COAL MINE COMMUNICATIONS

The tragic events at the Darby, Alma, Sago and Brookwood No. 5 coal mines have highlighted the need for reliable communications between miners working inside a mine and those outside, writes National Institute for Occupational Safety and Health (NIOSH) Pittsburgh Research Laboratory's **William H Schiffbauer** and **Jürgen F Brune**.

Communication problems are not new. Research in this area goes back as far as 1922 when the US Bureau of Mines performed experiments to detect radio signals from inside their experimental mine in Bruceton, Pennsylvania. Many improvements to mine communications have been made over the years but for any number of reasons the underground coal mining industry has been behind in implementing advances.

Present communications systems for underground mines can be hard-wired or wireless. Both types of systems can fail when faced with fires, roof falls, explosions, and power or battery failure. Currently installed wireless communications systems usually employ a special antenna cable called a "leaky feeder". Fiber optic cables are also used in some applications to form a "backbone" for wireless transceivers. Through-the-earth (TTE) and wireless radio systems are less common. Except for TTE systems, most wireless systems require some wire-bound components, which are susceptible to failure during disasters as cable breakage interrupts communications.

A particular requirement for electronic communications systems in underground coal mines is that they need to be designed so they cannot create sparks that might ignite a gassy atmosphere. "Permissible" designs usually involve protection standards such as intrinsic safety or explosion-proof features and may require additional protective features determined by the approving authorities. Permissible design typically limits the output power of wireless devices and makes transmission from the mine to the surface more challenging.

Coal mines present a unique environment for radio signals. Radio signals generally require a clear path ("line of sight") or open air for signal propagation. Stoppings and roof falls halt or impede conventional radio signal propagation. It is also believed that ionized air that can result from a mine fire could impede wireless signals. 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.

In the mid-1970's the US Bureau of Mines conducted research on this and many other phenomena associated with radio signal propagation in coal mines. This research was done in response to the Coal Mine Health and Safety Act of 1969 and aimed at increasing the survivability of coal miners trapped underground during disasters. It included the determination of the optimum frequencies for reliable communications.

Frequencies investigated ranged from extremely low frequencies (ELF) to a few gigahertz. Propagation measurements were conducted both within the mine as well as through the earth. Extensive electrical noise measurements were performed both underground and on the surface at a representative sample of mines throughout the coal fields. To be heard or detected, the radio signal generally must exceed the noise.

Modern signal modulation and processing techniques, such as spread-spectrum and ultra-wide band (UWB), have changed that paradigm to some degree, but still the signal-to-noise ratio is a critical factor to communications success.

In an underground coal mine, the options for communication signaling include through-the-wire (TTW), through-the-air (TTA), and TTE. TTW communication signals in a coal mine can travel over twisted pair, coax, CAT5, trolley, leaky feeders, and fiber optic cables. Each of these cable types has unique properties and limitations. Therefore, cables must be selected to suit the characteristics of the signals being conveyed.

With TTA systems, 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 testing in the underground mine environment.

Research has shown that medium frequencies (MF) are beneficial to underground communications in both coal and metal/non-metal mines under certain circumstances. MF technology has less severe attenuation characteristics compared to ultra-high frequencies (UHF) communications and it does not require the use of a leaky feeder cable. Furthermore, it does not experience the high noise levels of ELF, very low frequencies (VLF) and low frequency (LF) communications.

Testing using MF technology has proven ranges of 1000-1500 feet in conductor-free areas, and as much as two miles in conductor-filled areas where parasitic propagation effects help the signal travel longer distances. Some of the higher frequencies — very high frequencies (VHF), UHF, and super high frequencies (SHF) — propagate in a line-of-sight mode 1000 feet down a mine entry. However, it is unlikely that an unaided (ie no leaky feeder) VHF or UHF signal would be able to travel around more than about two crosscuts.

