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Contents

Applied Research of Stratified Multi-objective Optimization Algorithm in the Wireless Networks

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Abstract: Due to the cost, reliability and quality of communication equilibrium of the traditional FM radio network optimization algorithms during the construction , hierarchical multi-objective optimization algorithm is put forth. First, increase FM wireless networks mobile node and select new-adding link waypoints' optimal vector set, then design a hierarchical optimization model, and then use hierarchical multi-objective optimization algorithm to solve the problems of VHF wireless networks. Finally, compared simulation experiment of stratified multi-objective optimization algorithm and Glid algorithm and violent search algorithm is conducted, and the experiment shows that: stratified multi-objective optimization algorithm is smaller than traditional optimization algorithms in areas such in the network nodes, the average communication jump and the average attenuation of communication after running 50 times, i.e. lower cost, better network reliability and communication quality.

Keywords: Path discrete; Constraints; Objective function; Network node

1. Introduction

Different from the usual wired communication networks, wireless ad hoc networks can be laid easily and quickly without pre-infrastructure. Self-organizing wireless network's data link layer technology is one of the key technologies of self-organizing wireless networks. Based on TCP/IP protocol, FM radio network with self-organization is different from conventional WLAN, it use frequency hopping transmission and static TDMA MAC technology. This FH-TDMA transmission system helps ensure the reliability of the communication node and anti-jamming, It is easy to implement self-organizing network environment changes. But features and defects of FH-TDMA transmission system presents special requirements for FM channel link layer protocol's design [1-4]. FM wireless networks have an important role in disaster relief and other emergency communication, but the way to build its network is still very backward. The traditional FM radio network is built based mainly on experience of the network optimization engineers and field measurements, but this approach is not only slow and costs highly, but also it's far away from the actual optimal network [5-7]. Therefore, it is necessary to build the network planning before construction, thereby improve network's reliability and communication quality, and reduce the cost of network construction [8-12].

At home and abroad studies on the FM radio network planning are not many, Wi-Fi hotspot planning focuses on 3G wireless networks and wireless sensor networks [13-17]. However, FM radio network planning and 3G wireless network planning have a degree of similarity. Therefore, we can draw on 3G wireless network planning algorithms. FM wireless networks have different planning methods under different needs and application contexts.

Under different needs and application contexts, FM wireless networks have different planning methods. This paper studies how to constitute optimal network with a given number of necessary conditions of network nodes and some adding mobile node as a relay node. Optimal network refers to the lowest-cost network construction, best network reliability and best quality of communication.

In this paper, the FM radio network is based on the road network, namely the choice of mobile nodes in the region can only be a vector path. So, first we need to discrete vector paths. In this article, an optional mobile node is called a vector waypoint which is obtained after discreet vector paths .

FM radio network planning algorithm is described in this paper as follows:

Input conditions: the position of the necessary network node, optional position of vector path on the relay node, the zone terrain elevation data and communication frequency used to calculate communication attenuation between nodes.

maximum number of hops between necessary nodes.

Optimal conditions: the number of increased points in a vector path, the average number of communication hops between the necessary network nodes, the average communication attenuation between the necessary network nodes.FM radio network planning's four constraints, namely the geographic scope, the size of the network, the acceptable communication quality and acceptable network reliability separately restrains network planning. 3 optimal conditions respectively optimize the planning network from the aspects of the cost of network construction, network reliability and network communication quality aspects of network planning optimization. The process is to find a vector that satisfies the constraints the optimal combination of waypoints from the vector of all selectable waypoint. Clearly, this issue is a multi-objective optimization problem. Therefore this proposed hierarchical multi-objective optimization algorithm is applied to FM radio network.

2. Models and Definition

2.1. Definition of objective function

Main objective of FM radio network planning is the cost of network construction, network reliability and quality of communication and get the optimum of the three through the use of appropriate network planning algorithm. To lower construction costs and obtain savings is an important goal of network planning when the communication needs and quality are satisfied .In building a VHF radio network, adding an additional vector waypoint means an increase in a communication vehicle. The reduction of the number of adding vector waypoints is particularly important to cost control. Therefore, the objective function is defined as the following:

$$f_1(x) = \frac{|s|}{m} \tag{1}$$

Wherein, f_1 (x) represents the average number of required adding vector waypoints when connect a necessary network node; x represents an increase of a set of vector coordinates of the waypoint; | x | represents the increase in the number of vector waypoints; m indicates the number of necessary network nodes.

