Performance Evaluation of Underground Mine Communication and Monitoring Devices: Case Studies

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Abstract Communication and environmental monitoring play a major role in underground mining both from production and safety point of view. However, underground mining communication as well as monitoring devices encounter several challenges because of the nature of underground features and characteristics. Lack of real time information from underground workings may hamper production and create serious safety risks. Proper communication and monitoring devices are inevitable requirements for better production and improved safety. Communication and environmental monitoring devices are basic element of underground mine infrastructure. This paper describes the performance of communication and monitoring devices being used in underground mines. An attempt has been made to assess the safety risks by these devices which may dictate future research directions.

Keywords Mine communications · Monitoring · Wireless communication · Tracking · Safety · Ventilation on demand

1 Introduction

Mining has been considered as one of the oldest endeavours along with agriculture. The mining industry is always considered to be very critical that sustain civilization of any country. India is enriched with a number of mineral reserves and ranks

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among the top producers of coal, chromite, iron, etc. There are two types of mining operation commonly practiced, viz. opencast and underground. Opencast operation is involved in the mining of ore at surface level, whereas underground mining is for minerals that occur at greater depth. In underground mining, mainly there are two types of mining methods widely practiced to extract the ore body. These are board and pillar also known as room and pillar, and longwall mining methods. In India, majority of coal mines are practicing board and pillar mining method. However, the percentage of ore extraction is lower than the longwall mining method. In underground metal mines however, a number of methods are practiced, the common methods being cut and fill, shrinkage and sub-level stopping. It is easier to communicate and carry out monitoring in opencast mines, since access to different locations is comparatively easier and there is less hindrance in communications. In a particular shift of operation, large numbers of miners are present inside a mine for production and other activities. To this high number of mine personnel; safety is a prime and critical concern for every mining industry [1]. Underground mine environment poses a variety of challenges, because of the typical constructional features and environmental conditions. The key hazardous parameters, viz. toxic gases, humidity, dust, noise, temperature and vibrations are required to be monitored. Among all hazardous parameters; toxic gases, humidity, noise, dusts and temperature are major key parameters and need to be monitored continuously [2]. For coal mines, methane is a prime concern because of its explosive nature and Carbon monoxide (CO) is also found occasionally which is a acutely poisonous gas. In metal mines, noxious gases like SO_2 and H_2S are needed to be monitored for better working environment. Therefore, continuous mine monitoring is very much crucial and critical need for the mining industries. Apart from these hazardous parameters, there is another unique set of characteristics in underground mines. These are mainly discontinuities in ore body, water seepage, poor visibility, narrow pathway, noise and rough surfaces. These set of unique features add additional challenges to mining professionals and researchers. Risks and their mitigation efforts to minimize the risks and improved safety in underground mines differs perceptibility from normal industries. Communication and monitoring of mine environment is very much required for any underground mine. It plays a significant role for both safety and production. Communication is the only source inside the mine working which uniquely contributes in emotional support among the miners. Also, it is used for better work coordination among miners to manage the mining operation efficiently. Presently, safe working operation is a prime concern for all mining industries. In the past, a numbers of accidents have occurred due to different hostile conditions present in underground mines. Any accident in underground mine brings loss of not only human lives, but also damage to infrastructure and causes problems in rescue and recovery work. On such occasions two way reliable communication may help to save lives and properties through planned rescue and escape operations [3]. There are mainly three kinds of communication techniques used in underground mines namely through the earth (TTE), through the wire (TTW), through the air (TTA). However, hybrid system is also in used and is reliable. Hybrid system includes both the features of TTW and TTA [2]. In India, wired based infrastructure is mainly used for both communication and monitoring purposes. However, recently few underground mines have attempted to install TTA communication and monitoring systems. In this paper, an attempt has been made to assess the safety and risks through present communication and monitoring devices. The experiences gained from the visit of two underground metal mines and one coal mines have been presented here. These studies have been carried out during the month of February–March in the year of 2014. We studied the newly installed communication and monitoring devices presently working in the visited mines. This paper targets current researchers which are working and developing solutions for the mining industries. Also, this paper will help researchers to understand and formulation of problems in a better manner for future research. The paper has been divided into four sections. In Sect. 2, we briefly share information about the visited underground mines. Section 3, deals with the studies on the present communication and monitoring devices. We have done performance assessment of the present communication systems based on different considerations mainly the basic operation, coverage and survivability for each studied mine. The concluding remarks and future research discussion is presented in Sect. 4. In Sect. 5 we ended up our studies with conclusions.

