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# Layout optimization scheme for coexistence of multiple coverage capabilities in base stations—based on genetic algorithm

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**Abstract.** With the development of 5G technology, communication networks have become increasingly complex, leading to a continuous growth in the number of base stations. While this has resulted in faster speeds, lower latency, and greater capacity, it has also presented a pressing issue: weak coverage points, areas with weak signal radiation from base stations. To address this challenge, this paper proposes a layout optimization scheme for the coexistence of base stations with multiple coverage capabilities, based on a genetic algorithm. The scheme considers the rational deployment of various types of base stations (represented as macro base stations and micro base stations in the paper) to improve the situation of weak coverage points. The specific steps of the optimization layout scheme include initializing existing base station coverage, calculating distances to weak coverage points, selecting new base station locations, updating data, and analyzing calculations. The final output includes the coordinates and types of new base stations needed. Through model simulation, the proposed optimization layout scheme can consider cost, coverage effectiveness, and threshold constraints while accommodating various requirements. Additionally, the scheme is highly applicable and can be integrated with computer analysis software. Finally, a dialectical analysis of the model is conducted, recognizing the flexibility and practicality advantages of the layout optimization scheme based on genetic algorithms, while acknowledging potential limitations such as overly idealistic assumptions.

**Keywords:** Communication site optimization, Genetic algorithm, Macro base station, Micro base station

## 1. Introduction

As mobile communication technology rapidly advances, the scale of operations becomes larger, and communication networks become more complex. In this context, constructing an efficient base station layout scheme becomes a significant challenge. Base station site planning is typically based on two main considerations: urban development planning and communication development planning.[1] This paper focuses on the second consideration, specifically addressing how to overcome the problem of weak coverage points during the process of communication development.

The typical goals of base station network planning include demand planning, network layout schemes, link budgets, etc. [2] This paper specifically investigates how, based on the coverage situation of existing antennas, to identify weak coverage areas in the current network and select a certain number of points.

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The objective is to minimize the cost of solving the coverage problem in these weak areas after new base stations are built on these points.

## 2. Literature Review:

The use of genetic algorithms for designing base station layouts has a long history. Scholar Yumei Luo from Kunming University of Metallurgy proposed using encoding to represent feasible solutions, including the number and positions of base stations. Each chromosome represents a base station, with its coordinates in the coordinate system being used for labeling.[3] This encoding method abstracts and simplifies the problem, making it easier to handle on computers. However, this method has potential limitations. Firstly, the encoding of the number and positions of base stations may result in information loss, as representing an infinite space and changing network states with limited encoding may lead to reduced accuracy. Secondly, the design of chromosomes needs to consider the effectiveness and adaptability of the encoding, or else it may lead to algorithm convergence difficulties or being trapped in local optimal solutions.

With the vigorous development of information technology, base station site selection also needs to consider the relationship between coverage rate, cost, and business volume in the target area. Therefore, the establishment of models is relatively complex. In this context, scholar Qingxi Xie from Shandong Normal University pointed out the significant importance of applying both particle swarm algorithms and genetic algorithms to optimize the site selection of base stations.[4] The combination of particle swarm algorithms and genetic algorithms in base station site selection demonstrates the integration of various optimization algorithms and innovative thinking. Particle swarm algorithms excel in global searches, while genetic algorithms are more suitable for local optimization. The combination of the two is expected to achieve better results in balancing global and local optimization. However, the complexity of the integrated algorithm also increases computational costs and operating time, requiring a trade-off between algorithm performance and computational efficiency.

From the literature review, it is evident that using genetic algorithms to study base station layout is highly feasible. However, existing research mostly focuses on the layout of the same type of base stations in specific environments. There is limited research proposing optimization schemes for the layout of different types of base stations (such as macro base stations with wide service coverage and high cost, and micro base stations with small service coverage and low cost). Therefore, this paper assumes the existence of two types of base stations (macro and micro) during the base station layout process and attempts to propose a theoretical scheme for the layout of central incentive base stations that balances cost and coverage rate.

## 3. Scene Setting and Model Assumptions

### *3.1. Scene Setting*

For ease of computational analysis, the given area is set to be 2500×2500 grids, i.e., 2500×2500 points, where the coordinates range from 0 to 2499 in both dimensions. Within these points, there exist a certain number of existing base stations and weak coverage points. Two types of base stations are involved in the construction process: macro base stations (coverage range 30, cost 10) and micro base stations (coverage range 10, cost 1). The coordinates of station sites during construction can only be selected from the 2500×2500 points within the given area. Simultaneously, to control costs effectively, the distance threshold between new and existing station sites is set at 10.

Let the coverage range of a chosen base station be denoted as d, and the coordinates of the points planned by the station be denoted as $P_0 (x_0, y_0)$. For a point with coordinates P (x, y), if $\|P - P_0\|_2 \leqslant d$, it is considered covered by that base station.

