ARTICLE

Emergency situation analysis: On the example of underground mining radio communication system

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Abstract: *Underground mine is the most dangerous environment for miners to work in, and the miners need to be evacuated immediately in case of an accident. This article aims to develop route options for safe emergency evacuation of miners from areas where there are no radio communication in underground mine to an area where radio communication is available in the underground mine on the example of an underground mine radio communication system. We have used the Dijkstra's algorithm in the study to determine the optimization of the short-term evacuation of miners in case of an accident in an underground mine. We have also developed the optimization of evacuation route to a place where there is radio communication failure owing to an accident to a place where normal radio communication is available. Using MATLAB it was possible to analyze the shortest route for evacuation from an area without communication to an area with normal communication, and for this purpose it gave us the possibility to analyze using any number of exits. The novelty of the study was using the shortest route option on the example of radio communication failure in an underground mine.*

Keywords: *reliability; Graph's theory; shaft; underground mine; optic; radiation cable;*

INTRODUCTION

Without a reliable underground communication system, today it is not possible to ensure normal operation in a mine, especially underground mine. Underground mine is a very dangerous environment for people to work in, therefore providing constant and reliable communication and information technology systems are critical for the safety of miners, and it is equally very important to improve the reliability of these systems on a scientific basis [1]. In order to ensure continuous and reliable operation of radio communication during an evacuation of miners, who are inside the underground mine, in the case of an earthquake or fire hazard, in other words, it is necessary to determine the optimal route for evacuating miners to a place in the underground mine where radio communication is normal from a place of a site in the underground mine where there is a radio communication failure.

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Basing on previous studies on the reliability of radio communication, it has been found that there is very few research on optimizing the reliability of radio communication for streamlining emergency evacuation of workers in case of an accident in an underground mine. We have used Dijkstra's algorithm [2] to determine ways and means of optimizing short-term evacuation of miners during an underground mine accident, and also to determine the optimization for evacuating workers within a vefry short span of time from a place where there is radio communication failure to a place where there is normal radio communication.

The authors of the article [3-6] have developed algorithm during accidents, of which only [3] have developed algorithms during an accident in an underground mine. The article [3] introduces the results of the Floyd-Warshall's algorithm for dynamic programming of short route algorithm for miners in case of an accident. However, the authors of the articles [7-18] have developed short route algorithms for non-underground objects (such as buildings). In the case of any accident near an underground mine, workers must be evacuated immediately. Depending on the scale and the danger of the accident, radio communication can be shut down in a place where an accident has occured, and rescue teams may be required to evacuate workers to other places that have normal radio communication. In this paper, we have used Graph's theory, and a Graph's model was developed for an underground mine with one shaft, two shafts, and three shafts, and Dijkstra's algorithm was developed for the current conditions of the Oyu Tolgoi underground mine radio communication. The novelty of the article is that it is possible to add the number of underground mine exits to this algorithm, as well as to analyse the options for exits from the underground mine. Precisely, the matrix entered in MATLAB shows the shortest of all possible route options after entering the number of cells and the number of exits from somewhere in the underground mine or in one of the cells (we used cell 2 in our results). After that possible route options will be analysed depending on the above results.

