Through-the-Earth and Other Types of Communication Systems for Underground Coal Miners for Disaster and Normal Operations

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Preface: This report constitutes a brief review of mine communications concepts and technologies that have been previously published by NIOSH, the U. S. Bureau of Mines and other sources, including information from manufacturers. It does not contain conclusions by NIOSH regarding the applicability or functionality of these concepts, technologies or devices in underground mines. This report has been prepared to provide an introduction to communications technologies.

Background

Recent tragic events and mine emergencies at the Alma, Sago, Quecreek and No. 5 mines have highlighted the need for reliable communications between the miners inside the mine and the outside. Present, wire-based communications systems may fail due to exposure to fires, roof falls or explosions tearing down wires, power failure or battery failure.

Today's communication systems used in underground coal mines generally employ a hard-wired system or a special cable called a "Leaky Feeder". Fiber optic cables are also used in some applications. Through-the-earth (TTE) and wireless radio systems are less common.

Hardware includes dedicated telephones, walkie-talkies, paging devices, and similar technologies. While hardwired and leaky feeder systems perform well under normal mining conditions they may fail during disasters as cable breakage interrupts communications. Armored, buried, borehole, loop-around and redundant cabling could improve reliability but would add to the maintenance and complexity of the system.

Coal mines are a particularly unique environment for radio signals. Radio systems require a clear path or open air for signal propagation. Stoppings or roof falls halt or impede conventional signal propagation. It is also believed that ionized air as a result of a mine fire can be a problem.

Some radio-based systems employ repeaters or Leaky Feeders within the mine that permit a radio signal to cover a larger area. However, not all radio signals will propagate down a coal mine entry due to the electrical properties of the coal and the surrounding strata.

Frequency selection has a great impact on signal propagation. Some frequencies utilize the coal mine entry as a waveguide, enhancing signal propagation, while other frequencies will not travel more than 50 feet. Unaided radio signals in a certain frequency range may propagate line-of-sight up to about 1000 feet but typically will not turn corners for more than a single crosscut. Parasitic propagation in the proximity of wires, conductors, pipes, and rails can enhance the propagation of signals at certain frequencies (medium frequencies).

In U.S. underground coal mines, regulations require that all electrical communications devices are approved by the Mine Safety and Health Administration (MSHA) as “permissible.” Permissibility can be achieved through explosion-proof (XP) or intrinsically safe (IS) design.

The following will discuss the advantages and disadvantages of various mine communications systems.

Presently Available Through-The-Earth (TTE) Communication Systems

A TTE system likely will have the best chance of providing contact with miners since it offers the best resistance to damage from roof falls, fires and explosions. There are several companies who offer TTE systems. Most are limited to communication from surface-to-underground. Only one system provides communications both surface-to-underground and underground-to-surface, but it is not a portable system. A brief description of each product is provided below.

Flexalert – Mine Radio Systems - Canada

Flexalert is an emergency evacuation system. It employs a low frequency electromagnetic field to convey information to miners wearing special cap lamp receivers. It is a one-way TTE transmission system. It consists of a 10 to 120 meter wire loop antenna that is strategically placed above the mine. The receiver is contained inside of a miners cap lamp. A received evacuation signal causes the cap lamp to flash. It also illuminates a secondary Light Emitting Diode (LED). Details on implementation and permissibility were not available.

PED – Mine Site Technologies - Australia

The Personal Emergency Device (PED) communication system is a one-way TTE transmission system that enables communication of specific text messages to individuals underground without any dependence on cables or wiring underground. It does not provide underground to surface TTE communications, but communications to the surface is facilitated via a separate Leaky Feeder system.

The PED system operates at a frequency of 1,000 Hz, and transmits digital messages to miners. Messages can be directed to an individual, to a group, or to all the underground personnel. When a message is received, the cap lamp flashes and the message is displayed on an Liquid Crystal Display (LCD) on top of the miners cap lamp battery. The first demonstration of the system in the United States was in 1990.

