Construction of Emergency Communication Network with Multi Constraints Based on Geographic Information

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Abstract. Aiming at the problem of deploying the vehicular relay station in the construction of emergency communication network, OpenStreetMap and FME tools are used to construct the electronic map which contains the geographic information such as roads and rivers. A Method for judging the line of sight propagation is also studied. The simulation results show that the proposed algorithm can be more reasonable and applicable to address the vehicle relay station, and can fulfill the requirements of the actual emergency communication link construction better.

Keywords: Emergency communication · Vehicle relay station Electronic map · Line of sight propagation · Antenna placement

1 Introduction

After large-scale natural disasters, the wired and fixed communication infrastructure in the affected areas is very likely to suffer the serious damage causing the communication interruption. A large number of facts show that existing communication networks are often unable to meet emergency communication needs in the face of sudden natural disasters and public events [1]. Sometimes, due to communication disruption, after the emergency rescue personnel arrived at the scene, they can not communicate well and coordinate the forces of all parties, thus the efficiency of emergency rescue was greatly reduced [2]. Therefore, the establishment of an interconnected, efficient and adaptive emergency communication network can enhance the ability to respond to sudden natural disasters.

In the actual disaster relief process, Relief Commanding Officer will deploy a number of microwave stations and specify the corresponding network topology in order to meet the needs of emergency communication. But between transmitting and receiving microwave stations there are often high mountains, trees and other obstacles. As a result, some of the microwave stations can not communicate normally, the original

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network topology can not be achieved as well. Due to the good mobility and flexibility of the vehicle microwave station [3], it is possible to ensure the proposed network topology by deploying vehicle microwave relay stations.

In the research of vehicle emergency communication, paper [4, 5] analyzes the design and reconstruction of the emergency communication vehicle, but does not study the deployment of communication vehicles in practical application; Paper [6] makes an exploration on addressing vehicle relay stations, but it does not take the factors such as roads and rivers in the actual geographic information into account so the accessibility of the communication vehicle is ignored. Therefore, in order to meet the rapid deployment of emergency communication network [7], we are now striving to find a method to solve the problem of being convenient for the deployment of relay stations under the network topology constraint. This method not only can guarantee the communication requirements of the network topology between the designated microwave stations, but also can combine with the flexibility of the vehicle relay stations, construct the emergency communication network quickly and effectively.

2 Construction of Emergency Communication Network with Multiple Constraints

2.1 Algorithm Idea

In order to construct the emergency communication links, firstly, extract the geographic information such as elevations, roads and rivers in the affected area. Secondly, evaluate the normal communication after giving the microwave stations and the corresponding network topology. Finally, calculate the position of the deployed vehicle relay stations and a series of parameters such as the heights and elevations of the microwave antennas to satisfy the network topology rapidly.

Sometimes, line of sight propagation can not be achieved by the transmitting and receiving station due to the block obstacles such as mountains and forests, so it is necessary to establish microwave relay stations to amplify the signal. In order to meet the requirements of the rapid deployment of the relay stations, the following constraints should be met:

(i) The relay stations should be built in places where the terrain is relatively flat and relatively low in altitude;
(ii) The relay stations should be placed near the road;
(iii) The relay station should be placed avoided the river;
(iv) Multiple relay stations should be placed like the word "Z" instead of one on the top of the hill;

Under the above constraints, AHP-TOPSIS (Analytic Hierarchy Process - Technique for Order Preference by Similarity to an Ideal Solution) algorithm is used for addressing vehicle relay stations. The optimal solution is determined by calculating the altitudes and attenuation of every alternative relay stations and measuring the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS) respectively [8].

2.2 Visualization of Terrain Conditions

In the visual construction of terrain conditions, the Digital Elevation Model (DEM), which is a special case of Digital Terrain Model (DTM), is used where Z axis represents the elevation value of the current position, in other words, it represents the altitude of the current position. Taking E120_N37 as an example, the visualization of the terrain construction steps are as follows:

(i) Use the DEM with a distance of 1/1200 degree downloaded from geospatial data cloud as the data source. And using the GlobalMapper tool to convert the DEM into the image file [9].
(ii) Use OpenStreetMap to download and extract a variety of terrain information [10].
(iii) Use the FME tool [11] to edit and stratify the map, extract the roads information separately and convert it into Excel or other data types of file containing the latitude and longitude information of roads.
(iv) Extract the rivers information by step two and three. In the end, combine the roads information, rivers information and elevations information of the map.