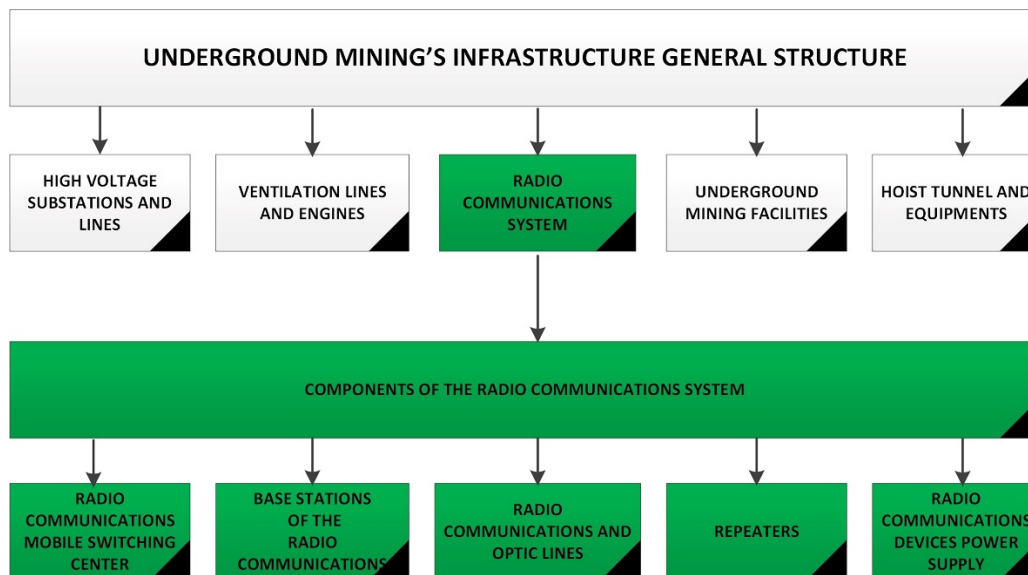Figure 1 shows a scheme of the general structure of an underground mine.

Figure 1. General structure of underground mine and radio communication system

Underground radio communication systems consist of core systems, which are located on the surface, transmission systems which consist of optical lines, and base stations, which are located underground, repeater amplifiers, radiation cables, and consumer radios [2]. Figure 2 shows the main components of an underground mine radio communication system.
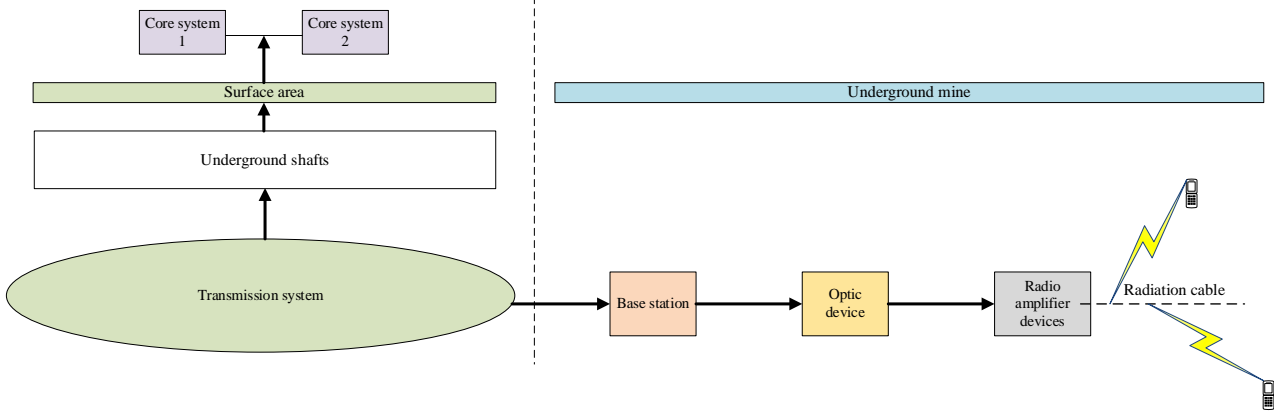
Figure 2. General connection of radio communication system in an underground mine

Radio amplifier device operates with its own frequency band, called a cell, tunnels with radio signal coverage. Cell 1 is connected to exit 1, cell 3 is connected to exit 2, and cell 5 is connected to exit 3. We have taken for our study an underground mine with three exits, and we have identified all possible routes through these three exits. The underground mine currently has shafts which are accessible to three underground mines, and all these three shafts are for the workers.

