Preliminary Assessment of Communication Systems

For Underground Mines for Normal and Emergency Operations

by

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1.0.0 Disclaimer

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2.0.0 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 outside. Present wired and wireless communication systems may fail due to exposure to fires, roof falls or explosions tearing down wires, power failure or battery failure. Coal mine communications research goes back as far as 1922 (Colburn, 1922) when the U.S. Bureau of Mines (USBM) performed experiments to detect radio signals from inside their mine in Bruceton, PA. Coal mine communications research has been conducted generally in response to major accidents such as those mentioned. It is the intention of this report to identify and document previously developed significant research as well as new and emerging technologies which can benefit and improve the safety and health of today's underground (UG) coal miners.

Communication systems used in today's UG 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 (Moussa and Lagace, 1982).

Coal mines are a particularly unique environment for radio signals. Radio signals require a clear path or open air for signal propagation. Stoppings or roof falls halt or impede conventional radio signal propagation. It is also believed that ionized air that can result from a mine fire could 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 which 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 1000 feet, but typically will not turn corners for more than two crosscuts. Parasitic propagation in the proximity of wires, conductors, pipes, and rails can enhance the propagation of signals at certain frequencies (medium frequencies).

In the mid 1970's the USBM conducted extensive research on this and many other phenomena associated with radio signals propagation at coal mines (Appendix A). This research and other development work was done in response to the Coal Mine Health and Safety Act of 1969 and aimed at increasing the survivability of coal miners trapped UG during disasters. It included the determination of the optimum frequencies for reliable communications especially during disasters. Frequencies investigated ranged from extremely low frequencies to a few GHz. Propagation measurements were conducted both within the mine as well as through-the-earth.

Extensive electrical noise measurements were performed both in and on the surface at a representative sample of mines throughout the coal fields. Electrical noise measurements are important to the success or failure to convey voice or data. To be heard or detected, the signal generally must exceed the noise. Modern signal processing techniques, such as spread-spectrum and ultra-wide-band (UWB) have changed that paradigm, but still the signal-to-noise ratio is a critical factor to communication success.

In UG coal mines within the United States, regulations require that electrical communications devices be approved by the Mine Safety and Health Administration (MSHA) as "permissible." Permissibility can be achieved through explosion-proof (XP) or intrinsically safe (IS) design.

3.0.0 UG Coal Mine Communication System Design

Before any new communication system is installed in a mine the electrical noise environment, both surface and UG should be measured, documented, and analyzed. Next, signal propagation measurements should be performed, documented, and analyzed. Candidate technology should be reviewed, tested, and evaluated. A heavy emphasis should be placed on interoperability. A "Risk Assessment" should also be done to determine the possibility of a system operating under emergencies conditions. Only then should a specific system be installed. Older mine communications systems should be technically reviewed and updated accordingly. Methods and devices should be added to the older systems to provide for interoperability and redundancy which will improve the odds that communications will be available during disasters.

3.1.0 Electromagnetic Interference (EMI)/Noise

Analysis and design of radio-communication systems requires knowledge of atmospheric-noise models. Also the performance of any electronic communication system is highly dependent on the electromagnetic (EM) noise of the environment in which it will be used. The selection of candidate operational/emergency EM mine communication and location systems should therefore only occur after EMI measurements are made.

If there were no natural or man-made electrical noise interference, TTE receivers could be extremely sensitive and transmitters could be very low power. Unfortunately, nature has imposed barriers and fixed limits which current technology and as yet has been unable to circumvent.

Clouds contain electrical charges with respect to each other and also the earth. Under storm conditions theses charges reach tremendous voltages which cause violent discharges evidenced as lightning strokes which may be between clouds, or clouds and the earth. This flow of current, often in the thousands of amperes, causes EM radio waves to be produced which may travel for hundreds of miles with sufficient

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intensity to interfere with radio communications in distant undisturbed areas. Other sources of EMI include galactic, cosmic, and even the earth's aurora magnetosphere. Much of this noise ends up in the extremely low frequencies (ELF), voice frequencies (VF), and very low frequencies (VLF) frequency bands. All have a negative impact on the operation of a TTE receiver.

The amplitude of man-made EMI decreases with increasing frequencies and varies considerably with location. It is typically due to electric motors, power lines, appliances, etc. Unfortunately most of the noise is in the frequency bands which are most appropriate for UG coal mine communications.

In receiver design, thermal noise is caused by the agitation of electrons in resistances. Selection of low-noise components for a TTE receiver can make a big difference in whether a signal is detected or not. Some receiver concepts have been built around high-temperature superconducting devices (SQUID - Superconducting QUantum Interference Device – See Appendix F) to minimize this problem. A precise evaluation of the quality of a receiver as far as noise is concerned is obtained by a determination of its noise factor.

The measurement of EMI outside of the receiver is done in the same way as radio-wave field strengths with the exception that peak, rather than average values of noise are usually of interest, and that the overall band-pass action of the measuring apparatus must be accurately known in measuring noise. Fortunately, for the UG TTE case, much data has been taken by and under contract with the former U.S. Bureau of Mines (Aidala et al, 1974).

3.2.0 Signal Paths/Signal Propagation

In an underground coal mine, the options for communications signaling include: Through-the-Wire (TTW), Through-the-Air (TTA), and Through-the-Earth (TTE). Each of these will be briefly addressed.

3.2.1 TTW

TTW communications signals in a coal mine can travel over twisted pair, coax, CAT5, trolley, leaky feeders, and fiber optic cables. Each of these cable types have unique properties which generally are selected to suit the characteristics of the signals being conveyed. Twisted pair is typically used for telephones and pager phones carrying only voice signals. Coax cables are used to convey higher frequency signals and are generally modulated with voice and/or data signals. CAT5 cables are specially constructed twisted pair cables that handle advanced digital protocols for computer networking. Fiber optic cables are in many cases used in place of CAT5 cables for the relay of computer networking protocols over longer distances. Trolley cables are normally used to provide power to mine locomotives, but can also act as a conveyor of medium frequency (MF) type signals. A leaky feeder cable is a specialized cable that enhances the propagation of certain radio frequencies underground. The signal characteristics of this cable require a more detailed description which is provided at the end of this section.