2 Background of Studied Underground Mines

For our studies, we have selected both underground coal and metal mines. This is because, we wanted to carry out analysis and assessment of both types of mines which are mainly involved in underground mine operations. However, there are other types of mines also there such as iron ore, manganese, limestone, etc. but most of them are involved in open pit operations. We have given name to our studied mine as Site A and Site B for the metal mines and Site C for the underground coal mines. In the following paragraph, we briefly present the information related to the studied mine site, i.e. A, B and C.

Site A: Site A, is a metal mines. This mine is involved in extraction of uranium ore. The extracted ore is utilized in the power plant for India. This mine is one of the most modernized mines of India and uses shaft sinking to access the ore body. At present, the wired telephone system is mainly used for two way voice communication purpose. There are approximately 650 mine personnel working per day. In this site, we studied the present communication and tracking devices installed and working inside mine tunnel. We further examined the operation and architecture of the installed system. Although wired based telephone system is working well, but with the vision of modernization in mining operation and improvement in mine safety and production; hybrid system based communication and tracking devices had been installed by the mine management. Therefore, we primarily focused on our studies about the newly installed wireless based communication and tracking devices for this mine.

Site B: Site B, is also a metal mine and is involved in uranium productions for India. This mine involves approximately 550 mine personnel per day. Entry to this mine is with an inclined driven at 8° to the horizontal. Here also TTW communication technique is used for daily communications. We examined the ventilation on demand system which is currently installed and working in the mines. This system is also used for monitoring noxious gas concentration, i.e. CO and SO_2. The other objective of the ventilation management system than better ventilation support is to save the energy consumptions by the ventilation fans.

Site C: Site C, is an underground coal mine. This mine uses board and pillar method to extract the ores. Presently, only wired telephone system is used for communication purposes. Communication is achieved with the help of central dispatch centre (CDC) which is at the surface. This CDC works as an interface for communication from surface to underground and vice versa.

3 Assessment of Present Communication and Monitoring Devices

3.1 Site A: Communication and Tracking Systems

Basic Operation: Presently, the installed system targets to track the mine personnel and mining equipment. The installed system is based on wireless local area network architecture (WLAN) and is shown in Fig. 1. Internet protocol (IP) phones are used for voice communication among mine personnel. Every IP phone is registered to the access points. There are total nine phones working currently and registered to the different access points. One person can have communication with the other who is in the range of an access point to whom those IP phones are registered. Ethernet is used as the backbone network. The access point is installed at different working locations inside the mine workings. The data are transmitted over the Ethernet cable to the server, which is installed in the underground control room. In the installed network, Radio frequency identification (RFID) readers are used for reading the passive tags mounted over the mine trucks and mine equipment. RFID readers are installed at different locations and is connected through radio frequency cables. When the tag comes under the range of RFID readers then it reads the tag id and that information is passed through the RF cable to the control room. At control room, the authorized person can see the location of mine trucks and equipment. This help to manage the resources efficiently.

