electronic World, 2021 (23): 166 - 167. doi: 10.19353/j.cnki.dzsj.2021.23.071.

[8] Li Chang, Liu Yanqing, Li Fei, Han Binjie, Zhang Jiajia, Liu Hongxing, Cui Liang. A method, apparatus, and equipment for siting base stations in a target area [P]. Hebei Province, China: CN108513305B, 2021-08 - 17.

[9] Yu JG, He Y, Song ZZ, Wang GL, Zhang J, Guo JQ, He JK. A traffic target recognition method based on the DBSCAN algorithm [P]. Beijing: CN113378751A, 2021 - 09 - 10.

[10] Huang Yulin. Greedy algorithm for 0/1 backpacking problem [J]. Journal of Ezhou University, 2006 (06): 38 – 40.

[11] M. Tang, G. R. Liu, G. Q. Deng. Solving the backpack problem with dynamic programming and greedy method [J]. Software Guide, 2007 (05): 111 - 113.