In the VHF wireless network, problems of arbitrary hop communication of any link between two necessary network nodes can let this link fail. Therefore, the fewer the average number of communication hops between the necessary network nodes, the higher the reliability of the network. The objective function is defined as the following:

$$f_2(x) = \frac{1 \le i \prec \sum_{1 \le i \le j} h_{ij}}{m(m-1)/2} \tag{2}$$

Wherein, f_2 (x) represents the average number of communication hops between necessary network nodes, ; x represents an increase of a set of vector coordinates of the waypoint; h_{ij} (x) represents the shortest hops of the communications link between the necessary network node i and j. The communication attenuation between necessary network nodes directly determines the communication quality of the entire wireless network. Therefore, another objective function is defined as:

$$f_3(x) = \frac{1 \le i \prec \sum_{i \le j} l_{ij}}{m(m-1)/2} \tag{3}$$

Wherein, f_3 (x) represents the average communication attenuation between the necessary network nodes; x represents an increase of a set of vector coordinates of the waypoint; l_{ij} (x) indicates the communication attenuation between the necessary network node i and j, if necessary, the network node i and j are needed to multi-hop for communication, the communication attenuation between them is the maximum of the multi-hop attenuation.

2.2. Hierarchical network planning optimization model

Hierarchical network planning optimization mathematical model is:

$$s = \min_{x \in k} \left[p_k f_k(x) \right]_{k=1}^{l} \tag{4}$$

Wherein, T represents the minimum solution of hierarchical multi-objective; Ps (s = 1,2,, L) for the first level of the mark, which means the corresponding objective function fs (x) (s = 1,2,, L) is the s priority level, and the relationship between the Ps satisfy s> s' Ps> Ps', which means that the s priority level "prior" to s' priority level. Under the condition of satisfying the constraint conditions. Firstly, get the minimal solution set of the objective function value of the second priority based on the minimal solution set of the objective function value of the first priority levels, and the rest can be done in the same manner. In general, multi-objective minimization of s+1 priority level should be done based on the solution set of the s priority level. In the last layer, solution set of Multi-objective minimization is the solution set of type (4).

In this paper, L = 3, i_e , three priority level's problem of hierarchical multi-objective minimization:

$$R = \min_{x \in j} \left[p_1 f_1(x), p_2 f_2(x), p_3 f_3(x) \right] \tag{5}$$

In VHF radio network planning, the cost factor is at the highest priority, the next is reliability of the network, and the last one is the communication quality of the network .Therefore, function of the first priority level is supposed as the average number of required-adding waypoints vectors f1 (x) which is needed to connect a necessary network node , and the function of the second priority level is supposed as the average number of average communication hops f2 (x) between necessary network nodes ,and the function of the first priority level is supposed as the average number of the average communication attenuation f3 (x) between necessary network nodes.

During the optimization process, partially focusing on certain optimization goals through a hierarchical approach can ensure that a more important optimal performance goal priority can be optimized firstly. Layering is usually not used alone, but more used in conjunction with other optimization algorithms.

2.3. Propagation model

For the planning wireless network, simulation and verification are conducted; communication attenuation between nodes is calculated by using Longley-Rice model. The communication attenuation through Longley-Rice model does not only consider the communication frequency and the distance between nodes, but also consider the terrain information, such as terrain irregularities, the average surface refractive and other factors. Therefore, attenuation communication by using Longley-Rice model can be a good fit the actual communication attenuation between nodes.

3. Hierarchical Multi-objective Optimization Algorithm Networks

3.1. Multi-objective network planning algorithm

Multi-objective network planning algorithm can be divided into linear programming algorithm, heuristic algorithms, and decomposition methods.

