A Design of Underground Communication Network

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Abstract. In order to meet the communication needs of underground space, it is necessary to build an underground communication network. Taking the data of a region as an example, considering the construction cost, the communication expense, equipment and lines carrying capacity and the characteristics of underground communication, the model of the problem was analyzed. By using the iterative judgment of position and quantity of information flow, k-means clustering algorithm, genetic algorithm and other methods, we established LANs and high-level nodes, as well as the trunk line and the branch line. The process of designing the underground network took into account many factors. And the final results meet the actual requirements and the common sense. It provides a reference for similar problems in the future.

Introduction

In order to solve the problem of increasing population and traffic congestion in many cities, how to make use of underground space reasonably has been paid more and more attention. The construction level of underground parking lots, underground shopping centers and air defense projects has been relatively perfect. In the information age, the underground communication network is important engineering facilities to ensure the circulation of information. And in wartime, it can also be used to ensure the communication of command transfer smoothly after move to underground, and also it is difficult to be destroyed. So the construction of underground communication network for the future urban construction and national defense security is of great significance.

In this paper, we first analyze the characteristics of the underground communication network, and then use the idea of mathematical modeling to analyze the network including nodes location, network structure and cable distribution. And a proposal integrated location, cost and other factors is proposed.

Characteristics of Underground Communication Networks

On the ground, we already have a relatively complete communication system. Through wireless base stations, we can make use of cellular communications technology to achieve 3G or 4G wireless communications. At the same time, we can use computers which connected the Internet for information exchange, or through Wifi and WiMAX technology for wireless Internet communication [1]. In addition, the distribution of user terminals on the ground is more dispersed, so the larger coverage of network is needed.

Underground communication network is different from the ground communication network. Due to the transmission medium constraints, wireless communication is limited, and can only be used in the local. Long-distance communication can only be achieved through the laying of cables to communicate [2,3].
The Design of Underground Communication Network

Statement and Analysis

Based on the OD matrix (Origin Destination) of information flow in a region, the quantity of information flow requirements of 114 terminals are described (as the data is too large, data will not be displayed completely). Through the rational design of the communication network, so that every terminal can meet its own communication need, at the same time, reduce network construction and use costs as much as possible. According to the characteristics of the underground communication network, we can use the router as a node to create a local area network (cover radius < 3 km), assuming that the throughput of each routing node is no more than 3000 Mb/s. At the same time, we can use the other kind of router with more power, to achieve long-distance interconnection, assuming that the throughput does not exceed 4000 Mb/s. Due to the difficulty of upgrading the underground network, the cable selection takes full account of the future development. Assuming that the cable is two ways and the transmission capacity of the cable each direction is 14400 Mb/s, and the cable cost is 350 million yuan per kilometer, the communication cost is 0.05yuan/kilometer. In order to make all the underground terminals meet their own communication needs, and to minimize the total cost, we can follow the following steps to analyze:

1. Calculate the required quantity of information flow of each terminal. Then, determine the location of the routing node, and create LANs.
2. Group the LANs, use advanced router as a high-level node to summarize the local area network traffic and communicate with other groups.
3. Determine the trunk lines between high-level routing nodes and the trunk lines between high-level nodes and information stations.
4. Determine the branch lines between the local nodes in the same group.

Set up LANs

First, according to the communication flow OD matrix, calculate the communication flow of each terminal, corresponding to the location of the terminal, and mark it in the Fig. 1.

\[
m_j = \sum_{i,j \leq k} m_{ij} + \sum_{i,j \leq k} m_{ij}
\]  

(1)

In the formula, \( m_{ij} \) is the matrix element at row i column j, \( m_i \) is the required quantity of communication flow for terminal i, \( k_i \) is the label for information station.