Based on the visualization of terrain conditions, we not only can see the terrains, roads and rivers directly, but also can extract the elevation of each point and the location of roads and rivers in the electronic map to do operations simply (Figs. 1 and 2).

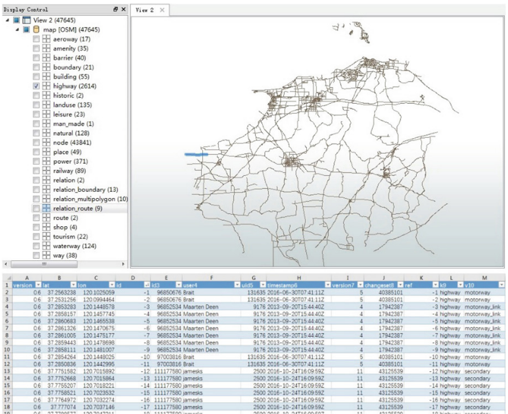

Fig. 1. Separation and extraction of roads information

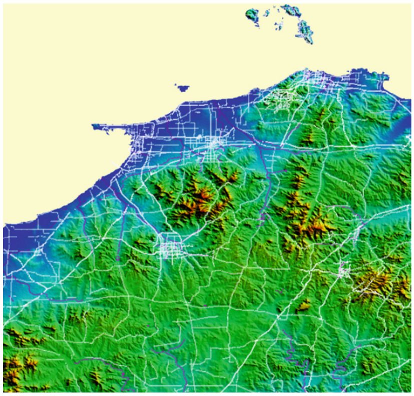

Fig. 2. Interface of electronic map

2.3 Analysis of Relay Station Deployment

In the construction of microwave communication link, path types are divided into line of sight (LOS) and not line of sight (NLOS) types. The choice of antenna heights affects the attenuation of microwave propagation, so it is necessary to design the antenna heights reasonably. In the project, the determination of the antenna heights is generally setting one end (transmitter or receiver) of the antenna height based on the known conditions firstly, then calculating the height of the other end according to the design requirements.

An algorithm for judging two-point LOS is as follows:

(i) Firstly, set the height range of transmitting and receiving antennas; Secondly, set the height of transmitting antenna h_{ta} from low-to-high in the range and calculate the height of receiving antenna h_{ra}. If the height of transmitting antenna is out of range, it is judged as NLOS, otherwise, go to the next step. In which: $h_{ra} = (2n + 1)\lambda d/4h_{ta}$ ($n = 1, 2, \ldots$).

(ii) If the height of receiving antenna is out of range, increase the initial height of the transmitting antenna, return to step 1, otherwise, go to the next step.

(iii) Calculate the path clearance H_c and the relative clearance P, if condition one and condition two are not satisfied simultaneously, $n = n + 1$, return to step 1, otherwise, go to the next step.

  (a) **Condition one**: The minimum clearance $H_{cmin} > 0$; in which $H_{cmin} = \min(H_c)$.

  (b) The path clearance H_c is an important parameter to judge whether the antenna can be transmitted as LOS propagation, and it refers to the distance between the obstacle and radio wave. Path clearance: $H_c = [(h_{ta} + H_1)d_2 + (h_{ra} + H_2)d_1]/d - H_3 - d_1 d_2/2Ka$ (m); in the formula, H_1, H_2 and H_3 refer to the altitude of the point of transmitting antenna, receiving antenna and the interpolation point; d_1 and d_2 are the distance between the reflection point and the transmitting and receiving antennas respectively; d is the distance between transmitting and receiving antennas; K is the equivalent earth radius factor; a is the actual earth radius.

  (c) **Condition two**: Relative clearance $P > 0.577$ (Or $H_c > F_0$). The working point is on the left side of a radiation lobe's maximum value on the P-V curve (making V large enough), and shall be landed in the lower lobe as far as possible [12]. The relative clearance P is the ratio of path clearance H_c to the first Fresnel radius F_1: $P = H_c/F_1$.