Fires, explosions, and roof falls do destroy cables in UG coal mines. Cables are not reliable. Some of the measures that can be taken to address the problems include using armor cable or conduit, burying the cable, creating redundancies by having multiple cables feeding the same portion of a system, providing loop-around, and providing borehole connections to main lines. Various software techniques have also been employed using sophisticated algorithms (such as the "spanning-tree algorithm") to direct signals when cable failures occur. Using armored cable or putting the cable in conduit is expensive. Providing

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redundancy by using multiple cables and loop-arounds can be complicated to design and manage as well as being expensive. Feeding cables through boreholes can protect the cables, but boreholes have their own unique set of problems such as, impede radio signals, water getting into the cable, etc. Also, cased boreholes can cost upwards of $30 a foot or so. In summary all of theses methods are vulnerable to complete failure when a fire, explosion, or roof falls in a mine occur.

Leaky feeder cable is designed to "leak" signal, which allows radio transmissions to both leak from the cable and also to enter the cable. Leaky feeder cable can be either a twin-core, coaxial cable in which the sheath (outer conductor) is pierced by a series of apertures: loose-weave cables, cables with holes or continuous lengthwise slots in the sheath. The cables radiate over their entire length. The increase in signal range is due to the lower degree of attenuation by the cable than by free-space propagation in the mine (Delogne and Liegeois, 1975). Leaky feeder cables commonly require specially placed line amplifiers and repeaters to compensate for signal loss. Each of these devices requires power and battery backups for operation when power fails. Transmission range can exceed 100 feet and receive range can exceed 300 feet in line-of-sight of the leaky feeder. There are four leaky feeder systems presently approved by MSHA:

- Mine Radio System, Flexcom, MSHA approval number 9B-219
- Varis Mine Technology, SmartCom IS, MSHA approval number 23-A050001
- DAC, RFM 2000, MSHA approval number 9B-201
- El-Equip Inc., Model VHF-1, MSHA approval number 9B-196

Advantages:

- The listed systems are currently available and are MSHA approved
- Provide clear two-way voice communications and low data rate signals
- Offer mine-wide coverage
- Portable radios that are small and efficient

Disadvantages:

- Radio signals in the VHF and UHF bands which are used on leaky feeder cables cannot penetrate rock
- Signal propagation is limited to line-of-sight-and within 300 or so feet of the leaky feeder cable
- Leaky feeder cables are subject to damage during a disaster and will most likely fail when most needed
- Leaky feeder cables are relatively expensive to install
- Repeaters must be installed at intervals to boost signal loss
- Maintenance and installation require skilled technicians
- Require battery backups

Further information can be obtained by contacting the cited vendors.

3.2.2 Through-the-Air

Much research has been conducted in UG coal mines. As far back as 1922, the USBM and the Westinghouse Electric Company (Westinghouse, 1979) conducted signal propagation tests towards the application of radio for mine rescue operations (Jakosky, 1924A). UG coal mines present unique challenges to radio signal propagation. The electrical properties of coal attenuate certain frequencies more than others. The propagation of some frequencies is enhanced by a waveguide effect due to the sandwiching of radio signals between layers of strata with varying electrical properties. The viability of wireless radio transmission in coal mines can only be determined through thorough testing in the UG mine environment. Many such tests have been performed at a large collection of coal mines. A partial listing is provided below:

- Propagation of EM Signals in Underground Mines, Terry Cory, Rockwell International USBM Contract No. HO366028 1977
- Communications/Location Subsystem, Westinghouse NTIS PB 208-267, Open File Report OFR 9(20-72)
- Preliminary Performance Predictions, for EM Through-the-Earth Mine Communications, Arthur D. Little, OFR 16-73
- EM Location System Prototype and Communication Station, Westinghouse, NTIS PB 226 600/AS
- Electromagnetic Location Experiments in a Deep Hardrock Mine, Continental Oil, NTIS PB 232 880/AS
- Electromagnetic Guided Waves in Mine Environments, Department of Commerce, James R. Wait, USBM Contract No. HO155008, 1978
- Electromagnetic Propagation in Low Mines At Medium Frequencies, Collins Radio, USBM Contract no. HO377053.

Research has shown that medium frequencies (MF) offer a viable approach to UG communications in both coal and metal/non-metal mines under certain circumstances. MF transmission is feasible for both personnel and vehicular communications. It does not suffer the attenuation characteristics and severe corner losses of UHF communications; nor does it require the use of expensive leaky feeder cable. Furthermore, it does not experience the high noise levels of ELF, VLF and LF communications. Research has demonstrated ranges of 1000 – 1500 feet in conductor-free areas, and much greater ranges in conductor-filled areas.

UG tests have shown that MF band EM signals couple into, and reradiate from, continuous electrical conductors in such a way that these conductors become the transmission lines and antenna system for the signals. The existence of electrical conductors in the entryway provides the means for what is has been called the “tunnel mode” or “parasitic propagation mode” of radio signal propagation in an UG mine. Testing has shown that MF signals propagating on one conductor would, by magnetic induction, induce signal current flow on other nearby conductor. Thus all of the entryway conductors and the magnetic coupling mechanism between conductors provide a means of mine-wide signal distribution. The method emulates the general properties of a leaky feeder without requirement of the specialized cable. USBM testing has also shown that MF radio signal propagation was possible in “natural waveguides” (coal, trona, and potash seams that are surrounded by more conductive rock) existing in certain layered formations (A.R.F, 1986). There have been a few commercially developed walkie-talkie systems that take advantage of this property. One vendor (Conspec) has a permissible system available. The range depends on a number of factors which include conductivity of the surrounding strata, type of floor and roof, distance to conductors, type of conductors, etc. The size of the antenna can also be cumbersome.

Some of the higher frequencies (VHF, UHF) propagate in a line-of-sight mode down a mine entry which can be upwards of 1000 feet. However, it is unlikely that an unaided (i.e., no leaky feeder) VHF or UHF signal would be able to travel around more than about two crosscuts.

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The selection of frequencies for use in an UG coal mine has been well researched, though more should be done. A few of the more significant highlights are 600 to 3000 Hz (voice frequencies – VF) is the best frequency for TTE signal propagation, 300 kHz to 600 kHz (MF) frequencies exhibit excellent parasitic propagation effects when in the presence of any conductive medium (e.g., wires, cables, tracks, etc.). The U.S. Coast Guard has developed a system (NAVTEX – http://www.navcen.uscg.gov/marcomms/gmdss/NAVTEX.htm) which operates at 518 kHz and is used for emergency signaling. This system should be investigated for potential adaptation to coal mines. Radio signals in the 27 MHz range are a poor choice for coal mine use. Radio signals in the 150, 500, 900 MHz and 2.5 GHz provide good line-of-sight propagation but typically won't turn more than a few cross cuts.

3.2.3 TTE

TTE communications can take on a few different forms. They include ground conduction, seismic, and wireless. Each type has unique characteristics which may be beneficial under certain emergency situations. Each will be discussed and references are provided for further information.