Coverage: Mining operations in an underground mine is carried out in a number of levels occurring at different depths from the surface. The working area in each level is again divided into a number of blocks or sections. These blocks or sections are connected with the main access through drivers, cross-cuts and raises. Limited line of sight is there for communication devices due to discontinuities in coal seams. The overall coverage of the installed WLAN architecture was limited to those areas

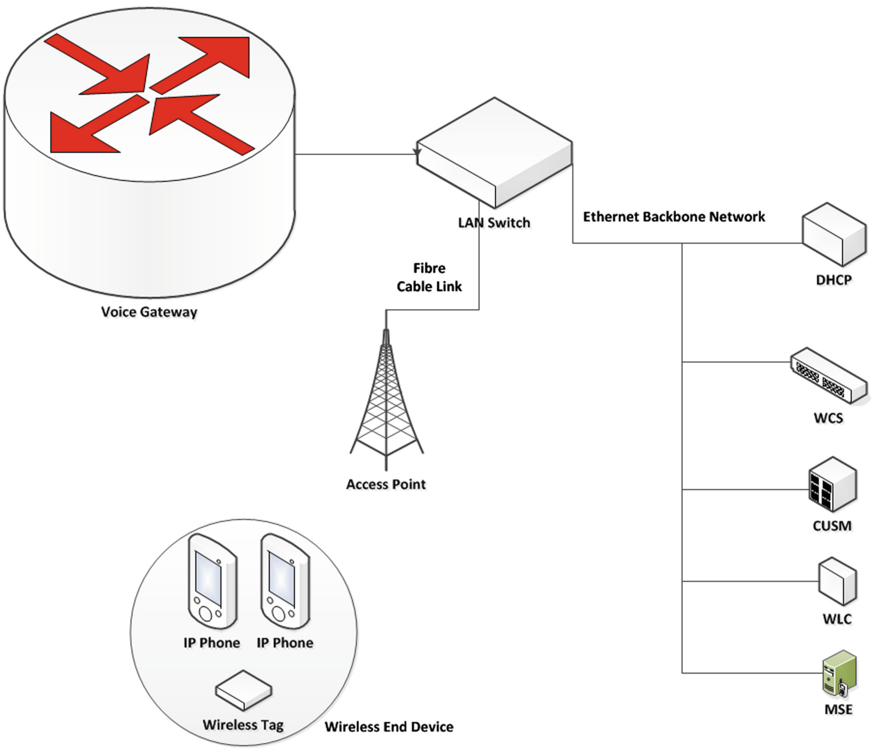

Fig. 1 Installed WLAN architecture

where access points were installed and the particular IP phone registered was coming under the range of that particular installed access point. Furthermore, the IP phone configuration to the access point was not dynamic means restricted to accessibility to which it is associated. To expand coverage area additional infrastructure would be required. The coverage of the present system installed is up to a length of 100 m as pointed out by the mine management. But during our studies 40 m distance was achieved for two way voice communication. The mobility support is limited to coverage area. Also dynamic configuration of the IP phone is not available.

Survivability: Post-accident communication is one of the most demanded features of communication and tracking devices to be installed in underground mines [4]. Therefore, the survivability of communication and monitoring devices even after catastrophic events, for example roof-falls, gas explosion, fire, collapse of the side walls and inundation are very much critical. The communication device can get damaged due to any of these events. This kind of uncertain condition present inside mines, need a full proof component design that must be rigid and immune enough to sustain in such environment. The current tracking and communication system is using ethernet as a backbone network. The chances of damages in the network is still there. However, the system is cased and immune to dusts and humidity, the ruggedness and shock resistivity is still have to be checked. In case any roof-falls or collapse of side wall occurs then the network will get affected and may lead to failure of communication. The system should be designed in such a way that the survivability of installed device is maximum after any accident.

3.2 Site B: Ventilation Management

Basic Operation: The installed architecture is based on the wired infrastructure. In the installed system, there are two major components; detector (transmitter) and controller which work as receiver. Detector is responsible for sensing the noxious gas concentration at working areas. The detectors are connected through fibre cable to the controller. The sensed data from the detector is transmitted over the cable to the controller. The controller further processes the sensed data on its own. The controller is further connected to the switch using relay cable for on/off operation for the ventilation fan. The maximum statutory limits for detector are 100 ppm for CO and 5 ppm for SO_2. After receiving the readings from transmitter i.e. detector, the controller worked with the following algorithms;

i. Switched on the fan if any or both conditions CO > 30 ppm, SO_2 > 1.5 ppm exist.
ii. Switch off the fan if both conditions CO < 10 ppm and SO_2 < 0.5 ppm exist.