MATERIALS AND METHODS

In this study we have determined the critical point of underground mine radio communication system and the possible route options for the part of the radio communication from the point where radio communication is lost by using the connection matrix of Graph's theory.
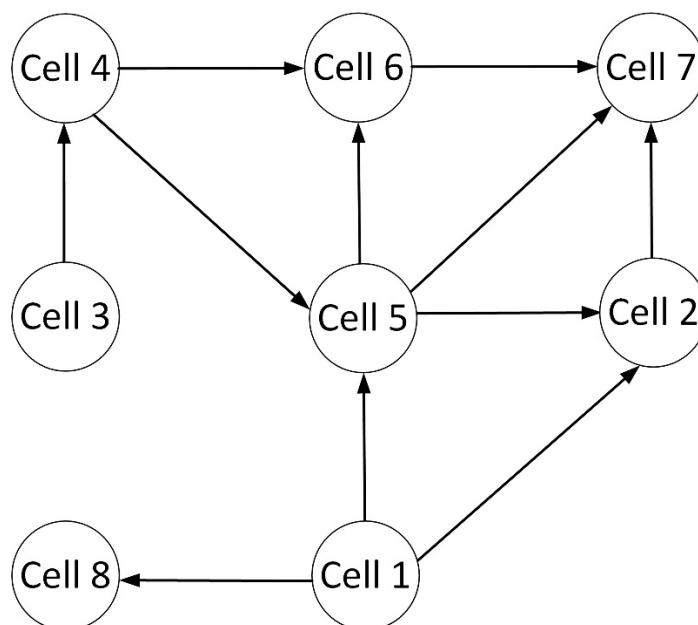

Figure 3. Current condition of underground radio communication radio amplifier devices connection on the example of the Oyu Tolgoi underground mine

Table 1. Connection matrix of radio amplifier devices in underground mine radio communication system

Cell numbers	1	2	3	4	5	6	7	8
1	1	1	0	0	1	0	0	1
2	1	1	0	0	1	0	1	0
3	0	0	1	1	0	0	0	0
4	0	0	1	1	1	1	0	0
5	1	1	0	1	1	1	1	0
6	0	0	0	1	1	1	1	0
7	0	1	0	0	1	1	1	0
8	1	0	0	0	0	0	0	1
Connected cell numbers	4	4	2	4	6	4	4	2

As shown in Figure 3 and Table 1, the main point of underground mine radio communication is point 5 and it is connected to the other six points. It is also clear from Figure 3 and Table 1 that points 3 and 8 are not very essential in terms of possible route options. In the current scenario, the Oyu Tolgoi underground mine has one, two and three exits, and the shortest route was determined in this condition. The matrix has underground mine communication cells as 1-8 that were developed by the Graph's method. Table 2 below shows the possible options for moving from areas where there is no communication to areas that have communication using these three exits from cell 2, and the results for single-exit, double-exit, and triple exits, along with their comparative reliability for the possibilities of using the shortest route to exit.

Table 2. Results of the radio amplifier device connection conditions inside the underground mine at Oyu Tolgoi

	Exit number	Each exit path options	Total availability	Shortest path options	Shortest path
Exit-1	1	5	5		cell2 to cell1
Exit-2	1	5	15	33,4%	cell2 to cell1
	3	10			cell2-cell5-cell4-cell3
Exit-3	1	5	20	75%	cell2 to cell1
	3	10			cell2-cell5-cell4-cell3
	5	5			cell2 to cell5

It is clear from Figure 3 that points 3 and 8 are not important points, we can see in Figure 4 how underground radio communication connection changed after connecting points 3 and 8 to each other and to point 5.
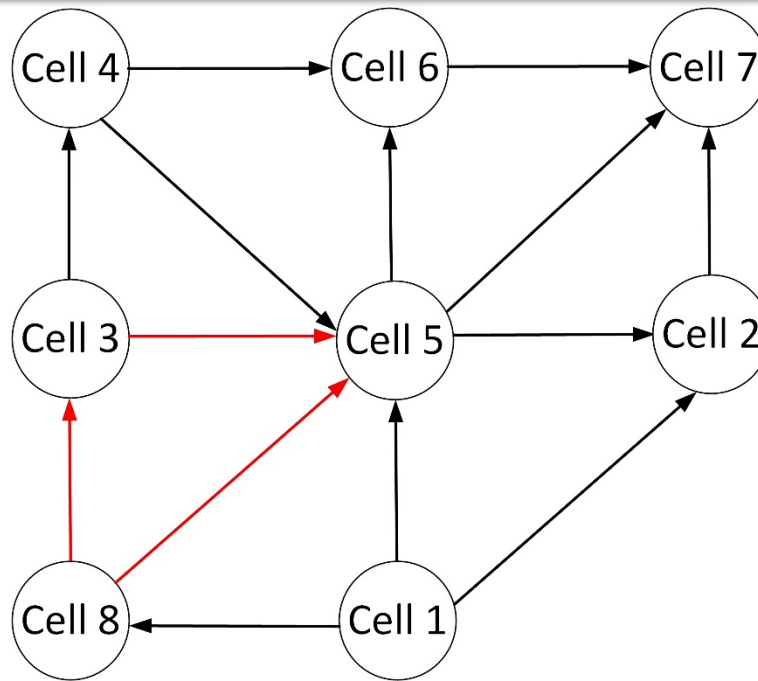
Figure 4. Radio communication network diagram in Oyu Tolgoi underground mine after changing