3.1.1. Linear programming algorithm

Linear programming is a classic algorithm on solving combinatorial optimization, but in the wireless network planning, the method is not widely applied. Wong JKL created the problem linear programming model due to this reason. Since integer solution of the problem requires, the authors use the simplex method combined branch and bound to solve the problem. The algorithm can get exact solutions for simple indoor network planning. Although this algorithm has the advantage of accurate solution, but due to the problem NP-HARD characteristic problem for large linear programming method; this algorithm is still in combination with other methods.

3.1.2. Heuristic algorithm

Due to the NP-HARD features of multi-target wireless network planning, many papers on heuristic algorithms have been studied, including greedy algorithms, simulated annealing, tabu search, genetic algorithms. Greedy algorithm has high efficiency, so it is easy to be seen on many papers. Amaldi E and other people constructed two kinds of greedy algorithm for wireless network planning. Zhang Chisheng and so on combined the limited enumeration with the greedy algorithm to construct GLiD cost algorithm for solving constrained wireless network upgrade issues. Since the greedy algorithm is easy to converge to a local solution, so it is often used as subproblems of other algorithms. Other advanced heuristic algorithms have been studied extensively in wireless network planning problems. Liu Shangyun and other people designed an algorithm based on simulated annealing to optimize the location and topology of UMTS network node. Xhafa F and so on constructed tabu search method to solve the wireless Mesh network planning issues.By optimizing the control of law, genetic algorithm’s initial solution is getting closer to the optimal solution through preferable choice, hybridization and evolutionary approach. The main drawback of genetic algorithm is the calculation of time cannot be controlled. Abdelkhalek O, etc. designed a genetic algorithm to solve the multi-objective node’s deployment of heterogeneous network.

Heuristic algorithms typically require specific design for specific problems; in general, solution of problem should be integrated by a variety of heuristics to optimize performance.

3.1.3. Algorithm based on decomposition

Due to multi-target wireless network planning problems are basically NP-HARD, to meet the actual computing needs, the decomposition algorithm also appeared in the literature. Assuming that all users and the candidate nodes are distributed in a set of plane, the entire structure is divided into different partitions through the difference of zoning optimize plane .In each partition structure, the partition of the optimal solution can be obtained by partial exact algorithm, the combination of these local optima is the global result. It can be shown that in the structure of these partitions, there must be a global solution of the partition structure approximates the optimal solution of the original problem.

3.1.4. Selection of vector waypoint that makes the connected partial network optimal

Traversal for all vector waypoint, if adding a vector waypoint can communicate the necessary network nodes sp, then select the vector waypoint that makes the connected partial network that contains node sp best. Definition of optimization of connected partial network and the definition of optimization of FM radio network final planning are the same, namely:

$$R = \min_{\beta\in\alpha}\left[p_1 s_1(x), p_2 s_2(x), p_3 s_3(x)\right] \qquad (6)$$

3.1.5. Selection of collection of vector waypoint that makes the newly adding link the best

Traversal for all vector waypoint , if adding a vector waypoint can not communicate the necessary network nodes sp, then choose vector set of points that makes the newly adding link the best by using dynamic programming method .Order n_{ij} represent the minimum number of vector roads that connect node s_i and s_j, there is the following recursive formula:

$$n_{ij} = \begin{cases} 0 & if\ s_i\ and\ s_j\ \ or\ l_{ij} \prec l_{\max} \\ \min\limits_{i \notin m} n_{ki} & if\ l_{ki} \prec l_{\max} \end{cases} \quad (7)$$

Make n_k represent the minimum number of point's vector road that connects necessary network nodes sp, there is the following expression:

$$n_k = \min\left\{\min_{1 \le j \le k} n_{ij}, \min_{1 \le m \le p} n_{pj}\right\} \quad (8)$$

Wherein, n_{pj} represents the minimum necessary number of vector waypoints connecting network node s_j and sp; N_{pk} represents the minimum necessary number of vector waypoints connecting network node sp and vector waypoints c_k.

Use previous hop node of each node to record number when calculating n_p to derive the necessary collection of points of vector path. If multiple vectors derive the same number of waypoints hops, then use the recorded previous attenuation of hop node of each node when calculating n_p, select the smallest attenuation of vector waypoint of previous hop.