3.2.3.1 TTE Ground Conduction Signaling

Ground conduction signaling, called "the TPS method" by the U.S. Army Signal Corps (Jakosky, 1924B); consists of injecting and receiving signals through the ground via ground-stake connections. Using this method, as expected, the signals in the VF range propagate the best. However experimental results proved the distance that the ground terminals must be separated are two to four times the vertical distance through which the signals are to propagate. A 1000-ft deep mine would be a challenge for this method. Water tables, conductive strata, and other factors reduce the operational distance.

3.2.3.2 TTE Seismic Signaling

Seismic signaling consists of using special sensors called geophones, to pick up rhythmic vibrations signatures created by a miner who pounds on roof bolts, the roof, or floor of the mine. A more in-depth description of this method follows in section IVA2 of this document.

3.2.3.3 TTE Wireless Signaling

A portable TTE system will likely have the best chance of providing contact with miners since it offers the best resistance to damage from roof falls, fires, and explosions. Part of the reason is the miner can keep the system on his/her person. Also, there is not necessarily a need for a pre-existing antenna infrastructure. However, in this type of system frequency, geology, noise, and depth will influence the probability of successfully communicating with the surface. A series of studies (Emslie et al, 1974) resulted in feasibility calculations to establish first-order estimates of the magnitude and variability of transmitter power requirements under different noise, overburden conductivity, and mine depth conditions; to identify relationships, conditions, or frequencies that are likely to limit or enhance system performance; to reveal items requiring further investigation and data required; and to suggest practical methods for optimizing system performance. Simple experiments to support these calculations were carried out along with detailed investigations of specific modulation, coding, noise-suppression, voice-compression and signal-conditioning techniques, aimed at producing TTE operational/emergency mine-communications systems that were not only effective, but also practical and economical. Today only a very few systems incorporate the results of those studies, and typically they only operate from surface-to-UG. More details on TTE wireless communication are provided later.

4.0.0 Emergency Communications

Though any communication system used in a mine can be termed an emergency communication system, it is statistically unlikely that a conventional or normal everyday-use hardwired or wireless system will survive and/or operate after a major roof fall, fire, or explosion in a mine. On the other hand, a TTE communication system which does not require a preexisting cable or open-air signal path for the signal to propagate, would most probably be capable of providing communications from the miners to the outside world during a disaster. Therefore TTE systems will be the major focus of this portion of this document. Also, rescue team communication systems are only used during mine emergencies and they will be discussed at the end of section IV.

4.1.0 Presently Available TTE Systems

There are several companies who now offer TTE systems. Most are limited to communication from surface-to-UG. Only one system (TransTek) provides a communication system for both surface-to-UG and UG-to-surface. However, it is not a portable system. Recently a few companies have appeared which expect to be providing a TTE system in the near future. A brief description of each vendor's product is provided below. See Appendix C for additional information.

4.1.1 GLON-GLOP – Faser - Poland

This system consists of Personal Mining Location Transmitter (GLON), and Measurement Mining Location Receiver (GLOP) PAM-G3/1.

The GLON transmitter is contained in a Light Emitting Diode (LED) based miners cap lamp. The GLON generates a 4000 Hz to 6000 Hz EM signal on 1 of 8 distinct channels. Range of the signal through solid rock is projected to be 75 to 150 feet.

The GLOP receiver can determine the distance and direction to a GLON transmitter. The GLOP features manual or automatic tuning. Its liquid crystal display (LCD) indicates the frequency, signal level, and the projected distance to a GLON. The GLOP features a three-axis antenna design which minimizes signal source directional anomalies. The system has European ATEX M1 certification.

Advantages:

- Useful for rescue teams trying to find miners within the mine
- Will transmit through the earth.
- Compact
- A portable cap-lamp battery operated system.

Disadvantages:

- Range is limited
- Not yet available in the US

- Not yet MSHA approved

4.1.2 Seismic Communications

Though not what may generally be thought of as a communication system, a seismic location system can locate a miner and can tell a miner his signal has been located. Research performed in the 1970's by the USBM produced a system and a method which could provide locations of miners to a depth of 1500 feet. This system is presently used by MSHA when disasters occur. Signals have been detected to a depth of 2000 feet. The seismic location system is truck mounted and is capable of detecting and locating the source of seismic vibrations produced by trapped miners. Miners may generate seismic signals by pounding on mine surfaces such as the roof, floor, ribs, but preferably roof bolts. These signals are detected by sensors called geophones installed either on the surface or underground. The system can monitor approximately 1 square mile over most mines (depending upon terrain). The system is highly mobile, and can be air lifted. The general procedures when escape is cut off are:

- Barricade
- Listen for 3 surface shots
- Pound hard 10 times on roof bolt or floor
- Rest 15 minutes then repeat pounding
- You hear 5 surface shots which means you are located and help is on the way

An attractive feature of this approach is that no special equipment need be carried by the miner to provide the seismic signal.

4.1.3 PED – Mine Site Technologies - Australia

The Personal Emergency Device (PED) communication system is a one-way TTE text messaging transmission system that enables communication of specific text messages to individuals. It features a belt-wearable receiving unit for individual miners. It does not provide UG-to-surface TTE communications, but communications to the surface is facilitated via a separate Tag based system.

The PED system operates at a frequency of 400 Hz, and transmits digital messages to miners. The system utilizes either a surface or underground antenna loop which radiates a radio frequency signal enabling one way communication to the underground workings. The power generated from the antenna is about 1200 watts. Presently there is only one US mine using a surface antenna. Use of surface antennas is limited due to problems with undulating terrain and obstructions. The maximum amount of cover for a surface antenna to be effective is about 2500 to 3000 feet. Underground antennas can be compromised in fires and explosions. Messages can be directed to an individual, to a group, or to all the UG personnel. When a message is received, the cap lamp dims and flashes for about 10 seconds and a message is displayed on a liquid crystal display (LCD) on top of the miner's cap lamp battery. Individual, group or broadcast messages can be sent. The first demonstration of the system in the United States was in 1990.

There are currently about 18 permissible PED systems installed in U.S. coal mines and one in a metal/nonmetal mine. There are 9 systems installed in Utah, 3 in West Virginia, 2 in Indiana, 1 in New Mexico, 1 in Colorado, 1 in Virginia, and 1 in New York, There are reportedly 140 systems in use worldwide, including; Australia, Canada, China, and Sweden. Mining companies that are using PED

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systems include Consol, Peabody, Centennial Coal, BHP, Adalux, and IGC. The first successful evacuation of miners attributed to the PED system occurred during the Willow Creek mine fire, in Helper, Utah, on November 25, 1998.