The distance between a detector and the controller was 600 m (Fig. 2).

Coverage: To support better work environment, ventilation is vital inside underground mines. The coverage of the installed ventilation management system is limited to working areas where extraction of minerals is going on. To cover new area with time, there is an obvious need of additional infrastructure support. This may lead to chances of vulnerability in safety because the wired infrastructure may get damaged. Also additional detectors and additional sink controllers will have to be installed. Currently only one controller is there. To ensure reliability additional or back up controller is still required.

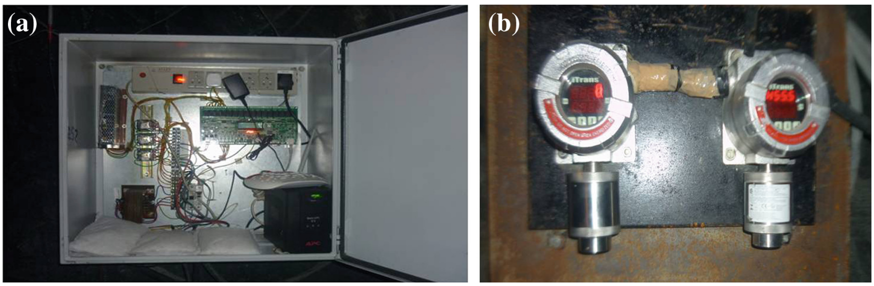

Fig. 2 Ventilation management system at site B. **a** Controller. **b** Gas detectors

Survivability: Environmental knowledge helps to improve the security measure to minimize the risks. The mining industry now feels the need to adopt a reliable and flexible communication technology to address different daily purposes. The ventilation management system is well cased and immune enough to dusts, humidity and explosions. The controller case is rugged and shock proof. Since, the wired connection is very complex, the chances of damages cant be avoided. The chances of damage may be caused due to movement of transportation systems, drilling operation and general maintenance works. At present scenario, Indian mines have mainly the wired infrastructure based monitoring devices. The disadvantage of having such infrastructure is that once the wired network has any technical issues or is damaged due to any of the incidents like roof-falls, fire, inundation and gas explosion then the entire system is affected and sometimes leads to collapse of overall communication system. This can create havoc among miners about their safety. At the very same time if any emergency occurs, then that may lead to serious accidents. In addition, this may further affect the overall mine production.

3.3 Site C: Present Communication System

Basic Operation: The studied site C, is currently using wired based infrastructure for two way voice communication from surface to underground and vice versa. The installed system is based on code system. There is one board at the CDC centre and that board is connected through the twisted co-axial cable. The telephone set is installed at prefixed known locations decided by the mine management at different working levels. Communication takes place with the help of an operator at the surface only. When a person working underground wants to talk with other mine personnel either on the surface or underground, then the first call he has to make is to the CDC. After receiving a call from underground working, the operator at the surface first identifies that from which working level the call is. He then switches the connection to the desired location demanded by the initial caller. The installed and working system is shown in Fig. 3.

Coverage: Wired communication inside mine works in fixed point communication fashion because of poor mobility support. In the mine, the telephone sets have been kept at prefixed locations. These locations are decided by the mine management. This limited position of telephone systems restricts the accessibility of the communication system. A person has to walk out for communicating to other working levels or to the surface. Furthermore, the sound quality is not so good due to additional noise in the network. Reliability of the overall network is adversely affecting due to the additional noise in the transmitted signals.

Survivability: The mine layout can vary considerably from mine to mine. The numbers of miners are grouped together in working section where ore is extracted. Whereas, different group of mine personnel is present inside mine for daily activities like drilling, blasting, transportation, maintenance, safety check, constructional

Fig. 3 Communication system at site C. **a** Chord based communication board at surface. **b** Telephone set

work and general maintenance. Every mine is involved in safety assessment on its own level to maximize the efficiency of installed systems and survivability. The communication system installed and working currently at site C, is a legacy system which is functioning since decades. It needs a regular check. Since, the wired connection is only the source of connection to different workings, the chances of network failure is high. The telephone set installed is having issue. Wired connection is done with the stitching in the side walls of the mine galleries. If any wire cut occurs then that working level will go for obvious communication failure. In such situation, the chances of risks can not be avoided. Also, the main circuit board at surface is having complex topology arrangement and is very old. To provide a secured environment for underground miners, it is also recommended that there should be a redundant communication path for backup in case any emergency occurs or the primary link fails.