4. Algorithm Analysis and Simulation Experiment

Assuming the necessary number of network nodes is m, vector waypoint number is n, then this approximation algorithm will be able to communicate all the necessary network nodes after executing at most m cycles. In every cycle, the time complexity of set of vector which is used to make the newly adding link the best is the largest by using dynamic programming options. Next, the time complexity of dynamic programming will be specifically analyzed.

To calculate the n_p, we need to calculate each n_{pj} and n_{pk}. Time complexity of calculating n_{pj} and n_{pk} is the same, so the author chooses the n_{pj} as an example for analysis. Suppose that mi is the number of vector points that are needed to connect each other, and then we need to calculate the number of pairs of attenuation:

$$S(n) = n + (n - k_0) + k_0 + ... + (n - k_0 - ...k_0)k_0 \quad (9)$$

Wherein, k represents the maximum number of communication hops between the necessary network nodes .From the above equation, time complexity of calculating n_{pj} is $o(n^2)$. For the part of the network that has been connected, there must be a constant c such that the number of nodes connected part of the network is less than cm. Therefore, time complexity of the calculation of n_p is $o(mn^2)$.

It can be obtained from the above analysis that this approximation algorithm's time complexity is *o* (m2n2). As a polynomial time algorithm, it can be used to guide the actual FM wireless network construction.

To verify the correctness of the algorithm, this paper selects a 50 km × 50km rectangular area and uses the simplified Longley-Rice model to plan the ultra short radio network which contains 5 necessary network nodes. There are 900 vector waypoints after desecrating the vector path. The constraints are as the following: the number of destination nodes of the network is not greater than 32, the attenuation of communication between nodes is not greater than 130dB, the number of communication hops between necessary network nodes is not greater than 6.

As compared with the performance of this algorithm, the simulation also implements GLiD algorithms proposed by Zhang Chisheng, etc. and violent search algorithm which can get optimal solutions; the results are shown in Figure 1. Among them, the square node represents the necessary network nodes; curve represents the vector path; circular nodes represent vector waypoint that the algorithm finally selects to FM radio network; connections between the nodes represent that the network link can be connected. As can be seen, under the input conditions and constraints, GLiD vector algorithm requires five additional waypoints to connect the entire network. However, the proposed approximation algorithm for hierarchical multi-objective optimization algorithm and violent search are the same, we only need to add four vectors waypoint to connect all the necessary network nodes, and both planned network topology is the same.

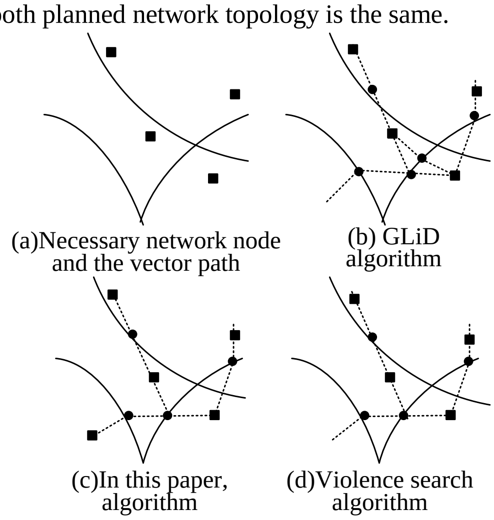

Figure 1. Comparison of different simulation algorithms

In order to validate the correctness of the algorithm when the input conditions change, we need to maintain the constraints and necessary number of network nodes, but randomly change the position of necessary network nodes, the statistical results of the average after the proposed algorithm and GLiD runs 50 times is expressed in

Table 1. Among them, the average traffic hops and communication attenuation means the average values between required network nodes.

Table 1. The Statistical Results under Different input Conditions

algorithm	The number of nodes	Average hop count of communication	Average communication loss /Db
In this paper, algorithm	8.96	3.3	127.947
GLiD algorithm	9.5	3.37	127.968

As can be seen from Table 1, when the position of the necessary network nodes randomly changes, compared with the relative GLiD algorithms, the algorithm's number of planned network nodes is less, the average number of hops and the average communication traffic attenuation is smaller , namely that the cost is lower and the network reliability and communication quality are better.