Advantages:

- Can contact one person with a message
- Can provide messages to all miners during the early stages of a mine fire including evaluation instructions
- Can be retrofitted with existing cap lamp manufacturers lamps such as Koehler, NLT, and MSA
- Can be deployed with an antenna on the surface enabling one-way communication from the surface

Disadvantages:

- Installations incorporating underground antenna loops may be compromised in the event of a fire or explosion preventing communications
- Mines using the systems in both the US and Australia, have reported reliability issues including shadow zones within the mine where communications are not possible, miners in "same locations" underground not all getting messages
- Communication is only one way with no way of verifying reception of the signal
- Systems employing underground antenna loops are not intrinsically safe and power must be removed in the event of a fan outage or other incidents such as mine fires and explosions, which disrupts communication
- Conditions are different at each mine, the systems don't work well in every mine

4.1.4 TeleMag - Transtek – United States

TeleMag is a wireless through-the-earth two-way voice and data communication system. It operates between 3000 Hz and 8000 Hz. It employs a single sideband modulated carrier technique. It uses a Digital Signal Processor (DSP) based tracking comb filter for attenuating harmonic-induced noise, which improves the signal-to-noise ratio thus improving the range of the system. It is a fixed, station-to-station system. It is not portable. The UG and surface antennae consist of a wire loop. It has been tested to depths of 300 feet. Extended communications from the surface and underground fixed stations using wireless handsets is possible. Calculations indicate that 1000 feet of ground penetration is possible. The first demonstration of the system was in August of 2000 (Conti, 2000) at the NIOSH Lake Lynn Laboratory mine. However, it is not permissible. Other mine installations are not known at this time.

Advantages:

- Provide clear two-way voice communications TTE
- Interfaces to other Transtek communication systems in the mine and above the mine which enables extended voice communications through the earth

Disadvantages:

- System is not MSHA permissible and is not portable
- System is restrained by not having a portable loop antenna. A fixed place loop antenna will be subject to destruction from a roof-fall, fire, or explosion

4.2.0 TTE Systems Under Development

In the past few months a number of different companies have decided to direct their efforts towards providing TTE systems for underground coal mines. The details follow.

4.2.1 Delta Electromagnetic (DeltaEM) Gradiometer Beacon Tracking System – Stolar – USA

A system consisting of a beacon transmitter and a DeltaEM wave gradiometer (receiver) has been developed. The DeltaEM receiver is portable and is used on the surface of the mine to locate the beacon transmitter. The beacon transmitter generates a 2000 kHz EM signal. The system is a prototype and is not yet MSHA approved. The DeltaEM receiver antenna consists of 3 ferrite-core antennas. There are three beacon antennas; 30 inch diameter loop, 6 inch ferrite-rod antenna, and large loop antenna.

4.2.2 TramGuardMinerTrack - GeoSteering-Gamma Services International – USA

GeoSteering presently markets an MSHA-approved proximity warning system called TramGuard for continuous mining machines. Information from the system is continually archived in the system and can be locally accessed with appropriate hardware and software. GeoSteering has been engineering a method to provide the data via a TTE connection with the surface. The data includes the identification of all miners local to the system, 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 at this time details are proprietary.

4.2.3 Subterranean Wireless Electric Communication System (SWECS) – Kutta Consulting – USA

This system is being developed under an SBIR contract to the U. S. Army CERDEC program. It is expected to be a fully portable system with TTE capability. The relative location of the underground device can be determined. Connections to other underground communication systems are planned.

The U.S. Army originally commissioned the project for wartime use in such places as Afghanistan or to communicate with soldiers who may be in a collapsed building. But in response to the 14 miners who died in West Virginia coal mines in the recent past, government officials recently directed Kutta to adapt the device for commercial use in the mining industry.

The patent-pending SWECS, consists of a PDA-type device with a screen and keypad, an 8-ounce radio and a foot-long antenna. It has push-to-talk capability similar to a walkie-talkie and fits into a small backpack. The device has been tested in caverns and Arizona mines, and can send voice communication through 800 feet of solid rock, and a digital photo through at least 400 feet of rock.
The SWECS has not yet been tested by MSHA for permissibility conformance.

4.2.4 Canary 2 - Vita Alert - Canada

Vital Alert has created an emergency broadcast network (EBN), called Canary 2, which is a two-way, through-the-earth, voice and text messaging technology for use in urban, subterranean and ocean environments. The technology was developed with Government support under Contract No. W-7405-ENG-36 awarded by the US Department of Energy. The technology was licensed to Vital Alert. The network's 2-way voice system has the ability to penetrate the earth to depths of up to a thousand feet. Vital Alert claims that its EBN's text messaging system can penetrate to 9000 feet.

The equipment consists of mobile surface units which employs a ferrite-rod as an antenna. Each surface mobile unit can communicate with several underground base units. Preliminary tests suggest the system can penetrate up to 400 feet of overburden.

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4.3.0 Research on TTE

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

4.3.1 CSIR Miningtek – South Africa

Miningtek developed a trapped miner-locating device. A prototype was successfully tested UG where it provided detection and location of a trapped miner at the distance of more than 100 feet through rock. It 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 ever resulted in a commercial product.

4.3.2 Institute 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 about 20 inches. The paper does not mention the distance from the beacon to the receiver. It is not known if the system ever became a commercial product.

4.3.3 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. Most significantly was their TTE research at frequencies between 600 Hz to 3000 Hz. The promise of the research resulted in the development of an extensive collection of system hardware. The miner-carried part of the system was a compact belt-worn device with a wire-loop antenna. The surface part of the system consisted of a transmitter and long wire loop antenna, and a handheld receiver with a 15-inch loop antenna (Lagace et al, 1980). Two varieties of the miner-carried devices were developed. One version provided a beacon signal to the surface. The second version was a transceiver composed of a beacon and a voice receiver. More than 100 miner-carried beacons were built. About a dozen or so contained a voice receiver. A collection of surface systems were created. Tests were performed at 94 UG coal mines which were a representative sampling of all coal mines in the U.S. Depths ranged to 1500 feet. Resulting data showed a 68 % probability of detection of the miner’s beacon at a depth of 750 feet (Lagace et al, 1980).