### *3.2. Model Assumptions*

(1) All points in the grid have consistent elevation heights, implying no terrain impact on base station construction and coverage.

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(2) Natural climate factors like temperature, weather, etc., and their influence on base station service and service capacity decay are not considered.

(3) Marginal overlap of any two adjacent grids, considering all base stations as point coordinates.

(4) Other special factors (political, cultural, force majeure, etc.) influencing base station construction are not considered.

To better express the relevant variables involved in the study, the following symbols are explained for subsequent formulas:

**Table 1.** Symbol Explanation

| Symbol | Explanation | Symbol | Explanation |
| --- | --- | --- | --- |
| $T_i$ | Weak coverage point | $SUM(S_i)$ | Total service capacity of all base stations |
| $O_i$ | Existing base station point | $H_i$ | New macro base station point |
| $S_i$ | Service capacity of base station | $W_i$ | New micro base station point |
| $C_i$ | Cost of base station i | | |

## 4. Model Analysis and Solution

### *4.1. Problem Analysis*

In the 2500×2500 grid, there are several weak coverage points and existing base station points. The objective is to choose certain unbuilt points for the construction of new base stations. Based on the information about weak coverage points and their service capacities, this problem can be abstracted into an integer programming problem: each newly built base station point has two possibilities, i.e., constructing a macro base station or a micro base station. The objective function aims to cover weak coverage points with planned base stations, and the constraints include the distance threshold between any two station sites being greater than a given threshold while satisfying coverage conditions.

### *4.2. Data Compilation*

Rrandomly generate several existing base stations and weak coverage points within the grid. Under coverage constraints, organize the coordinates of existing base stations according to the following formula:

$$||P - P_0||_2 = \sqrt{(x - x_0)^2 - (y - y_0)^2} \leq d = 30 \text{ [Macro Base Station]}$$

$$||P - P_0||_2 = \sqrt{(x - x_0)^2 - (y - y_0)^2} \leq d = 10 \text{ [Micro Base Station]}$$

Formula 1: Threshold constraints for macro and micro base stations

### *4.3. Model Formulation and Solution*

*4.3.1. Model Formulation.* Let the weak coverage points in the 2500×2500 grid be denoted as $T_i$, existing base station points as $O_i$, new macro base station points as Hi, and new micro base station points as Wi. Suppose the nearest macro base station to point $T_i$ is $NH_i$, and the nearest micro base station is $NW_i$. To solve the problem, both the threshold conditions and coverage satisfaction conditions need to be simultaneously met. This implies satisfying the following constraints:

$$\text{Threshold conditions}\begin{cases} ||P_H - P_0||_2 > 10 \\ ||P_W - P_0||_2 > 10 \\ ||P_W - P_H||_2 > 10 \end{cases}$$

$$\text{Coverage satisfaction conditions}\begin{cases} ||\forall T_i - NH_i||_2 \leq 30 \\ or \\ ||\forall T_i - NW_i||_2 \leq 10 \end{cases}$$

Formula 2: Constraints based on threshold and coverage satisfaction conditions

Given that for each newly built base station point, there are only two choices: constructing a macro base station or a micro base station. Assuming the number of constructed base stations is n, the service capacity of base station i is $S_i$, the cost is $C_i$, and the total service capacity is SUM($S_i$). Introduce variables $p_i$ and $q_i$, satisfying the following definitions:

$$p_i, q_i = \begin{cases} 0, \text{Not constructing a base station} \\ 1, \text{Constructing a base station} \end{cases}$$

Formula 3: 0-1 model

Next, dynamic programming and analysis are performed for V(I,i)=V(I-1,i), i<Si. When Si is greater than SUM(Si), the maximum service capacity obtained by choosing the first i base stations is the same as the maximum service capacity obtained by choosing the first i-1 base stations.

To obtain V(n,SUM($S_i$)), it is necessary to iterate backward to V(n-1,SUM($S_i$)). This process continues until reaching the first base station and determining whether to choose it. Therefore, an additional constraint is added to the original constraints: the base station selection is "either a macro base station or a micro base station." For any weak coverage point ($T_i$), only one choice is allowed between a macro base station and a micro base station, i.e., $H_i$ and $W_i$ are mutually exclusive at $T_i$.

The objective function is transformed as follows:

$$\text{MAX SUM}(S_i) = \sum_{i=1}^{n} S_i p_i + \sum_{i=1}^{n} S_i q_i$$

Formula 4: Transformation of the objective function after making base station construction choices for weak coverage points

Under the premise that the service range of each base station is limited and aiming to minimize expenses, it is necessary to evenly distribute the workload for each base station and avoid situations where the workload differs significantly. This implies minimizing the variance of the workload for each base station. Therefore, constraints are formulated to minimize the variance of the workload.