Table 3. Results of after changing connection

	Exit number	Each exit path options	Total availability	Shortest path options	Shortest path
Exit-1	1	23	23		cell2 to cell1
Exit-2	1	23	52	44.20%	cell2 to cell1
	3	29			cell2-cell5-cell3
Exit-3	1	23	65	80%	cell2 to cell1
	3	29			cell2-cell5-cell3
	5	13			cell2 to cell5

Table 3 above shows the analyzed options for switching from a place where there is no radio communication to a place where radio communication is available, with the lowest possible route crossings and their comparable possible route options at one exit, two exits and three exits. The part is marked with red lines and they are the newly drawn lines.

RESULTS AND DISCUSSION

To assess the reliability of underground mining radio communications, using Dijkstra's algorithm, the critical points of a complex system that includes many radio communication components were determined by the connection matrix-based Graph's method. The most important point was point 5 from Figure 3. For current connection and reliability improvement the connection was changed by matrix method possible route options transferring from a place where there is no connection to a place that has communication, and their comparable possible route options as well as the shortest route options were analyzed. The following results were obtained upon analysis. According to the results of connecting points 3 and 8 to each other and to point 5 and Table 4 shows results of significant improvement of the shortest route distance possibilities, reliability, and shortest route distance options for moving from a place where there is no connection to a place where connection is available. We have used MATLAB software method for the analysis,

and the method has allowed to move from a place without connection to a place with connection, and it is possible to analyze the shortest route options and for this analysis, any number of exits can be used. Additionally, the shortest route program was developed on MATLAB, and the algorithm works in the following order. You first put into the model the connection where you can see which tops are connected to other tops and the distance between the connected tops. Basing on which, the following information can be obtained.

1. Graph or the route and tops figure are shown in general view. In other words, it shows a general graph.

2. The next step is to provide a connection matrix showing the length of the routes given by the graph.

3. We will provide the conditions. In other words, we will show the point from where to go out to which exit.

4. Then a red line on a detailed graph will be shown of which route to cross and which tops. A detailed graph is one that shows the level of the underground mine in different colors and shows the location (of the exits) and exits are painted in different colors.