(iv) After getting the heights of the transmitting and receiving antenna, judge the path types as follows. If the elevation angle from transmitting antenna of physical field of vision is larger than that of the transmitting antenna to the receiving antenna, the path is tropospheric scatter path, in other words, it's NLOS path. Otherwise it's LOS path. The method to judge the NLOS path is: $\theta_{max} > \theta_{td}$; in which $\theta_{max} = \max(\theta_i)$ ($i = 1, \ldots, n - 1$).

  (a) θ_i: The elevation angle of the transmitting antenna to the ith interpolation point: $\theta_i = (h_i - h_{ts})/d_i - 10^3 d/2a_e$ (mrad); In the formula, h_i: The altitude of the i_{th} interpolation point; d_i: The distance between the transmitting antenna and the i_{th} interpolation point; a_e: The median effective earth radius suitable for this path; h_{ts}: The average altitude of transmitting antenna, $h_{ts} = h_0 + h_{ta}$ (m); in which h_0: The altitude of the 0_{th} interpolation point (i.e. the point of the transmitting antenna), h_{ta} is the height of the transmitting antenna.

  (b) θ_{td}: The elevation angle of the transmitting antenna to the receiving antenna: $\theta_{td} = (h_{rs} - h_{ts})/d_i - 10^3 d/2a_e$ (mrad); in the formula, h_{rs}: The average altitude of receiving antenna, $h_{rs} = h_n + h_{ra}$ (m), in which h_n: The altitude of the n_{th} interpolation point (i.e. the point of the receiving antenna), h_{ra} is the height of the receiving antenna.

2.4 Link Space Propagation Attenuation Index

The attenuation of the spatial propagation of the link [13] L_f should satisfy: $L_f \leqq [P_t] + [G_t] + [G_r] - [L_t] - [L_r] - [P_r]$; in which: P_t: The transmitted power of the microwave station; P_r: The received power of the microwave station; G_t: Antenna gain of transmitting station; G_r: Antenna gain of receiving station; L_t: Feeder loss; L_r: Branch loss.

The sensitivity of the general receiver is −120 dBm. Assume that a transmitter with a transmit power of 30 W is used, the transmitting and receiving antenna gain are both 20 dB, the feeder and branch loss are both 5 dB. Calculated that L_f is less than or equal to 194.77 dB.

The calculation of L_f can be found in Recommendation ITU-R P.676:

$$L_f = L_{b0}(p) + A_{ht} + A_{hr}(\text{dB}). \tag{1}$$

In the formula, $L_{b0}(p)$ is the basic transmission loss given by the LOS model and be predicted 90% of the time that will not be exceeded; A_{ht}, A_{hr} is the corresponding additional loss due to the height in local scatterer–Gain effect.

2.5 AHP-TOPSIS Algorithm with Multiple Constraints

Calculate the Weight of Each Index Using Analytic Hierarchy Process (AHP). In the process of multi-attribute evaluation, different attributes have different importances, the corresponding weight is also different. In some multi-constraint conditions difficult to quantify, AHP gives the method to calculate the weight of each attribute.

(i) Construct the criterion layer judgment matrix A as shown in Table 1, C_i:C_j = a_{ij}, The greater the a_{ij}, the higher the importance of C_i than C_j.

Table 1. Judge matrix

	Attenuation (C_1)	Elevation (C_2)	Corner (C_3)	Distance (C_4)	Inclination (C_5)
Attenuation (C_1)	1	2	4	5	7
Elevation (C_2)	1/2	1	2	3	6
Corner (C_3)	1/4	1/2	1	3	4
Distance (C_4)	1/5	1/3	1/3	1	2
Inclination (C_5)	1/7	1/6	1/4	1/2	1

(ii) Carry out the consistency test of the criterion layer matrix that $CR = 0.024 < 0.1$. It can be proved that satisfy the consistency index. In which: $CR = CI/RI$, $CI = (\lambda - n)/(n - 1)$, λ is the largest eigenvalue of the matrix, n is the dimension of the matrix, and RI is the random consistency index.

