The West Virginia Mine Safety Law of 1-2006 as it regards to Wireless Installations in U/G coal mines, a perspective and alternatives.

In mid-January the West Virginia legislature adopted an act with provisions requiring all coal mines to install a VLF one-way wireless warning system and a wireless man-tag and tracking location system.

The bill also had provisions that stated these systems were to provide complete "mine-wide" coverage to be compliant.

First, an explanation of the technologies as cited is in order.

The Very Low frequency (VLF) cap lamp signaling system

This system is based on the radio propagation characteristics of low frequency, high power radio signals typically operating lower than 30000Hz, as low as 400 Hz in some systems. The idea is that these bands can propagate through the earth.

Initially these systems were developed to communicate to submarines in the 1940's one-way with huge antenna networks buried in the earth, transmitting long distances through earth and water to the subs. Due to their low frequency range, antennas were very long, miles in some cases (on the surface) and transmit power levels very high. The subs would let out a long trailing cable at specified time to capture the messages wireless. (1)

If a compact antenna is substituted for a longer one, the signal required to develop usable reception is quite high, as in the VLF one-way alerting systems mounted in vehicles or cap lamps. This is why a *portable* AM radio has less range than a car radio using a *longer* car mounted antenna. Frequencies used in VLF are much lower, in the audio range.

Mine Usage

Since the 1960's and forward a number of vendors introduced the VLF concept to mining. The idea was to lay a loop on the surface or underground and transmit a high power pulse to receiving units modified to attach onto a cap lamp battery.

Coverage was and has been found impossible to predict due to a number of factors. First, if the transmitting cable is installed on the surface, any conductive layer between it and the mine galleries would stop the signal flat. At different seasons coverage would vary due to ground water changes and temperatures.

Mine Usage, Con't

If surface installation was not practical due to terrain or property issues the cable is installed underground along the perimeter of the mine. In this case the signal is stronger and more predictable. In every mine interviewed VLF signals have been found to interfere with other wired speaker phone systems in the mine due to the high power of the pulse. Many had disabled the transmitter due to this issue. Coverage was found to be unpredictable until a system is actually installed. Many mines report that the signal reliability is spotty in initial tests and the system not purchased. (2)

Local shielding of VLF signals

Due to the low frequency range of these systems, signals are susceptible to blockage if the receiving antenna (as on a cap lamp) is adjacent to metal. Miners are often riding equipment and can't receive the warning. If they are in a refuge chamber or working in or near metal container or cabinet they may not receive the signal.

Susceptibility of signal blockage due to EMI masking.

EMI (**E**lectro-**M**agnetic **I**nterference) is generated from a number of sources. Vehicle generators, electrical a/c power centers, regulators and transformers emit EMI fields. These fields *mask* VLF signals as they fall within the same band and make them useless as an emergency alert device if the miner is nearby.

In summary, the VLF type system has been found to work in some installations with encouraging results, but not even ½ the attempted installations realized coverage results providing reliable enough signal to be depended upon in an emergency .

Is VLF signaling reliable enough to require ***every*** coal mine to install this equipment? – The answer is a qualified ***no***. Providing all the above factors are working in his favor, in some mines it can be a reasonable option ***if*** the coverage is verified. VLF paging cannot be depended upon as a positive solution worth sweeping legal mandate. On the positive side in mines where signal coverage is adequate the trade off can be beneficial.

One thing is for certain, many mines in WV and across the country have tested this technology and removed it as unusable, and will now be forced to reinstall, pay for, and be in violation if the system does not operate according to this legislation.

Tagging - Tracking systems

The bill also provides for wireless tagging and tracking systems to be on order by February 28. Coverage is also to be “mine-wide”

These systems operate on the concept that a small, low power transmitter is attached inside a cap battery or small pager sized unit carried by the miner. This “Tag” transmits a unique digital ID signal over-the-air wireless in frequencies typically ranging from 130 Khz, 400Mhz and 915 Mhz or higher. The ID signal is “captured” (if within receiving range) by a fixed “reader”.

The operation of the reader is more complicated. Once the man-tag signal is identified and received (generally the tag needs to be within 60 ft of the reader), (3) and the entire message correctly captured, the reader then resends a serial data signal into a hard-line collection or other network. This data includes the tag number and the reader location.

The collection network feeds a computer that time stamps and displays the information and location in tabular form and/or on a mine map CAD drawing showing reader and people locations. Some readers allow wireless connection if a mine-wide radio system is installed.

Collection network

Readers, tags and their *radio range* set the resolution of the miner location. Readers require a wireline, radio or network connection to the host computer on the surface to pipeline the data back to the host computer to operate. Readers also require continuous power - like 120 VAC.

