A Method for Determining Access Node of Microwave Relay Network Based on Genetic Algorithm

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Abstract. In order to improve the deployment efficiency of the microwave relay network, a method for determining access node of microwave relay network based on genetic algorithm is proposed in this paper. System analysis of network structure characteristics, node attributes and deployment process, the access node deployment issues is transformed into continuous area location issues. After discretization the area, the set of candidate access nodes is obtained considering boundary points and boundary chords. Comparing the coverage set of each access node, the candidate set is de-redundancy. Then taking coverage ratio maximum and the deployment cost minimum as the optimization goal, the optimal set of access nodes is obtained from candidate set by using genetic algorithm. A case with 50 user terminals is simulated by our method. Results show that after de-redundancy and genetic algorithm calculation, the number of access nodes is optimized from 240 to 17, and only 9 user terminals are repeated covered by different access node.

1. Introduction
Modern warfare is increasingly demanding the real-time, accuracy and flexibility of equipment organization. How to use engineering methods to quickly integrate limited resources and accurately deploy operational elements is an important reason for determining the victory of war. The microwave relay network nodes are mainly divided into a backbone node (BN) and an access node (AN). The user terminal accesses the network through the access nodes [1], and the access nodes are interconnected through the backbone nodes [2]. In theory, the access node's ability to access the user terminal is not limited, and there is no directionality. The distribution of user terminals can be regarded as known. In actual use, the bottom-up approach is used to determine the access nodes and the backbone nodes. That is, firstly, according to the location of the user terminals, the location of the access node is determined, and then the location of the backbone node is determined by the location of the access nodes. Due to the large number of user terminals, the location of the access node is difficult to determine. It is necessary to ensure the full coverage of the user terminals and to pursue the minimum number of access nodes. This is a combination optimization problem, and genetic algorithm has advantage to solve those problems [3-5]. Based on the concept of boundary points and boundary chords in Ref. [6], the set of candidate access nodes is obtained by discretization and de-redundancy, and the concept of coverage ratio is introduced. And then the optimal set of access nodes is obtained from candidate set by using genetic algorithm.

2. Feasibility analysis and assumptions
2.1. Feasibility analysis
In this paper, the geometric coverage model is established, and the effective coverage ratio is used as the objective function. The candidate nodes are formed in the candidate region of the two-dimensional plane discretization processing, and the user terminal position is considered to be relatively fixed. Regarding whether the initial conditions and model selection are consistent with the actual combat, the following three explanations are made:

(1) Effective coverage issues. If the geographic area of the combat area is small, the deployment cost of the global coverage is not high, and the cellular grid (virtual cell) method can be used to ensure the minimum overlapping coverage area, which is not the research focus of this paper. The main concern of this paper is how to achieve effective coverage better, and all user terminals access the upper-level network under low deployment cost conditions in a relatively wide operational area with the number of access nodes cannot meet the global coverage requirements.

(2) The influence of terrain. In practical applications, the candidate node position determined by the modelling solution is a reference position and is not fixed. In actual using, it can be flexibly adjusted according to the local terrain and in the vicinity of the reference position to avoid problems such as poor visibility and unsuitable opening.

(3) User terminals status. In practice, the user terminal is often in motion, but this does not mean that the access node and the backbone node are also in motion. On the one hand, it is a limitation of the technical system, for example, the microwave link cannot be connected in a moving manner; on the other hand, the movement of the backbone and the access node will cause the communication quality to decrease.

2.2. Model hypothesis
Hypothesis 1: The coverage of the access nodes is a circular area with the radius of \( r \), and the quality of the communication signal is not distinguished in the area;

Hypothesis 2: The access capability of the access node is not limited, and the connectivity problem between the access nodes is not considered;

Hypothesis 3: The deployment cost of all access nodes is the same, and the total cost of deployment can be represented by the number of access nodes;

Hypothesis 4: The priority of the user terminal is not differentiated according to the level.