5. This route is the shortest one and the total length of this route is given.

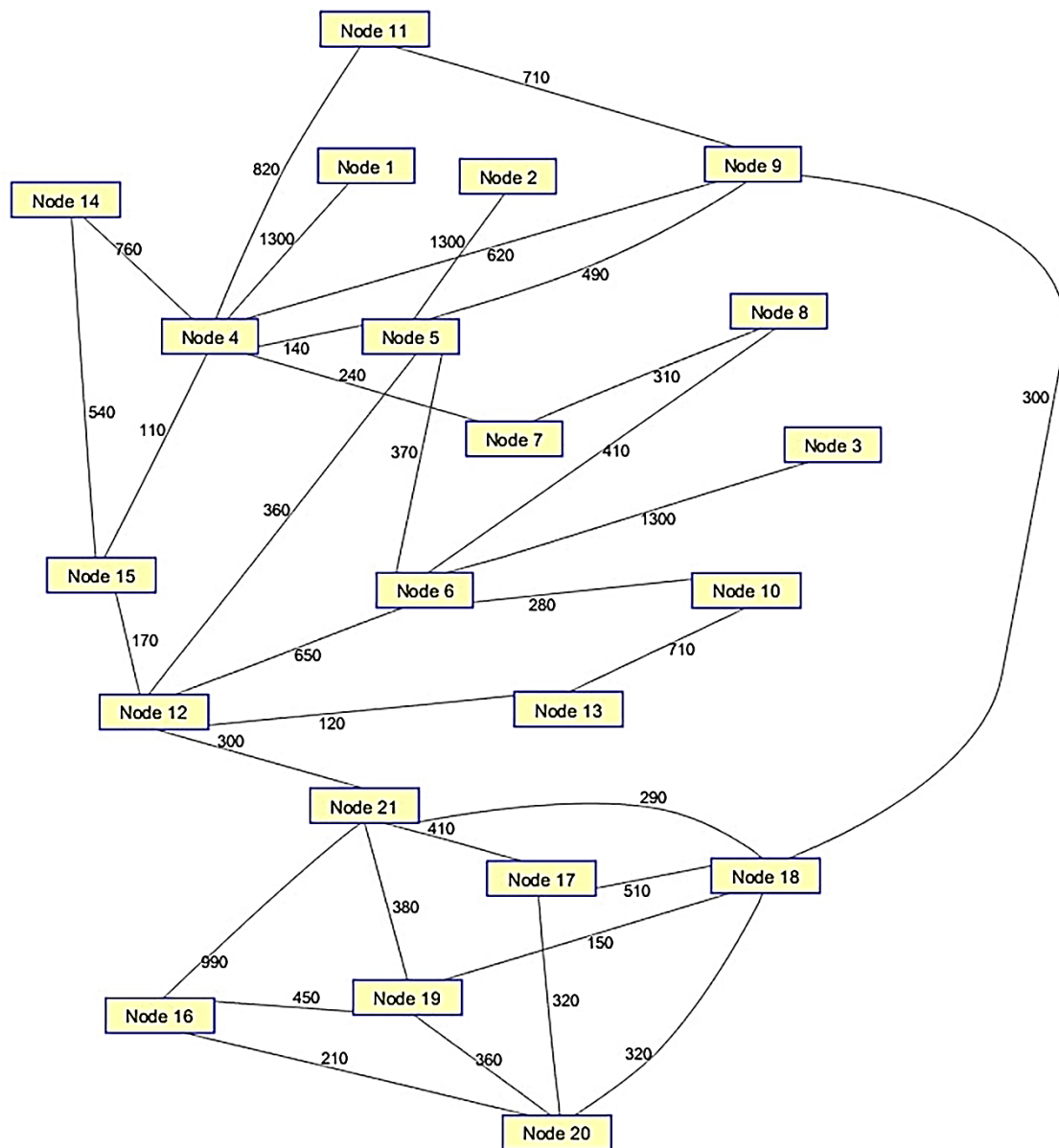6. Also, it will indicate which points (tops) are crossing each other.