There are currently 17 permissible PED systems installed in U.S. coal mines and one in a metal/nonmetal mine. The first successful evacuation of miners attributed to the PED occurred during the Willow Creek mine fire, in Helper, Utah, on November 25, 1998.

TeleMag - Transtek – United States

TeleMag is a wireless through-the-earth two-way voice and data communication system. It operates at 4 kHz. It is a fixed, station-to-station system. The underground and surface antennae consist of 60-ft diameter loops. It has been tested to depths of 300 feet. The first demonstration of the system was in August of 2000 (Conti, 2000) at the NIOSH Lake Lynn Laboratory mine. It is not permissible. Other mine installations are not known.

TTE System Under Development

GeoSteering - TramGuardMinerTrack

GeoSteering presently markets an MSHA approved proximity warning system called TramGuard for continuous mining machines. Information from the system is archived in the system and can be locally accessed with appropriate hardware. GeoSteering has been engineering a method to provide the data via a TTE connection with the surface. The data includes the identification of all local miners, their distance from the system, and other useful data. This part of the system will be called TramGuardMinerTrack. The system is portable and includes a backup battery. In-mine tests are now being conducted, however details are proprietary.

Research on TTE

Research on TTE has been conducted by a wide variety of universities and government agencies around the world and resulted in a few commercially available products. Some of the more significant developments are provided as follows.

CSIR Miningtek – South Africa

Miningtek developed a trapped miner-locating device. A prototype was successfully tested underground where the device provided detection and location of a trapped miner at the distance of more than 30 meters through rock. The system consisted of a uniquely coded belt wearable miner's tag and portable search unit. The tag is built into a metal buckle and includes an LED and buzzer (Kononov, 1999). It is not known if this development resulted in a commercial product.

Institute of for Advanced Physics, University of Innsbruck - Austria

Research at the University of Innsbruck (Nessler, 2000) resulted in the development of a system which was composed of a beacon contained in a miner's cap-lamp, and a hand-held location receiver which could search for the trapped miners beacon. Field tests at the Schwaz/Tirol mine demonstrated a detection accuracy of 50 cm. The paper does not mention the distance from the beacon to the receiver. It is not known if the system became a commercial product.

U.S. Bureau of Mines – United States

In the mid 70's to the early 80's the U.S. Bureau of Mines conducted extensive electronic communications research over a broad spectrum of frequencies and system types. Frequencies investigated ranged from extremely low frequencies (ELF) to a few GHz. Most significant was their TTE research at frequencies between 600 Hz to 3000 Hz.

The research resulted in the development of several communications devices (Lagasse, 1980). The above-the-mine part of the system consisted of a transmitter and long wire loop antenna, and a handheld locator receiver with a 15-inch loop antenna. The miner-carried part of the system was a compact belt-worn device with a voice receiver and a wire-loop antenna that would be unfolded during an emergency to provide a beacon signal to the surface. The concept was validated through the resulting tests at 94 coal mines at depths up to 1000 feet. A statistical analysis of the data concluded that, at 750 feet depth, there was a 68% probability of signal detection. Despite promising tests the device failed to gain commercial success.

Other Coal Mine Communication Systems

Underground coal mining employs a diverse mix of communication devices (Kohler, 1992) including telephones, loudspeaking telephones, radios, trolley phones, shaft or hoist phones, and emergency or rescue team communication systems. I addition, some mines today use hand-held radios.