(iii) The normalized feature vector corresponding to the largest eigenvalue of the matrix is obtained: w = [0.4563 0.2583 0.1611 0.0785 0.0458]. w is the weight of each attribute.

AHP-TOPSIS Algorithm [14–16]. By combining the TOPSIS method with AHP, the weight calculated by AHP is introduced: $t_{ij} = w_j \cdot b_{ij}$; where: t_{ij} is the weighted specification value of each attribute and b_{ij} is the original value of each attribute. Based on this, construct the PIS and NIS of the problems and the distance between candidate points and the PIS and NIS to calculate the comprehensive evaluation index, then sort all alternatives and get the optimal solution.

Determine the worst alternative: $t_{wj} = \{[\max(t_{ij}|i = 1, 2, \ldots m)| \, j \in J_{-}], [\min(t_{ij}| i = 1, 2, \ldots m)| \, j \in J_{+}]\}$;

Determine the best alternative: $t_{bj} = \{[\min(t_{ij}|i = 1, 2, \ldots m)| \, j \in J_{-}], [\max(t_{ij}|i = 1, 2, \ldots m)| \, j \in J_{+}]\}$;

Where:

$J_{-} = \{j = 1, 2, \ldots n| \, j$ associated with the criteria having a negative impact};

$J_{+} = \{j = 1, 2, \ldots n| \, j$ associated with the criteria having a positive impact};

Distance between the target alternative and the worst condition:

$$d_{iw} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{wj})^2}, i = 1, 2, \cdots, m \quad (2)$$

Distance between the alternative and the best condition:

$$d_{ib} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{bj})^2}, i = 1, 2, \cdots, m \quad (3)$$

Comprehensive evaluation index:

$$s_{iw} = d_{iw}/(d_{iw} + d_{ib})(i = 1, \ldots, m) \quad (4)$$

The Specific Steps of the Algorithm

(i) Given the specified network topology, determine the path types of the microwave stations for communication by the algorithm mentioned in 1.3, if it's LOS, the relay station is not needed, if it's NLOS, go to the next step.

(ii) Determine the constraints of the relay station addressing range, and limit the range of alternative points: $P = P_c \cap P_r - P_w$. In which: P_c: Set of points in the circle where the center is the midpoint of the two microwave stations, and the diameter is the distance between the two stations; P_r: Set of points less than 10 m on both sides of the road; P_w: Set of points the river passes through. If the point can be transmitted by LOS with any station, then list it as an alternative point.

(iii) Calculate the altitude h of each alternative point, according to formula (1) to calculate the spatial propagation attenuation L_f and other parameters, according to formulas (2)–(4) to calculate the comprehensive evaluation indexes s_{iw} and sort them. The larger the s_{iw}, the better the point.

(iv) Judge whether the optimal relay station and the two microwave stations can transmit along LOS and compare the link attenuation value. If the LOS transmission can not be satisfied or attenuation value is beyond the setting range, go to step 3, using the suboptimal point. If all alternative points can not meet the above conditions, take the optimal point and the NLOS microwave station as transceiver stations, go to step 2 and searching for a second relay station; Otherwise, go to the next step.

(v) Once the communication between the original microwave stations is satisfied, the operation is completed. Output all relay stations' positions, and calculate the antenna height, elevation and other parameters.

3 Experimental Simulation and Program Evaluation

Still take the E120_N37 area as an example, select a number of microwave stations and set the proposed network topology randomly: 1-2, 1-3, 1-4, 2-3.

Set the maximum height of the transmitting and receiving antennas to 20 m, and specify the transmitting antenna height (initial value of 3 m). It is judged by the algorithm that microwave stations 1 and 2, 1 and 3, 2 and 3 can not transmit from each other by LOS. The locations of the vehicle relay stations calculated by the algorithm are shown in Fig. 3 (red hatch fill); the latitudes, longitudes and elevations of the relay stations and microwave stations are shown in Table 2.