To provide “mine-wide” location, readers will have to be placed in large numbers and a substantial power grid installed and serviced to power them. It is obvious that readers may require MSHA approval (to provide coverage to “inby” locations) and will increase the electrical load, number of a/c power connections (adding to potential spark hazard substantially) not to mention man power to maintain and expand the complex system. If not MSHA approved, the entire system will be shut down with the A/C mains in the event of a methane explosion and/or ventilation failure.

It should be noted that to my knowledge, no system of this type has been successfully installed in any US coal mine. One critical issue is the shielding of man tag transmissions while traveling in man carts. Although the tag transmit frequency may be optimized for mining applications, signals as still limited to line-of-site e.g. - 60 feet.

Transport carts are in integral part of mining in WV and many coal States as the close-in deposits are exhausted and crews travel further and further in the mine - at up to 20 MPH. Further research in actual use would be required. Only one system in the world exists that addresses this transport issue. Currently, large hospitals employ tagging for mobile asset management, e.g. where a heart monitor is located and on which floor, not a worker.

Application of above systems in current disasters of Jan 2006

First the question must be asked "How would a wireless man-tag or through the earth pager work to save a trapped miner"?

Tagging - Tracking system. This technology would have helped determine where the crews were *prior* to a blast or fire. These networks would have, more than likely, been partially destroyed. Resources could be dispatched to the wrong locations unless the miner can communicate a *current* position. On the positive side a rescue crew would have a quick overview of personnel locations prior to an accident. Tags will still transmit without readers and can be used to locate a miner within 100 ft or so if the rescue crews carried an appropriate receiver and a directional antenna is used to locate the tag transmission "ping", like those used by back country skiers in avalanche prone area's in the West. Most tags operate at very low signal levels off-the-shelf, unlike avalanche units.

As most methane detonation related accidents occur after crew positioning, *current* location is critical to make rescue resource decisions. This will not happen without communication with the trapped miner, 2-way communication. With the law fully implemented the *voice of the miner* is still not heard, just like 100 years ago. Rescue crews and the trapped miners still have to guess what is the best option to execute a recovery. Tagging, with a reasonable number of read locations can be useful in many mines to the resolution of 2000ft in a trackway, beltline or section.

VLF through the earth. This system, *IF* operable after an explosion or fire would be helpful to update miners as to the rescue process or other pertinent data. Again the trapped miner has no way to *communicate* location, needs or perspective. As effected crews would either attempt escape or seek a refuge chamber the latter may be unable to receive the signal as outlined due to signal shielding. In the Sago disaster an underground transmitting cable would have likely been destroyed, rendering the system useless. On the other hand IF it were operable the crews *could* have left a receiving system outside a chamber and received updates as to the rescue process *if* coverage would have included the area directly and exactly where a lamp was left.

Current 2-way Wireless Systems used underground

A number of 2-way wireless systems are currently in use world-wide in mining. Less than 10% of US mines incorporate such systems due to various reasons, mostly economic in nature and somewhat due to service or other issues. These systems are divided into 3 basic groups as to wave length employed. A number of foreign countries, including Brazil, Peru, South Africa, Sweden, countries in central Europe, China, Canada and Chili operate some of the most advanced systems in the world and yet the US lags far behind in the implementation of these technologies. (4), (5)

It is difficult to conceive that in the unseen and dangerous working conditions inherent to underground mining why broader use of 2- way wireless is not employed. Economic issues rank high on the list; however, so many systems have been introduced in the US with such poor results that many operators have given up on seeking new wireless technologies. Many systems have been overrated and when installed found useless, the chief of these being VLF and LF (low frequency) systems. Others were not properly maintained and others left to disuse out of frustrations of poor operation and range or inability to keep the system serviced.

LF 30-300Khz Systems

These were introduced in the 1970's &80's, 90's. At the beginning, expectations were high due to advocating by the USBM and other published government reports. LF could use a simple cable run in the mine or even cheaper existing power cables already present. A huge limitation was the hand carried portable units which were large, heavy and incorporated a wraparound strap antenna. Few of these portable devices were produced and fewer used.

Mines currently use LF 2-way where the antenna is mounted directly over the transceiver in trolley type man transports for wireless operation, these having a range from cable measured in 10's of feet.

As mentioned previously in this paper, these systems quickly were found not to meet expectations, had little range, employed only fixed mobile units and required a dispatcher to relay communications. They are susceptible to EMI noise and shielding issues.

VHF (150-174 MHz) "Leaky Feeder" Revolution

In the early 1980's, Dr. David Martin, engineers Robert W. Haining and Roger Parsons (6) were commissioned by British Coal to research every conceivable method to communicate wireless underground. Their final and most practical solution was the "Feed Forward" amplifier method. This system incorporated a VHF repeater signal through a chain of bi-directional amplifiers, connected by "leaky feeder" or radiating coax cable. Power requirements of the network was low and with a simple 13.8 VDC power supply on the surface, 10,000's feet of mine galleries could have reliable, predicable IS radio coverage, up to 150meters laterally from the cable. Commercial portable radios could be employed, and no dispatcher was required due to use of a repeater radio base station, a major improvement over other technologies.