The objective function is as follows:

$$min \frac{\sum_{i=1}^{N}\left(\sum_{j=1}^{n} y_i, p_j - \bar{y}\right)}{N}$$

Formula 5: Objective function considering the minimization of variance

Combining the constraints, the following mathematical model can be established:

$$min \sum_{i=1}^{N}\left(\sum_{j=1}^{n} y_i, p_j - \bar{y}\right)^2$$

$$\text{s.t.} \begin{cases} \sum_{j=1}^{n} y_{i,j} = 1 (i = 1,2 \ldots, n) \\ y_{i,j} \in R \end{cases}$$

Formula 6: Mathematical model obtained by combining constraints

*4.3.2. Computational Solution Based on Genetic Algorithm.* The Genetic Algorithm (GA) is derived from evolutionary biology and population genetics, simulating the natural selection and genetic mechanisms of biological evolution in Darwinian theory. This algorithm, utilizing mathematical methods and computer simulation operations, often achieves favorable optimization results when solving complex combinatorial optimization problems [5,6].

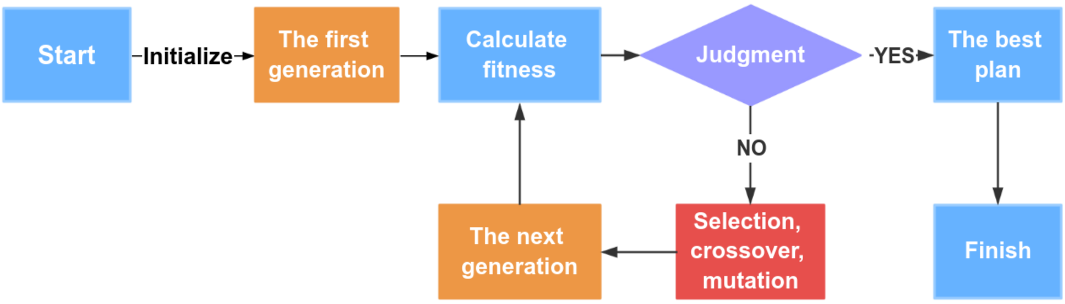


**Figure 1.** Schematic Diagram of Genetic Algorithm Steps

The specific steps of the genetic algorithm are as follows:

1. Initialization: Set the evolution generation counter t=0, with a maximum evolution generation T. Randomly select 10,000 coordinates from the 2500×2500 grid as the initial population P (0).

2. Individual Evaluation: Calculate the fitness of each individual in the population P(t).

3. Selection Operation: Based on the fitness evaluation, directly inherit optimized individuals to the next generation or generate new individuals through pairing and crossover for the next generation.

4. Crossover Operation: Apply the crossover operator to the population, which plays a central role in the genetic algorithm.

5. Mutation Operation: Apply the mutation operator to the population, changing the gene values at certain gene loci of individual strings in the population. The population P(t) undergoes selection, crossover, and mutation operations to obtain the next generation population P(t+1).

Through programmed calculations, the results of macro and micro base station siting are obtained. Upon verification, the business volume of services provided by the newly built base stations covers the weak coverage points in the grid, indicating the feasibility of this method.

## 5. Analysis of Model Advantages and Limitations

### *5.1. Model Advantages*

Firstly, when establishing the model, it comprehensively considers construction costs, coverage effectiveness, and threshold constraints, demonstrating a comprehensive consideration. Secondly, the model can easily be combined with software such as SPSSPRO, enhancing feasibility. Thirdly, the use of the genetic algorithm allows flexibility, as the fitness function can be tailored to meet specific requirements of the problem.

### *5.2. Model Limitations*

Firstly, treating site locations as point masses overlooks spatial layout characteristics in reality. Secondly, for ease of theoretical analysis, the influence of factors such as terrain, climate, and politics is excluded, leading to potentially overly idealistic assumptions.

## 6. Conclusion

In conclusion, based on the genetic algorithm, this paper proposes a specific solution for optimizing base station layout.

1. Initialization: Mark all points within the coverage range of existing base stations as covered points, and calculate the quantity of all weak coverage points.

2. Distance Calculation: If the distance between the nearest existing base station and the weak coverage point is greater than the distance threshold, the point is not covered and requires the construction of a new base station.

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3. Central Point Selection: Choose an unoccupied point in the given area as the new base station location. Assume constructing either a macro or micro base station and record the required cost.

4. Data Update: Update the coverage status of all weak coverage points and mark the points within the coverage range of the newly built base station as covered points.

5. Analysis and Calculation: Repeat steps (2)-(4) until all weak coverage points are covered. Compare the construction costs under different scenarios, prioritizing the lowest cost scenario that meets the coverage conditions.

6. Output Results: Output the coordinates of the newly built base stations and their corresponding types.

Overall, this solution aims to achieve full coverage of base station signals in the region, assuming the distribution of macro and micro base stations. By targeting weak coverage points and considering factors such as cost, coverage range, and threshold conditions, it presents an innovative base station layout scheme.

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