Wireless TTE systems send ELF-VLF magnetic waves through the ground. Existing prototype systems capable of two-way voice communication typically are stationary and require extensive loop antennas or ferrite rod antennas. Power for the underground transmitter is limited due to permissibility requirements. In this type of system frequency, geology, noise and depth will influence the probability of successfully communicating with the surface. Generally a TTE will operate below 10kHz.

A portable, person-worn wireless TTE system provides a good chance of establishing contact with miners since, with no dependence on a wired infrastructure, it offers the best resistance to damage from roof falls, fires and explosions. The US Bureau of Mines had developed a permissible person-wearable TTE system capable of receiving voice signals from the surface and transmitting coded information back to the surface. Manufacturers are currently reviewing this design.

Recent introductions of advanced communication technology into the coal mining environment include hard-wired and wireless computer-based data networks which can provide voice, video, monitoring and data transfer. These technologies employ a large variety of data transmission protocols, networks and system topologies. A few of the protocols include: TCP/IP

(Transmission Control Protocol/Internet Protocol), WiFi (Wireless Fidelity), ZigBee, CSMA/CD (Carrier Sense Multiple Access/Collision Detection), and VOIP (Voice Over Internet Protocol). These protocols are similar to those used for cell phone and computer networks. The network types can include: Local Area Networks (LANs), Personal Area Networks (PANs), Wide Area Networks (WANs), and Wireless Local Area Networks (WLANs).

These networks consist of branches and nodes and can be configured in various topologies or arrays that can be designed with variable redundancy. If one of the paths is interrupted, the network may be able to use a different path to transmit the signal.

An exciting possibility for coal mine communications using modern wireless network technology includes cell phones. A WiFi-enabled cell phone employing VOIP protocol, and a suitable "hotspot" infrastructure, will work underground; however, permissibility issues must still be addressed.

Interoperability of communications systems with other data transmission systems used in underground mines can be a major issue and must be addressed. Some wireless systems tested in underground coal mines were found to interfere with atmospheric monitoring systems.

Another notable highlight in response to the recent disasters was the lack of knowledge of the position of the miners in the mine. Miner tracking systems utilize wireless communications technology and can be integrated with communication networks. Tracking systems use active (battery-powered) or passive radio-frequency ID tags or similar technology to identify themselves as they pass a tracking station or beacon in the mine. The tracking station records this event.

Some stations can measure the distance to the tag by measuring the intensity or time of flight of the radio signal. Others may triangulate the miner's location by comparing signals received by multiple beacons. It is also conceivable to create tracking devices that use technology similar to global positioning systems, using "pseudo satellite" beacons inside the mine.

Other possibilities include enhancing tracking accuracy using a combination of gyros, accelerometers, and magnetometers which can continuously compute the miners' position throughout the mine without needing to be within range of a beacon. In order to convey the information to outside the mine, all of these types of tracking systems require a communication link that may be susceptible to damage from explosions, fires or roof falls.

The National Institute for Occupational Safety and Health has formed a Mine Emergency Communication Systems Partnership with the United Mine Workers of America, United Steel Workers of America, Mine Safety and Health Administration, state government mining agencies in Pennsylvania and West Virginia, coal operators, the Bituminous Coal Operators' Association, the National Mining Association, the Industrial Minerals Association of North America, and the National Stone, Sand and Gravel Association.

The partnership is developing a series of testing protocols for underground mine communications systems. These protocols are intended to provide a quantifiable method for comparing systems. A few fundamentals of these evolving protocols are: testing should include analysis of the electrical noise environment, both at the surface and underground; signal propagation measurements should be performed, documented, and analyzed; a heavy emphasis should be placed on interoperability; testing should be conducted to ensure that new systems and existing systems will work together while not interfering with the operation of one another; and a "Risk Assessment" should be conducted to determine the likelihood of a system being compromised in an emergency.

The participants in the Mine Emergency Communications Systems Partnership are currently testing a variety of mostly new communication technology of the types previously discussed. Some of the results are very promising. Details about these tests and other useful information can be found at http://www.msha.gov/techsupp/pedlocatingdevices.asp AL