3. Access node determination method
The problem of the deployment of the microwave relay network access node is a continuous area location problem. Due to the large size of the alternative location, the efficiency of the genetic algorithm is reduced. In order to narrow the selection range of the alternative solution, firstly, the deployable area of the access nodes should be compressed and discretized, and then the redundant candidate nodes should be removed to improve the accuracy and effectiveness of the subsequent calculation. The optimal access node set should cover all user terminals with a minimum number of access nodes.

3.1. Candidate area and candidate node set
The candidate area is the initial compression of the access node deployable area in the combat area. As shown in Figure 1, the distance of adjacent two user terminals \( v_1, v_2 \) is \( \text{dis}(v_1, v_2) \) and the access node coverage radius is \( r \). When \( \text{dis}(v_1, v_2) \leq 2r \), with \( v_1, v_2 \) as the center and \( r \) as the radius, there must be an intersection area (a deep shadow part in Figure 1). If an access node is deployed in the area, two user terminals can be covered at the same time; if an access node is deployed in a lightly shadowed part, and only one user terminal can be covered; If an access node is deployed in a blank area, none of user terminal can be covered. The dark shadow portion of the intersection is the candidate deployment area for the two nodes. Similarly, it can be extended to other user terminals, and a candidate area can be generated between any two user terminals whose distance is smaller than \( 2r \). So, the range of the
suitable area to deploy access node is greatly compressed when only consider the candidate area.

![Figure 1. Two-node candidate area](image)

Figure 1. Two-node candidate area

However, the above method narrows the scope of the alternative area, but still belongs to the continuous area. It is necessary to select some representative points in the candidate area, and construct a set of discrete points to facilitate modeling. Based on this idea, reference [6] proposes the concept of boundary points and boundary chords according to geometric principles. As shown in Figure 2, the user terminals $v_1$ and $v_2$ of $\text{dis}(v_1, v_2) \leq 2r$ form a set of boundary points. The boundary points are connected as boundary strings. The boundary string is symmetric. The boundary points $k_1, k_2$ which have distance $r$ away from $v_1, v_2$ become the candidate nodes. For example, at $k_1, k_2$, the access node can simultaneously cover two $v_1, v_2$ user terminals and convert the continuous space into discrete points.

![Figure 2. Alternative node formation method](image)

Figure 2. Alternative node formation method

If the distance between a user terminal and all other user terminals is greater than $r$, it is an isolated node. In the actual opening, the access node should be deployed separately at the node to ensure that all user terminals can be covered by the access node.

3.2. Redundancy removal

The size of the candidate node set depends on the number and location relationship of the user terminals. When the number of user terminals is large, the user terminals covered by different access nodes may be included in each other, resulting in redundancy of the candidate nodes. When the above redundancy occurs, deleting the candidate nodes that cover the user terminal is relatively small, and the size of the candidate node set can be further compressed to reduce the amount of calculation.

3.3. Access node selection process

The access node selection process flow is shown in Figure 3. The specific process is implemented as follows:

Step1. According to the method of Figure 2 in 3.1 section, initially determine the set of candidate access nodes $A_{\text{initial}}$ in light of the location of the user terminals;
Step2. According section 3.2, compares the user terminals of each candidate access node covers. If the user terminal set of access node $AN_i$ is a subset of the user terminal set of $AN_j$, the $AN_i$ is a redundant node and should be deleted. And then, the access node set $A_j$ after the redundancy removal is obtained.

Step3. The candidate node in $A_j$ can still be further filtered. The reason is that some user terminals covered by a candidate access node $AN_i$ are repeatedly overwritten twice. This selecting step can be implemented by using genetic algorithm and then the optimal set $A_f$ of access nodes can be obtained.