![Figure 1. Communication flow of each terminal.](image)

In the figure, four red dots indicate the existing network information stations in this region, and the quantity of information flow (unit Mb/s) has been marked in the corresponding position. According to the following steps can be based on the terminal traffic requirements and relative location to establish a local area network (LAN):

1. Select the farthest point in the region from the center, and establish a LAN.
(2) Add the node with nearest distance to this LAN, calculate the total traffic in this LAN. Determine whether the sum of traffic is larger than 3000 and whether there is a circle so that all nodes in this LAN are in the circle with its radius less than 3km.

(3) If so, repeat the step (2), if not, delete the point that has been added to the LAN, perform the step (1).

*Through the above algorithm, each terminal can be added to the LAN to meet the communication needs of the terminal.* Algorithm iterative process and the result (with the number of each LAN) shown in Fig. 2.

![Algorithm iterative process and the result.](image)

After the implementation of this step, we can block the specific information of the terminal, focusing on the relationship between the LANs.

**Set up High-level Routing Node**

According to the problem, the information station can only be connected with the high-level routing node, through OD matrix M, the traffic flow from information center can be calculated:

\[
\sum_{1s \leq 1i} \sum_{1s \leq 1j} m_{ij} - \sum_{5s \leq 5i} \sum_{5s \leq 5j} m_{ij} = 47603.26
\]

Since \(47603.26/14400 = 3.306\), so **at least four high-level nodes are required.** At the same time, it can be calculated that information flow that not through the information center is:

\[
\sum_{5s \leq 5i} \sum_{5s \leq 5j} m_{ij} = 15590.24t
\]

It can be seen that only \(15590.24/(15590.24+47603.26) = 24.67\%\) of the traffic flow did not go through the information station. While the LANs are relatively close. Therefore, the high-level nodes’ position should be closer to the information station, to reduce the underground tunnel mileage of high-level node to the information station, at the same time, reduce communication expense. Therefore, select point 5,15,20,26 as a high-level node.

**Group the LANs**

Because the quantity of information flow of each LAN is similar, and the LANs within the same group should be close to each other. We can use k-means algorithm for clustering [4,5]. Set four categories and define the four high-level nodes as the center. The gravity of the center is proportional function to the distance. By clustering, **LANs in each group are shown in Table 1.**
Table 1. Clustering results.

<table>
<thead>
<tr>
<th>Group Number</th>
<th>Center Number</th>
<th>LANs' Numbers in This Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>1-8</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>9-15</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>16-22</td>
</tr>
<tr>
<td>4</td>
<td>26</td>
<td>23-30</td>
</tr>
</tbody>
</table>

Set Trunk Lines

In order to describe the relationship between the local area network more accurately, we need to calculate the OD matrix of groups $P = \{p_{ij}\}$. The results are shown in Table 2.

$$p_{ij} = \sum_{\text{node in group } i} \sum_{\text{node in group } j} (m_{ij})$$  \hspace{1cm} (4)

$$p_{ik} = \sum_{\text{node in group } i} (m_{ik})$$  \hspace{1cm} (5)

$$p_{ki} = \sum_{\text{node in group } i} (m_{ki})$$  \hspace{1cm} (6)

Table 2. The OD matrix of groups.