4.4.0 Rescue Team Communication Systems

Life lines are a standard part of mine rescue and recovery operations, and their use is mandated by law (30 CFG 49.6). The wires or cables that make up the lifeline must be strong enough to be used as a manual communications system. The life line must be at least 1,000 feet in length. An approved sound-powered rescue team telephone system was developed using this cable in 1946 by the USBM (Forbes et al, 1946). Many of today’s teams use a system that hasn’t changed much since that date, although there has been a number of advances in the technology. In 1991, the National Mine Rescue Association and the Mine Rescue Veterans conducted a membership survey on the problems associated with the use of life lines during mine rescue, as well as practical ways of improving life line procedure. One of the recommendations was to use radios which allow all team members to communicate with each other, as well as the fresh air base. Radio-based systems have been developed and have improved communications. A sampling of vendors and equipment for coal mine rescue team communications systems include:

- Con-space Communications
- Conspec Controls, RimTech
- Draeger, Soundpowered Rescue Team Communications
- TransTek, ResQCom
- Rock Mechanics Technology, MComm

Further vendor information can be obtained from the complete vendor list in appendix C.

5.0.0 Normal Coal Mine Communication Systems

UG coal mining employs a diverse mix of communication devices (Kohler, 1992) and technologies including telephones, loud-speaking telephones, radios, trolley phones, shaft, and hoist phones. The more modern system can also deliver digital data, digital voice, and even video. Today’s predominant systems however are conventional telephones, loud-speaking telephones, and radios. A quick sampling of all coal mine communication system types, both normal and emergency. The type of technology involved, a general description of their capabilities, a few of the vendors who can supply the technology, whether the technology is MSHA approved, and a brief list of the advantages and disadvantages of each technology type is provided in Appendix B (Existing Mine Communications and Tracking Technology). Other useful data is also provided.

Though recent events have shown that most normal communications systems can fail during disasters, they still can play a significant role for normal everyday use. 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 most predominant support structure is called a leaky feeder. One relatively new concept using radio in a mine is called “WiFi.” WiFi requires strategically placed wireless repeaters. Interestingly, these systems are digital, which opens up a new realm of possibilities, including simultaneous delivery of voice (VoIP), data, and video, over the link. There has also been a merging of technologies which combine leaky feeder, Ethernet, and WiFi. A few cell phone vendors now market a phone that combines standard cell phone communications protocols such as Code Division Multiple Access (CDMA) or Global System for Mobile communications (GSM) with 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. Reference information for all of the vendors and distributors of the equipment mentioned throughout this document can be found in Appendixes B, C, D, and E. Each appendix groups the contained data into tables or lists for easy access. Appendix B is a table of technology types. Appendix C is an alphabetical list of all vendors, manufacturers, distributors, and research organizations. Appendix D1 and D2 are tables of manufacturer information. Appendix E is a distributor list. Appendix F is a table of research organizations.

5.1.0 Telephones

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Telephone communication links are required by law -- see 30 CFR, Part 75 Paragraph 75.1600.

75.1600 Communications

The communication systems that are now in use at each mine will be acceptable at the present time. However, there must be at each mine an operative means of communications between each working section and the surface when the working section is more than 100 feet from the portal.

75.1600-1 Communication Facilities; Main Portals; Installation Requirements requires that a telephone or two-way communication facility be located on the surface within 500 feet of each main portal.

75.1600-2 requires that there be a telephone or equivalent two-way communication facility at each working section, located not more than 500 feet outby the last open crosscut and not more than 800 feet from the farthest point of penetration of the working face.

In 30 CRF Part 23, Telephones and Signaling Devices, must be explosion-proof or intrinsically safe. The telephones must be supplied with back-up power supply in the event of a power outage. The entire system must be XP or IS in the event of a loss of ventilation.

Telephones for UG mining are integrated into ruggedized housings to survive the environment. Battery operation is common. Versions of the phones include signaling lights. Operationally they are much like conventional surface-type phones. The telephones are interconnected through multiple pair cables and a private branch exchange (PBX - telephone switching system). Safe operation of the systems is due partially to barrier circuits installed at the entrance of the mine which limit the electrical energy of the signal to safe levels. Barrier circuits and lightning arrestors protect against sudden energy surges. A few phone systems have been developed which incorporate multiplexed voice channels over a common radio channel permitting single-pair wired operation.

Advantages:

- Relatively cheap and reliable
- Easy to use
- Doesn’t require skilled maintenance

Disadvantages:

- Dependant of the electrical continuity of the line
- Prone to failure due to bad joints, moisture, corrosion, and damage from roof falls, explosions, and fires
- Require battery back-up systems

Several vendors can supply telephone systems for underground use. They include:

- AmpControl
- Austdac
- Conspec Controls
- FHF
- Gaitronics
- Hard-Line

- Marco

Other details can be obtained by contacting the vendors listed in Appendix C.

5.2.0 Page Phones – Loudspeaking Telephones

The pager phones used in many UG coal mines are battery-operated, party-line telephones with provisions for loudspeaker paging. The system is two-wire, non-polarized, and is operated by self-contained batteries. Paging phones were introduced during the later 1950’s when a progression of new equipment came to the mining industry. Basically each paging phone unit is self-contained, consisting of a speaker, telephone handset, 12-V or 24-V battery power supply, and solid-state amplifier and associated circuitry. Power is drawn only while the unit is in operation. The majority of mines use party-line paging phones. The units are interconnected with twisted-pair cable to make a system for audio paging and semi-private calling. With this arrangement, a miner can page a person, a place, or the entire mine. System operation does not depend on one central interconnecting device.

Implementation of pager phone systems has resulted in two-wire phone lines being an integral part of the topology of all mines; interconnecting all operating areas with each other and with a central “dispatch” or supervisory location on a common bus. The implementation of these phone lines does not conform to any uniform or standard practice: that is, the phone lines are implemented using many kinds of wire, many differing splicing techniques, many wire termination techniques, and many different wire hanging/suspension techniques. Typical phone lines in a single mine may use twisted-pair line, house wire, multiple-pair cable, and sometimes single conductors individually attached to insulators.

For all practical purposes, noise on phone lines appearing in the usual transmission line (differential) mode results from mode conversion of monofilar (common) mode noise which is electromagnetically induced or coupled to the phone line from a multiplicity of discrete sources. The mode conversion is due to line imbalance. Thus, characterizing the excitation “source” of common-mode noise is of prime importance. Secondarily, the actual differential-mode noise (or ratio of common-mode to differential-mode noise) is important (Corey, 1981).