Figure 5. Model of randomly analyzed Graph's route length based on the example of the Oyu Tolgoi underground mine radio communication system
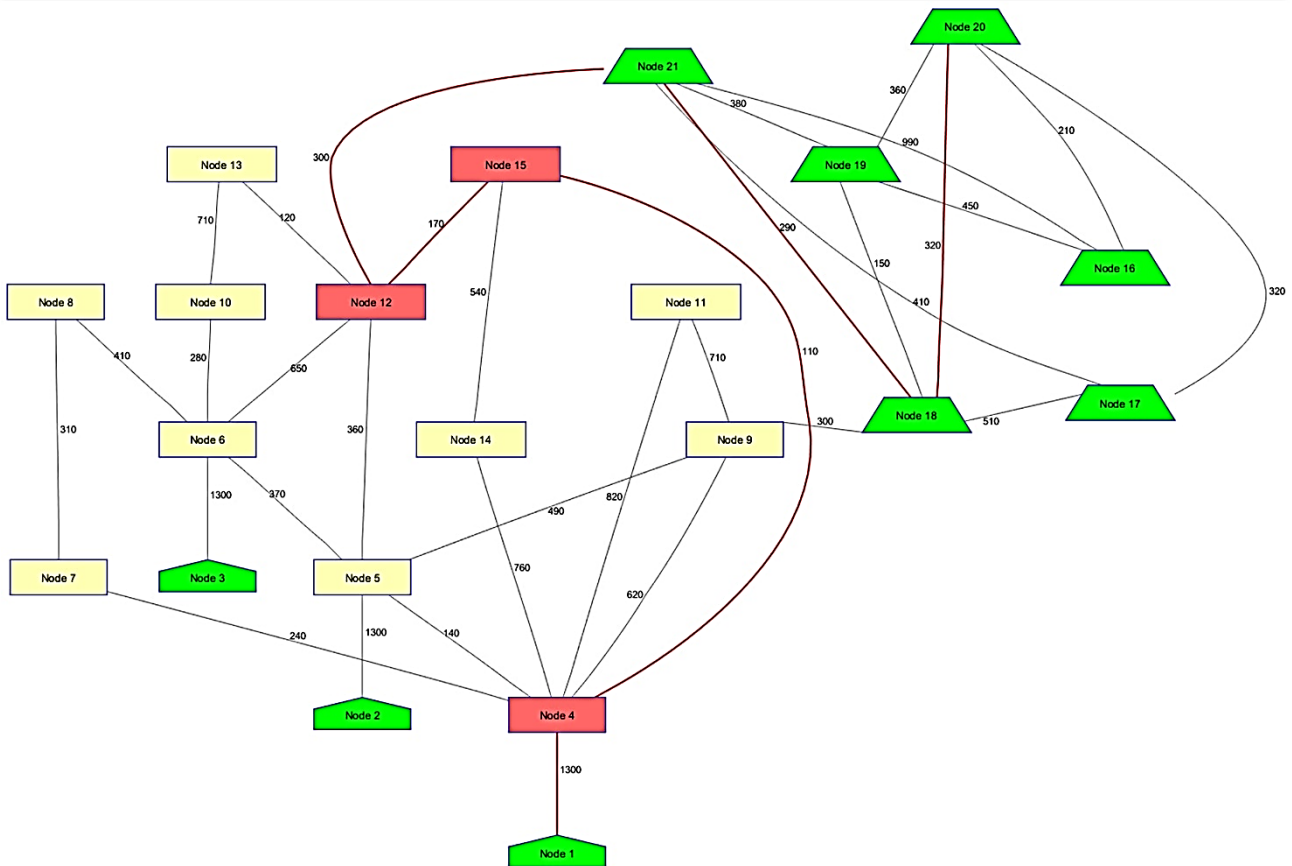
Figure 6. Detailed Graph's model based on the example of the Oyu Tolgoi underground mine radio communication system

The study has shown that it is possible to fully analyze in , using Dijkstra's algorithm, the length of the route for the safe evacuation of workers who are at various levels of the underground mine using the shortest route, emergency evacuation of workers to a place in the mine where radio communication operates normally from a place that has radio communication failure, emergency evacuation from underground mine in the case of an accident in the mine. Compared to the previous article [3], a special feature and a novelty of this article is that it is possible to develop Dijkstra's algorithm using the MATLAB software and determine the shortest route in case of an underground mine accident by a simple and an easy method.

CONCLUSIONS

This results of the study reveal the shortest possible route for evacuation options for underground miners in case of an accident in the underground mine and also determining, using Dijkstra's algorithm, the optimal route to the accident affected place where there is radio communication failure. The study also helped resolve an issue raised earlier on the need to provide constant, reliable radio communication during evacuation of miners in the underground mine in case of an earthquake or a fire hazard. In other words, answer was found to the queston of identifying the optimal route for evacuation of workers from a site in the underground mine that has radio communication failure to a place in the mine that has normal radio communication. In the first part of this study, the most important exits of the studied underground shafts were identified, using the Graph's matrix method, and the shortest route options were offered. In the next part, the shortest route from any one point of the underground mine was developed in the MATLAB software using the Dijkstra's algorithm, and the algorithm that used the software is much more innovative and special

than the article cited in [3] and other cited articles. The significance of the study is that, as the number of underground mine shafts or exits increases, the numbers of shortest routes from the underground mine in case of an accident will increase and also according to the experiment results, it is possible to analyze the shortest route options from a place without communication to a place with a normal communication, and for this purpose it is possible to use any number of exits in an emergency using the method that is being offered by us. In the future, this algorithm can be used not only for underground radio communication systems, but also for efficient management of urban traffic related decision-making.

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