4 Discussion

Operations involved in mining industries have been considered as a most hazardous production activity due to various risks parameters like humidity, poor visibility, toxic gas concentration, poor ventilation, potential rock falls, water seepage and dusts [5]. The summarized studies of the studied communication systems presently working in different mines is given in Table 1. The studied underground mines have communication systems based on WLAN and TTW architecture. It was being noted that however the communication system is working fine, but risks of failure of devices are still a concern. The performance of the communication devices in surface area found to be good but in case of underground mine workings their performance was poor. Additional noise in the transmitted signal degrades the signal quality at the receiver end. Scalability and accessibility of the devices are

Table 1 Summarized studies on present communication and monitoring devices

Mine site	Architecture	Coverage	Survivability	Type	Performance	Maintenance
Site A	WLAN	Limited	Poor	Hybrid	Good	Complex
Site B	Wired	Moderate	Poor	Through the wire (TTW)	Good	Complex
Site C	Wired	Limited accessibility	Very poor	Through the wire (TTW)	Poor	Complex

found poor and needs to be researched in future. Wired based system is inconvenient to dispose in areas like narrow pathways and the area to be exploited. Also, the coverage and maintenance problem is there with wired communication devices. In view of the deployment cost, wired infrastructure is expensive and needs a regular performance check. It can be analysed that post-accident, two way reliable communication may help to save lives and properties through planned rescue and escape operations [3]. In the current scenario in Indian mines, communication and monitoring devices is limited to wired infrastructures, which is further restricted to coverage, flexibility, reliability and scalability. Normally the mines have separate communication and monitoring technologies. However, there may be some mines which are satisfied with only one installed communication system, which can be used for both monitoring and communication purposes, since, the installed devices are packaged with proprietary protocols. Therefore, interoperability, and further scalability of the network is another issue to be resolved. The opportunities with wireless communication and tracking devices to be deployed in underground mines are totally different than traditional wireless communication in normal industries. Underground mines are highly prone to risks and continuous monitoring of mine environment is complex and needs interdisciplinary research efforts. An improved safety working environment not only boosts the confidence in miners, but also indirectly helps in enhanced productivity. To support mobility, ease deployment, easy maintenance and scalability; a robust and reliable wireless communication technology may be best suited to such a hostile and dynamic environment. Wireless infrastructure is very much capable to minimize these limitations moderately. Having a wireless infrastructure inside mines, gives a number of advantages over traditional wired network [6]. The necessity of wireless communication in underground mines has evolved from maximization of productivity, tracking and monitoring and also communication between miners for better coordination as well. The complexity in maintenance and network scalability of wired infrastructure is giving opportunities for new wireless technology to be deployed in underground mines in the near future.

5 Conclusion

Most of the underground mines in India have wired systems for monitoring mine environment and two way voice communications. It may be noted from the mines studied in the paper that the communication devices had a limited to moderate coverage area and their survivability is poor. It is also noted that the performance is poor to satisfactory under normal conditions. However, in emergency situation failure of these systems may lead to disastrous consequences. It is also noted from studies that the maintenance of the systems are complex. As the mines are becoming larger, the communication devices must have extended coverage area which may require interoperability efforts by the researchers. A number of research opportunities are available which can be achieved by means of new emerging wireless communication technologies. However, one has to carry out research on characteristics of the wireless channel inside underground mines. The present communication scenario of the Indian mines implies that to enhance the safety goals; research on reliable communication and monitoring system is still needed. Since, the underground mine workings pose various safety risks; one has to ensure that the developed system is intrinsically safe to avoid any dangerous occurrences.

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