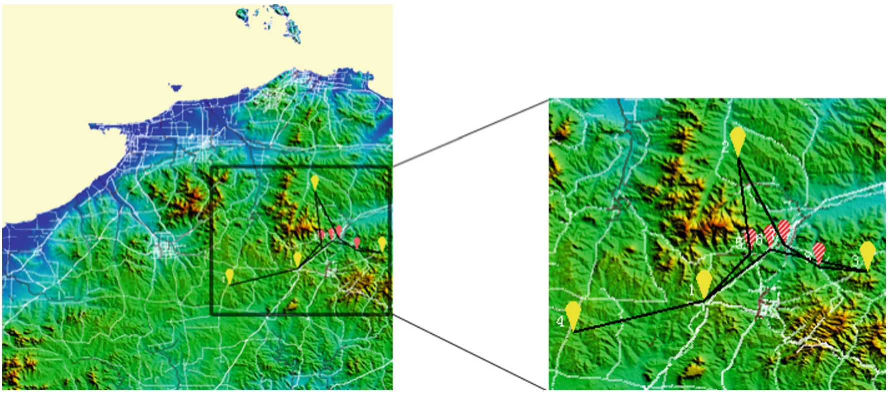

Fig. 3. Emergency link construction of random area (Color figure online)

Table 2. Calculation results

Microwave station number	Longitude/(°)	Latitude/(°)	Elevation/(m)
Microwave station 1	120.75209	37.31874	203
Microwave station 2	120.79625	37.51541	150
Microwave station 3	120.96709	37.35791	223
Microwave station 4	120.57959	37.27541	210
Relay station 5	120.81292	37.38375	126
Relay station 6	120.83875	37.39042	115
Relay station 7	120.85625	37.39708	93
Relay station 8	120.90208	37.36542	122

In order to meet the needs of practical applications, the algorithm finally calculates the antenna heights h_{ta} and h_{ra}, elevation angle θ_{td} and azimuth angle as shown in Table 3.

Table 3. Microwave link

Microwave station number	Antenna height/(m)	Elevation angle/(°)	Azimuth angle /(°)	Attenuation/(dB)
Microwave station 1-5	5.00, 7.75	2.02, −3.03	EbN 46.90, WbS 46.90	117.96
Microwave station 5-2	3.00, 18.97	0.18, −1.83	WbN 82.78, EbS 82.78	125.37
Microwave station 1-6	8.00, 16.18	3.02, −4.26	EbN 39.59, WbS 39.59	120.41
Microwave station 6-3	20.00, 20.00	1.24, 33.08	EbS 14.21, WbN 14.21	172.74
Microwave station 1-4	9.00, 13.93	24.40, −26.19	WbS 14.10, EbN 14.10	123.72
Microwave station 2-7	4.00, 14.18	1.75, −3.34	EbS 63.11, WbN 63.11	129.41
Microwave station 7-8	3.00, 17.65	2.50, −3.10	EbS 34.64, WbN 34.64	116.37
Microwave station 8-3	20.00, 20.00	0.77, 31.94	EbS 6.58, WbN 6.58	161.03

As shown in Fig. 3, the relay stations calculated by the algorithm are selectively distributed near the road but not in the river. The elevation of each relay station is not too high, therefore the fast deployment requirements can be met. It can be seen from Table 3 that the antenna height of each microwave station is within the setting range, and the attenuation value of each link is less than 194.77 dB, which satisfies the general receiver's sensitivity requirement. The calculation of antenna heights, elevation angles and azimuth angles not only proves the feasibility of the algorithm, but also improves the practicability of the algorithm.

4 Conclusion

This paper introduces an emergency communication network construction method combining multi - constraint geographic information, which is used to implement the proposed topology network. Combined with the electronic map, taking into account the actual roads and rivers and other geographic information, the locations of the vehicle relay stations are calculated and simulated under multiple constraints. In addition, the heights and elevations of the transmitting and receiving antennas in the network are also planned. The results show that the method can meet the reachability requirement of vehicle relay stations, and the link attenuation and antenna placement parameters are within reasonable limits and can be effectively used in emergency network construction. In the future work, the algorithm will be combined with spectrum planning and other technologies to allocate the frequency of the constructed communication network.

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