<table>
<thead>
<tr>
<th>row\Column</th>
<th>k1</th>
<th>k2</th>
<th>k3</th>
<th>k4</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>k1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1224.798</td>
<td>1393.61</td>
<td>2615.214</td>
<td>1936.855</td>
</tr>
<tr>
<td>k2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1353.624</td>
<td>2912.806</td>
<td>1171.099</td>
<td>1155.174</td>
</tr>
<tr>
<td>k3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3347.989</td>
<td>1049.138</td>
<td>988.0702</td>
<td>898.7681</td>
</tr>
<tr>
<td>k4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>843.2122</td>
<td>541.0739</td>
<td>442.1944</td>
<td>1376.749</td>
</tr>
<tr>
<td>1</td>
<td>1283.13</td>
<td>1438.271</td>
<td>3504.054</td>
<td>875.0441</td>
<td>0</td>
<td>1198.49</td>
<td>452.4587</td>
<td>542.6367</td>
</tr>
<tr>
<td>2</td>
<td>1461.82</td>
<td>3004.843</td>
<td>1093.301</td>
<td>568.0861</td>
<td>954.0466</td>
<td>0</td>
<td>845.5422</td>
<td>803.2327</td>
</tr>
<tr>
<td>3</td>
<td>2717.444</td>
<td>1226.552</td>
<td>1034.287</td>
<td>473.3955</td>
<td>275.9909</td>
<td>633.5298</td>
<td>0</td>
<td>1689.03</td>
</tr>
<tr>
<td>4</td>
<td>2044.166</td>
<td>1224.341</td>
<td>943.3418</td>
<td>1460.79</td>
<td>291.6765</td>
<td>572.2373</td>
<td>1727.512</td>
<td>0</td>
</tr>
</tbody>
</table>

As each high-level node traffic is not much difference, we should choose ring or mesh network as the trunk line’s structure. By calculated, the depreciation expense each day of building a connection between high-level node 1 and 3 is:

$$\frac{\text{length} \times \text{Cost per kilometer}}{100 \times 365} = 166245.2$$  \hspace{1cm} (6)

The amount of communication reduces per day due to shortening the line is:

$$\Delta \text{length} \times (p_{13} + p_{31}) \times \text{Cost / kilometer} \times 60 \times 60 \times 24 = 17377.5$$  \hspace{1cm} (7)

Therefore, the cost is much greater than the daily savings. So the cable from high-level node 1 to high-level node 3 should not be built. Similarly, the cable of high-level node 2 to high-level node 4 should not be built either. To sum up, should use the ring structure.

Set Branch Lines

To build the right cable to connect LANs in group 1, we must introduce the following variables: the length of each line is $l(n)$. Because there are 8 LANs in the group, there should be $8 \times (8-1)/2 = 28$ connections between each other. So set $n=1,2,\ldots,28$; a variable is assigned to each line, $x(n)$. It indicates the break of line $n$, 0 means break, 1 means connected. So, it is known that the construction cost of the route is:
According to \( l(n) \) and \( x(n) \), we can get the shortest distance between \( i \) point and \( j \) point in the network as \( a_{ij} \), and the shortest path matrix \( A = \{ a_{ij} \} \). Using the OD matrix \( M \), we can extract the OD matrix \( B_1 \) of LANs in group 1. The communication expense can be calculated as:

\[
\text{Cost}_1 = \text{Construction_cost} / \text{kilometer} \cdot \sum_{n \in N} l(n) \cdot x(n) \tag{8}
\]

\[
\text{Cost}_2 = \text{Communication\_expense} / \text{kilometer} \cdot \sum_i \sum_j a_{ij} \cdot b_{ij} \tag{9}
\]

Therefore, the goal of this problem can be understood as by changing \( x(n) \) to optimize the objective function: \( (\text{Cost}_1 + \text{Cost}_2) \).

Using the genetic algorithm [7], set the target to \( (\text{Cost}_1 + \text{Cost}_2) \), after iteration, can be obtained: \( x(n) = 1000000100000100001000100101 \). Similarly, the connection of rest of the group can also be obtained.

The final underground communication network design shown in Fig. 3.

![Figure 3. The final underground communication network design.](image)

**Conclusion**

In this underground network design, the first established 26 routers and LANs, taking into account the cost and information traffic. From these routers, 4 high-level nodes were selected. And then grouped LANs according to high-level nodes. According to the order from the whole to the local, trunk lines and branch lines are designed. The network is divided into two layers: The first layer uses a ring structure and the second layer is in series. The trunk line adopts the ring structure, while the branch line adopts the series structure. The design takes into account construction costs and communication expense, and meet the limitations of practical applications and the common sense of network design. This design idea can be used to solve similar problems in the future.

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**References**