Advantages:

- Paging telephones provide two-way voice communications wherever phone lines are installed.
- They are battery backed up with replaceable batteries; batteries last for a very long period of time.
- They are relatively cheap and reliable
- They are easy to use

Disadvantages:

- A one-conversation party line may be inadequate for larger mines
- Voice paging can be easily ignored
- Mine-wide paging for all communications can be annoying

Several mine page phones are approved by MSHA. They include:

- Appalachian Electronics Instruments, 101 Page Phone – MSHA approval 9B-71, Midgi-Talker – MSHA approval 9B-71-1

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- Comtrol Corporation, Loudmouth Page Phone, MSHA approval 9B-71
- Gai-Tronics, Mine Dial Page Phone, Model number 491-204, covered by MSHA approval 9B-221
- Gai-Tronics, Model numbers AM7011, AM7012, AM7021, and AM7022, covered by MSHA approval 9B-155
- Pyott Boone, Model numbers – 112-112P-118-119, covered by MSHA approvals 9B-102 and 9B-163
- Pyott Boone, Model 128 Mini Page Boss, covered by MSHA approval 9B-158
- Mine Safe Electonics, Model IIA Mine Phone, covered by MSHA approval 9B-164
- Mine Safety Appliances (MSA), Pager III, covered by MSHA approval 9B-85

Other details can be obtained by contacting the vendors which are listed in Appendix C.

5.3.0 Trolley Phone – Trolley Carrier Phones

Trolley carrier phones are relatively unsophisticated devices typically operating at carrier frequencies of about 60 to 190 kHz using narrow-band frequency modulation. The equipment is typically rated at 25 watts. Most mines use a few fixed-location trolley carrier phones and a large number of mobile trolley carrier phones on locomotives, jeeps, and portal buses.

The operating environment for trolley carrier phones is quite severe. The mobile units are subjected to constant vibration and shock, and suffer the extremes of temperature variations from season to season. The also operate in 100% relative humidity environments during much of the warm season. They are frequently exposed to acid vapors, dust, and dirt. The electrical environment in which the carrier phones must operate is harsh. The trolley wires are known to have voltage extremes running as high 12,000 volts for a few milliseconds, and to be subject to the ever-present AC ripple generated by power rectifiers.

The transmission line that interconnects the carrier sets represents the major difficulty in obtaining and maintaining good carrier phone performance. It is not the fundamental character of the transmission line that imposes this problem. Rather it is the many bridging loads necessarily placed across the trolley wire and the branches imposed on the trolley wire/rail by rail haulage requirements.

The attenuation rate for a typical trolley wire rail in a conductive medium in a tunnel is approximately 1 db/km. A typical trolley carrier phone can accommodate a 70 dB transmission loss (i.e., a loss from 25V rms to 8 mV rms). With an ideal antenna this would mean a range of 40 miles. However, the bridging loads such as mine motors, lightning arrestors, signal and illumination lights, vehicles, insulators, and borehole shorts, all greatly degrade the communication path.

Addressing the signal propagation issues, some mines have made use of auxiliary wires strung for the sole purpose of providing aided transmission. This line is free of the branches and other impediments to good propagation. Inductive-coupling loops and ferrite-bar couplers have shown improvements to some systems (Little, 1977).

Trolley carrier phones operate in a wide variety of mine topographical layouts – mines ranging from as small as a few miles to many miles in dimensions and encompassing many miles of trolley wire/rail, including switches, crossovers, sidings, and the usual configurations found in rail haulage systems. They also operate in the face of an ever-changing mine layout as the mining progresses. They operate in an environment that is generally detrimental to electronic equipment with a minimum of maintenance and a lack of good maintenance tools. There are frequent problems with performance. The problems are evidenced by lack of coverage of certain regions of the mine, breakdown of equipment, and noise-imposed performance limitations.

Several vendors can supply trolley phones. They include:

- Conspec Controls
- Comtrol Corporation
- Gaitronics
- Hughes Supply

Other details can be obtained by contacting the vendors listed in Appendix C.

Advantages:

- Provides communications to all rail haulage vehicles using trolley cables

Disadvantages:

- Noisy
- Coverage problems in large systems
- Usually single-channel operation

5.4.0 Hoist Phones

Hoist communications are necessary to permit communication between persons in the hoist cage and the surface or underground. Particularly in coal mines, a phone line directly connects the cage to the mine communication system. In deep hard-rock mines, it is difficult to maintain such a cable.

Earlier research identified that radio could be used to improve the hoist communications problem, based on the premise that it would be advantageous to use the hoist cable (rope) as a radio signal conduit. Signal propagation would be provided by means of coaxial mode of transmission in which the hoist cable serves as the inner conductor and the surrounding rock acts as the outer conductor of an envisioned coaxial cable. Since the rock/concrete of the shaft is a poor electrical conductor the current in the outer conductor of the coaxial line is not confined to a very thin surface layer as in a metal coaxial cable, but spreads radially to a distance that is generally many times the shaft diameter.

Research results indicated that the coaxial mode of transmission, showed that a broad minimum in overall signal loss would occur between 100 kHz and 1 MHz, possibly centered on 300 kHz. However, the most favorable frequency selection is highly dependent on determining the EM spectral noise data over that frequency range (Spencer, 1974).

To get a radio signal into the hoist cable the signals must be inductively coupled onto and off the hoist rope transmission line. One method that was developed involved the use of a ferrite or powdered iron toroidal core coupler which also provided signal reception. Several hoist phones are available. They include:

- Comtrol Corporation
- Conspec Controls

Other details can be obtained by contacting the vendors listed in Appendix C.

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5.5.0 Walkie Talkies

A walkie-talkie is a portable, bi-directional radio transceiver. Major characteristics include a half-duplex (only one of receive or transmit at a time) channel and a push-to-talk switch that starts transmission. The typical physical format looks like a telephone handset, possibly slightly larger but still a single unit, with an antenna sticking out of the top. Generally walkie-talkies operate in the VHF and UHF bands. In coal mines they are commonly used with the support of a leaky feeder cable and line amplifiers. A few MF band walkie-talkie systems have been created. The antennas consisted of a bandolier type antenna which wrapped over one shoulder. They could be used without any existing antenna support structure. There presently are no walkie-talkies approved by MSHA. Kenwood may receive an MSHA approval in the near future. Other details can be obtained by contacting the vendors listed in Appendix C.

Advantages:

- Provides wireless portable communications
- Can provide wide areas of coverage
- Can be used on longwall sections

Disadvantages:

- Only works line-of-sight
- Requires a leaky feeder infrastructure to go around corners and to provide whole mine coverage
- Leaky feeder line amplifiers require battery backup systems.