For the quantitative study of the number of target network nodes, the average number of communications hops between necessary network nodes, and the average performance of communication attenuation of the proposed algorithm when the constraint conditions change, the paper conducts simulation about different situations of maximum communication attenuation between nodes, the results are shown in Figure 2 to Figure 4.

As can be seen from the simulation results, the proposed approximation algorithm for hierarchical multi-objective optimization of network planning are significantly better than the LiD algorithms in terms of cost, reliability, communication quality and performance, and the performance of all aspects is similar or even identical to the optimal solution of violent search.

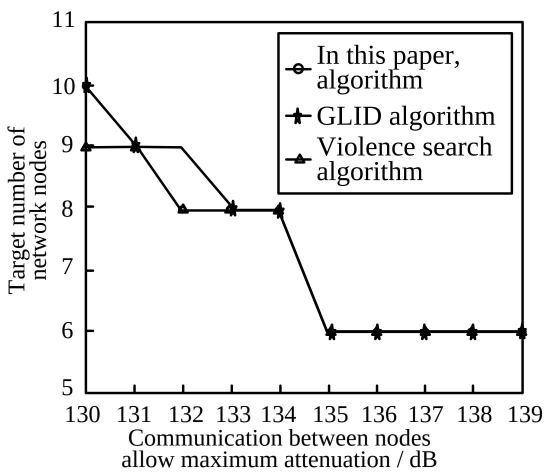

Figure 2. The number of network nodes under different constraints

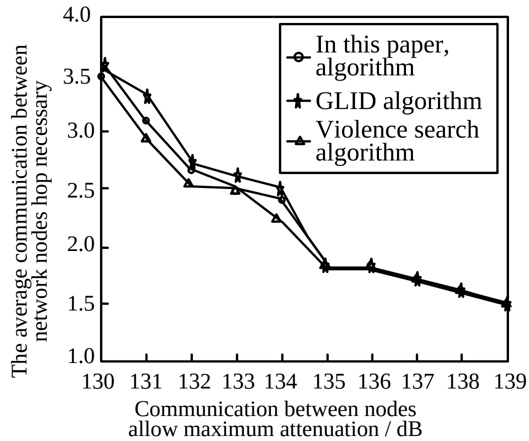

Figure3. The average number of communication hops under different constraints

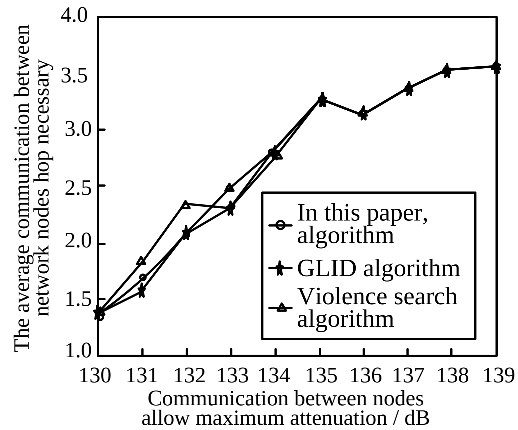

Figure 4. The average communication attenuation under different constraints

5 . Conclusions

This paper studies how to increase certain mobile nodes as a relay node to constitute the optimal FM wireless network based on certain given necessary network nodes. To achieve the balance between network construction cost, reliability and quality of communication , we design a hierarchical optimization model and under the model define the objective function of FM radio network planning .To solve the model,we propose a hierarchical multi-objective optimization approximation algorithm, which combines advantages of the greedy algorithm and dynamic programming , and it can achieve the approximate optimal solution which satisfies the constraints according to the priority level of the objective function . In addition, the article also analyzes the time complexity of the algorithm, and compares the algorithm with other wireless network planning algorithm on simulation .Simulation results show that the algorithm can find the solution which is similar or even equal to the optimal solution, and the planned network is much better than GLiD algorithms in terms of cost, reliability, and communication quality.

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