![Access node selection process](image)

**Figure 3.** Access node selection process

4. Genetic algorithm implementation

Genetic Algorithm (GA) is a non-deterministic intelligent search algorithm that simulates the natural selection of biological evolution. Different living organisms have different genes, so the ability to adapt to the outside is also different. Through natural selection, individuals with strong adaptability are usually able to survive and reproduce.

4.1. Fitness function

The fitness function of the genetic algorithm is

$$
\min \sum_{a=1}^{m} \sum_{t=1}^{n} \theta_{at} \tag{1}
$$

s.t. \hspace{1cm} \sum_{a=1}^{m} \theta_{at} \geq 1, \forall t \in C \tag{2}

Where $\theta_{at}$ is the coverage ratio, it means the times of each user terminal covered by different candidate access nodes, $m$ is the number of candidate access nodes, $n$ is the number of user terminals, and $C$ is the set of user terminals. The value of $\theta_{at}$ is obtained as follows, when the user terminal $t$ is covered by the access node $a$, $\theta_{at} = 1$, otherwise $\theta_{at} = 0$. The goal of genetic algorithm optimization is that equation (1) is the smallest. And the ideal situation is that all user terminals were covered by access node only once (namely $\forall \sum_{a=1}^{m} \theta_{at} = 1$).

4.2. Encoding

Binary encoding is used in this paper. A possible subset of candidate node set $A_i$ is used as the
chromosome \( P = [p_1, p_2, \ldots, p_i, \ldots, p_m] \). The length of the chromosome is the length of the node set \( A_i \), when the access node \( i \) is selected, \( p_i = 1 \), otherwise \( p_i = 0 \).

4.3. Operator selection

The tournament operator is used as selection operator. This selection operator is more sensitive to the difference of the adaptive values of the children. Single point crossover method is used as crossover operator. Mutation operator uses basic position variation.

5. Analysis of case and simulation results

The algorithm is implemented by MATLAB. The parameters are set as follows: initial population size \( NP=20 \), number of iterations \( GEN=40 \), crossover rate \( PC=0.6 \), and mutation rate \( PM=0.8 \). The number of user terminals is 50, distributed in a square area of 10 square kilometres, and the distribution of user terminals (purple circle) is shown in Figure 4(a). First, according to the access node generation method in Section 3.1, all the candidate nodes (open triangles) set \( A_{\text{initial}} \) are obtained as shown in Figure 4(b). At this time, there are a total of 240 alternative access nodes, and the number of redundancy nodes is large. Subsequently, according to Section 3.2, the access node is filtered, and 206 nodes are filtered out, leaving only 34 nodes (Figure 4(c), blue square); Finally, using the genetic algorithm, the remaining 34 access nodes are selected. Under the requirement that each user terminal has more than one coverage, the coverage ratio is optimized, and the optimal access node set (Figure 4(d), red five-pointed star) is obtained. It can be seen that the access node is further reduced, leaving only 17 nodes.

![Figure 4. Generation and selecting of access nodes ((a) distribution of user terminals (b) to (d))](image-url)
initialization of access nodes (c) redundancy of access nodes (d) further filter of access nodes using genetic algorithms

The curve of fitness (total coverage ratio $\theta$) with the number of iterations is shown in Figure 5. After the number of iterations reaches 18, it gradually converges to the global optimal solution, and the coverage is closer to 60 from 130. The optimal total coverage ratio value is 59 (ideally, the coverage is 50, that is, all user terminals are only covered once). The repeated coverage of all user terminals are only 9 times, which achieves the purpose of effective coverage.

![Figure 5. Coverage ratio as a function of the number of iterations](image)

6. Conclusion
A method of selecting access node for microwave relay network is proposed in this paper. The set of candidate access nodes is obtained by discretization and de-redundancy. In light of coverage ratio concept, the optimal access node set is acquired by using genetic algorithm from candidate set. After calculating by genetic algorithm, the number of access nodes is reduced from 240 to 17. The method of this paper can be further used in other communication networks. In the future work, we will determine the position of backbone node according the access nodes calculated in this paper.

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