5.6.0 Longwall Communications

Longwalls can advance as much as 200 feet a day. As with any part of the longwall system the communication link must also be continuously extended. There are many communication systems which have been developed for use on longwall. They include hard-wired and wireless systems. The wireless systems can employ MF, VHF, and UHF walkie-talkies. Several companies can provide longwall communications. They include:

- Ausdac
- Conspec Controls

Other details can be obtained by contacting the vendors which are listed in Appendix C.

5.7.0 RFID or Tag-Based Systems

Radio-frequency identification (RFID) refers to the technology that uses devices (called Tags) attached to objects that transmit data to an RFID receiver. RFID provides tracking and accountability of persons and other assets. RFID is provided by a combination of wireless readers interconnected via leaky feeder, WiFi, or other systems. RFID first appeared in tracking and access applications during the 1960s (Grayson and Unal, 1998). It consists of devices that can either be passive or active. Passive RFID is used in relatively short-range applications which do not contain a power source. Active RFID is used in longer range applications and can be read up to 300 feet away. Tag reading is localized to the vicinity in which the tag reader is installed. In mining RFID can provide improved response to downtime, identification of

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workers entering or leaving a mine, control of personnel traffic into hazardous areas, identification of vehicles entering or leaving production units or passing specific locations in the mine, tracking of supplies and materials, and maintenance scheduling. There presently is no real-time tracking system available for underground use. Operation is limited to the range of the Tag reader.

Several companies can provide RFID/Tag-Based systems. They include:

- Davis Derby
- El-Equip
- Grace Industries
- Impro
- Marco
- Mine Site Technologies
- Saco
- Sira
- VAK
- Varis

Advantages:

- Provides people or asset tracking and accounting
- Determines position of miners up to the point of a disaster by reviewing logged files.

Disadvantages:

- Range is limited
- Requires readers in area to be covered

6.0.0 Antenna Design for Coal Mine Appropriate Communication Systems

Though many mines use standard walkie-talkie style of radios for communications it does not necessarily mean that they are the best radio for the environment. Research as mentioned in the VLF and MF ranges has shown that alternative types of radio could be more useful. One problem with the use of these lower frequencies is the antennas required can be quite large and cumbersome and likely would be an inconvenience for the everyday miner. Addressing that concern some research has indicated that more compact designs are possible (Curtis et al, 1977). Integrating ferrite rods into antenna designs can make for more compact antennae with minimal effect on range performance. MSHA IS issues will have an impact on design types.

7.0.0 Interaction of Radio Transmissions on Mine Monitoring, Control Systems, Explosives

Many tests have been conducted to determine if control and monitoring equipment in the Nation's coal and metal/nonmetal miners were susceptible to radio-frequency interference (RFI) from communications sources. These tests were conducted to decrease the possibility of RFI causing monitoring systems to be unreliable, preventing RFI from causing malfunctions in mining equipment, providing the

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mining industry with information on EM compatibility (EMC) standards, developing a frequency coordination plan for use in UG mining, and to identify the need of manufacturers to adopt RFI suppression standards (A.R.F. 1986). A principal part of the work was to identify classes for mining equipment that could potentially be susceptible to RFI.

Though tightly controlled, explosives are used in underground mines. There are many factors which could lead to unplanned explosions and radio frequencies have been one of them. Addressing those issues the Institute of Makers of Explosives (www.ime.org) has created an information book (SLP – Safety Guide for The Prevention of Radio Frequency Radiation Hazards in the Use of Commercial Electric Detonators) to identify what frequencies and at what power levels could be cause for concern. Pilot check wire current sensors, ground fault detectors, and other current protection device could be adversely affected by RFI and even specific radio frequencies. Though little could be found on the subject, this is one area that definitely needs to be investigated.

8.0.0 Radio Remote Controlled Continuous Mining Machines and Others

Over the years there have been instances where one piece of radio-controlled equipment has interfered with the operation of other radio-controlled equipment. This has occurred when two or more radio systems from the same vendor are operated in close proximity. This problem has resulted in the generation of information bulletins from MSHA. Though the more modern radio systems have addressed the problem through special encoding schemes, it is prudent to be aware of the potential hazard. With the recent activity in the area of mine communications for coal mines, new technology will be introduced into the mines which may not account for the possibilities unless properly addressed.

9.0.0 Proximity Warning Systems

Proximity systems are not necessarily communication systems but they have many of the same features. They generally provide one or more wireless links between coal miners and their machines. In the underground mining environment there is presently only one MSHA approved system (GeoSteering - TramGuard). At least one other company has been developing a similar system (Nautilus). These systems may be adapted to interact with other communication systems in mines in the near future.

10.0.0 Data Networks in Coal Mines

There presently is a wide collection of different digital data networks being used in mines. They include a combination of computers, computer-like devices, monitoring and control systems, and communications devices that interoperate across common transmission mediums. The networks can take on a variety of forms. Local area networks (LANs), Personal Area Networks (PANs) wide area networks (WANs) and wireless local area networks (WLANs). TCP/IP and variants of it have generally been accepted as the common intercommunication protocol across these network types. The following sections of this paper provide a brief description of applicable information relative to data networks which are being or will be used in coal mines.

10.1.0 TCP/IP

Transport Control Protocol/Internet Protocol (TCP/IP) is a protocol system – a collection of protocols that support computer network communications. Basically it is a common set of rules that helps

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to define the complex process of transferring data (Casad, 2001). Present-day TCP/IP networking represents the synthesis of two developments that began in the 1970's; the Internet, and the LAN.

10.2.0 Ethernet

Ethernet is fundamentally a communications standard (IEEE 802.3) used on LANs. An Ethernet LAN typically uses coaxial cable, fiber-optic cables, or special grades of twisted-pair wires (CAT5 or better). The most commonly installed Ethernet systems are called 10BASE-T or 100Base-T and provide transmission speeds up to 100 Mbps. Devices are connected to the cable and compete for access using a Carrier Sense Multiple Access with Collision Detection (CSMA/CD) protocol. This is a system where each computer listens to the cable before sending anything through the network. If the network is clear, the computer will transmit. If some other node is already transmitting on the cable, the computer will wait and try again when the line is clear. Sometimes, two computers attempt to transmit at the same instant. When this happens a collision occurs. Each computer then backs off and waits a random amount of time before attempting to retransmit. With this access method, it is normal to have collisions. However, the delay caused by collisions and retransmitting is very small and does not normally affect the speed of transmission on the network. Ethernets can employ a version of TCP/IP and in some cases is even used on leaky feeder transmission lines. Newer versions of Ethernet can support 1000 Mbps or more. A few of the vendors who can supply Ethernet-based systems are:

- Mine Site Technologies
- Varis

10.3.0 WiFi

WiFi is short for 'wireless fidelity', a term for wireless local area networks 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 UG coal mines. The vendors who can supply WiFi technologies for mines include:

- Ekahau
- Ipackets
- Mine Site Technologies
- Northern Light Technologies

10.4.0 Wireless Mesh Networks

Another interesting and applicable technology to the needs of UG 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. Mesh networking with respect to WiFi types of systems is now being addressed by the Extended Service Set (ESS) Mesh Networking Task Group (802.11s). The new IEEE 802.11s standard will enable a collection of Wireless Access Points (WAP) to be interconnected with wireless links that enable automatic topology learning and dynamic path configuration. The group aims to release the standard by 2007. A form of mesh networking in lower data rate applications such as wireless sensor networks are generally addressed by IEEE 802.15.4 standard for wireless personal area networks. Multivendor

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operability of products using the IEEE 802.15.4 standard is contained in what is called the Zigbee specification set. Wireless modems (sometimes called "Hot Spots" 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 to be 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. Note that wireless mess networks are currently used under mandate by NFPA (http://www.nfpa.org/) for structural fire response and commercially available Underwriters Laboratory (UL - http://www.ul.com/) IS devices but do not currently have voice capability.
A few of the vendors who may soon supply wireless mesh networks for mining are:

- Grace Industries
- Rajant

10.5.0 VoIP

Ethernet networks support internet protocol (IP) telephones, also known as voice over IP (VoIP) telephones. VoIP telephones are used in many of today enterprises. Typically VoIP telephones are hardwired to a wall socket, Ethernet hub or switch. There are also wireless systems. There are international standards (H.323), and they are compatible with public networks. A few VoIP based systems are now available to the mining industry. These phones can work in combination with leaky feeder systems which incorporate Ethernet protocols, fiber-optic networks, and WLAN systems. Each of these network types are now being used in UG mines.

10.6.0 Network security/firewalls/Viruses

Any connections made to outside networks are vulnerable to any number of security breaches, not to mention outright attacks. It is only prudent to provide the proper protection, especially when the lives of miners could be at risk should any of the control, monitoring, or communication systems fail. A firewall is a set of related programs, located at a network gateway server that protects the resources of a private network, such as the outside office area for an underground mine, from users from other networks. The firewall will prevent outsiders from accessing the mine's private data, communications, and control resources and will also control access to outside. A firewall, working closely with a router program will filter all network packets to determine whether to forward them toward their destination. A firewall is often installed in a specially designated computer separate from the rest of the network so that no incoming request can get directly at private network resources.

Anyone working with computers connected to the Internet must have virus protection software even if they have a firewall installed. Viruses can be embedded in emails, in software applications, and in virtually any data they may be received through an Internet connection. Whether any mine has yet had a major data or communication network failure due to a virus is unknown, but that possibility does exist. All computers and computer-based systems should, of course, include automatic virus detection. Regular updates to that software should be performed.

11.0.0 Cell Phone Technology

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Cell phone technology can be used in a coal mine. First the mine must have a WiFi infrastructure; secondly the phones must be WiFi-enabled, and thirdly the cell phones and infrastructure must meet MSHA permissibility requirements. Recently at least two present cell phone manufacturers provide the combined normal operation and WiFi ability (Motorola, and Nokia). At least one company (ECOM) sells an IS cell phone, but it is not yet WiFi-enabled.

12.0.0 Interoperability

Today there is very diverse group of control, communication, and monitoring systems being used in UG coal mines. Many of these systems work independently, especially legacy systems. What may be a perfectly stable system today could fail as soon as a new device is added to the environment. Some efforts should be made to ensure compatibility not only from an interoperability standpoint, but also from the potential interference standpoint. Interoperability and interference can be an issue for all system types including control, communications, and monitoring systems. The UG coal mine environment is rich with potential interference sources including DC trolley power, AC and DC machinery power, stray currents, high-voltage cables, and variable-frequency drives. Any one of these sources could terminate a critical life-support system.

Wireless networking in any environment today involves many often non-interoperable systems working on different carrier frequencies, and protocols. What is needed is some interpreter that accepts multiple frequencies and protocols from various devices – no matter which vendor or application, and converts them to a common data model, regardless of heritage. Some of the protocols include Ethernet, IEEE 802.11 (WiFi), 802.16 (WiMAX), 802.15.4 (Zigbee), plus RFID, VoIP, and other proprietary/vendor specific protocols, along with associated network security issues.

The same interoperability issues are also challenging traditional emergency response and noted in the 9-11 commission (http://www.gpoaccess.gov/911/index.html) and Rand studies (http://vivisimo.rand.org/vivisimo/cgi-bin/query-meta?input-form=simple&query=9-11+commission). The mining communications industry should work toward conformance to these standards.

From a coal miner survivability standpoint it only makes sense to enable all of the voice communication devices to interact with all other voice systems. This would be especially true during disaster situations. A properly designed system should be capable of providing this ability.

13.0.0 Training and Maintenance

It will take more than a few hand tools and a multimeter to maintain the types of systems being discussed. Technicians will require a broad background knowledge covering communications, control systems, and monitoring systems. Maintenance should be performed on regular intervals, and periodic drills should be conducted to verify the ability of the systems to perform when disasters occur.

14.0.0 Risk Assessment

Any safety system for use in coal mines should evaluated to determine if it posses any risk to miners. This particularly includes communication systems. It is doubtful that a properly conducted risk assessment has ever been conducted on a mine communication system. This reference provides at least preliminary information on safety system risk assessments (Sammarco, 2005).

In order to aide in risk assessments, guidance on the impact on wireless signals due to noise sources, geology, mine entry geometry, and mine infrastructure is needed. The many research projects completed by the USBM in the 70's did, identify, characterize, and document that kind of information. Future research could expand this knowledge base. NIOSH is presently creating a prototype web page containing the USBM information.

15.0.0 Summary

It is clear that much work needs to be done to improve the state of UG coal mine communication system design in the United States. Systems already in place in mines should be evaluated and brought up to an acceptable level of reliability. New mine designs should incorporate most, if not all, of the ideas highlighted in this document. Signal propagation measurements should be made both in mines and TTE to determine what signals best suit the given environment. EMI sources should be identified and eliminated or suppressed to an acceptable level. Systems should be designed and custom engineered, based on the unique character of the given mine environment. Interoperability should be stressed through all communication links whether they carry voice or other data. Previous and present technology should be reviewed and applied as defined by the system needs. Risk assessments and disaster scenarios should be performed to highlight any insufficiencies in the final system design. Training and maintenance should given priority status in order to keep mine communications systems functioning, especially during disasters.

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