Though recent events have shown these systems to be unreliable during disasters, they will be discussed because significant reliability improvements may be possible. Particular emphasis will be put on radios since this technology affords the miners the most flexibility and instantaneous communications. Radios can require an elaborate support structure to compensate for the poor radio signal propagation environment of a coal mine. The predominant support structure is called a “leaky feeder.” One relatively new concept using radio in a mine is called “WiFi.” A few systems have appeared that indicate that the backbone infrastructure (Leaky Feeder) may no longer be required. These systems require strategically placed wireless repeaters. These systems are often digital, which opens up new possibilities, including simultaneous delivery of voice (VOIP), data, and video, over the link. There has also been a merging of technologies which marry Leaky Feeder, Ethernet, and WiFi. A few cell phone vendors now market a phone that combines standard cell phone communications protocols such as Global System for Mobile communications (GSM) and WiFi. With the appropriate software installed in a PC at the mine office, and a WiFi network installed in the mine, a miner can walk into the mine and continue to use his cell phone. Permissibility is still an issue for this equipment. Radio Frequency Identification (RFID) is another presently popular system type. Basically, RFID provides tracking and accountability of persons and other assets. RFID is provided by Leaky Feeder, WiFi, and other wireless system types used in mines.

Leaky Feeder

To allow certain radio frequencies to propagate underground, it is necessary to replace a standard surface antenna system with a cable network (Leaky Feeder). The Leaky Feeder can be installed to effectively radiate the signal throughout the mine. The cable is designed to "leak" signal, which allows radio transmissions to both leak from the cable and also to enter the cable. Specially placed line amplifiers and repeaters compensate for signal loss. Each of these devices requires power and battery backups for operation when power fails.

Ethernet

Ethernet is the most widely-installed local area network (LAN) technology employing a special data communications protocol called TCP/IP that is becoming more widely implemented in underground mines. Voice communications over TCP/IP (VOIP) is possible. An Ethernet LAN uses coaxial cable or special grades of twisted-pair wires. TCP/IP has also been adapted for use on Leaky Feeder cables.

WiFi

WiFi is short for ‘wireless fidelity’, a term for wireless local area networks (WLAN) conforming to a protocol specified in IEEE 802.11b,g. WiFi has gained acceptance in many environments as an alternative to a hard-wired LAN. Many airports, hotels, and other services offer public access to WiFi “hotspots” so people can log onto the Internet and receive emails on the move. Hotspot WiFi-based communications systems are also available for underground coal mines. It is unknown if these systems are permissible.

Medium Frequencies

Worth mention are the unique properties associated with medium frequencies (300 kHz – 3 MHz). These frequencies exhibit a phenomenon called parasitic propagation. The system emulates the properties of a Leaky Feeder without a specialized cable, but range varies depending on several factors. There have been a few commercially developed radio systems that take advantage of this property. One vendor (Conspec) has a permissible system available. The size of the antenna can be cumbersome.

LAMPS – CSIRO – MineCom - Australia

CSIRO scientists developed a communication system to monitor the location and health of miners underground in an emergency situation. The Location and Monitoring for Personal Safety System (LAMPS) was design to support search and rescue operation and improve their response time in emergencies. The system consists of equipping each miner’s cap-lamp with a transponder that transmits the miners ID, his location, and vital health signs to wireless beacons. It could also be used for environmental monitoring. It requires a network of wireless beacons distributed throughout the mine. It does not require a continuous hard wire connection between beacons. Implementation or permissibility information is not available.

Wireless-Mesh-Networks

Another interesting and possibly applicable technology to the needs of underground coal mining in the future is identified as a "Wireless-Mesh-Network. It's based on WiFi technology and employs special, TCP/IP based data protocols. Protocols have not yet been standardized, as this is an emerging technology. IEEE has developed applicable standards, but there are several providers on the market, and it is uncertain as to which ones may become dominant. Wireless modems (sometimes called Hotspots or nodes) are strategically placed throughout a work area, and each unit can receive, transmit, or act a signal repeater. This multi-hop style network can be designed redundant and automatically configures itself and also has a "learning" and "self-healing" capability. There are no predefined signal pathways between the nodes. Failure of any one node or closure of any one signal path (due to loss of power or an event such as a fire or a roof fall) has little impact on the whole network. The application of this type of network could greatly enhance the reliability of a wireless coal mine network. Still, if all possible radio signal paths are closed or if too many nodes fail, communications will stop.

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