Subsequent to this definitive work, Mr. Haining installed systems in South Africa and Canada with encouraging results. Soon dozens of mines were enjoying mine-wide 2-way communications and many reports were coming in reporting huge efficiency and safety enhancements. Now in day to day operation, any miner could have reliable wireless communications with low cost portable radios readily available from many commercial vendors.

Many US hard rock mines employed this technology successfully including the Homestake and Henderson mine complexes, the largest in North America. Greens Creek Mine, the US's #1 silver producer installed the first of these systems in 1988 that has been in continuous uninterrupted operation at this writing, credited for daily efficiency and safety of life in a number of instances. (7)

Due to the fact that radio frequency propagation in confined spaces is dependent on wavelength, a brief discussion and simple calculation will help the reader better understand the issues at hand;

A radio wavelength is calculated with the following formula:

$$\frac{468}{1\ \text{Mhz}} = \tfrac{1}{2} \text{ wave antenna radiator in feet}$$

Where the ½ wave for 1 MHz = 468 ft, or where ½ wave for 4.68 MHz = 100 ft. (8)

An understanding of antenna efficiency is important relative to propagation in tunnels that will be discussed in more detail later in this paper. The most efficient antenna is a pure copper wire related to this calculation capturing the corresponding wavelength over the air. This electromagnetic RF wave is then converted to electrical energy and feed to a receiver set the desired frequency.

The Coal Dilemma

On the coal scene things were different. In seams lower the 6 ft these VHF signals dropped off, with many systems having a range of 50ft or less from the overhead leaking cable. This was due to the wavelength of the VHF (150-174 MHz) radio band - about 12 ft or a 6 ft ¼ wave. To compound the issue, MSHA, responsible for issuing approvals of the 2-way commercial portable radios for use "inby", held up approvals for these units for over 2 years on the heals of approving the latest LF/VLF systems. This action virtually halted all sales of VHF or UHF 2-way systems in US coal mines while sales of VLF and LF, the only approved alternative, moved forward in coal mines. Currently the worlds largest mfg. of advanced portables, Motorola, has abandoned efforts to apply for approval for it's latest units, and who can wonder why after spending 2 1/2 years in their last attempt?

The results were disastrous in this period, the coal industry was left with an inadequate wireless solution, huge monies had been spent and frustrations with wireless in coal mines ebbed. Several VHF and UHF systems submitted for approval were denied, one was approved (a British version of VHF) but no MSHA approved portable existed to use it with! Coal prices plummeted and little interest remained to try new systems with no portable radio approved.

Conversely, US and Canadian hard rock mines were enjoying great success and valuable safety benefits from reliable VHF and UHF systems, while coal was left behind.

VHF limitations in Coal

Vhf systems with a ½ wavelength of 12 feet easily absorb in coal resulting in short range. The 12 ft wave cannot travel down a low seam trackway but a few dozen feet before getting scattered. VHF has poor metal penetration characteristics; an example is if a beltway is in the path from portable radio to the receiving radiating cable, the signal will be blocked, even if the total distance path is less than 75 ft. Vehicles and equipment such as power centers will also block the 12 ft wave, severely limiting range from cable.

On the positive side, VHf is far clearer than LF systems and hand portable units far more convenient and useful. VHf also is impervious to EMI and noise that weighs heavy on LF systems and does not interfere with wired communication networks. VHf, if correctly installed, offers a predicable solution and range and is proven in several coal installations with 6 ft + seams and even provides adequate coverage in lower seams if close to the cable.

UHF systems

UHF systems operate in the frequency range from 300 Mhz -3 GHz and have far different transmission properties in narrow passages and in soft rock, such as in coal mines, than do lower bands.

Rugged portable handsets are available in 150, 450, 800 and 900 MHz versions hardened for mining. Cell bands are 800, 900 Mhz and 1.8 GHz, also have excellent confined space coverage, although present unique challenges to extend miles underground. 450 Mhz networks exist and have proven capability and perform better not-line-of-sight (around corners and through stoppings to some distance).

Due to the characteristic that the higher the frequencies (800 Mhz +) takes on the more direct "beam" properties of light, signals above 450 MHz require more transmission points like light, although they can transmit great distances u/g. At this writing, MHSA has no approved hand portable unit in any of these bands, although submissions are over a year old for a 150 and 450 MHz portable by one mfg..

The Wavelength issue

With a wavelength of 3ft or less, UHF has been demonstrated to communicate *miles* line-of-site in mines. As early as 1982, the USBM (9) conducted studies verifying this characteristic in a softrock mine. Lateral and not-line-of site coverage (from the feeding antenna network) of UHF 450 Mhz systems out performed VHF systems by far, documented by tests conducted by the late Mr. Al Isburg at Black River Mine in Kentucky. (It should be noted that Black River currently employs a 450 Mhz system and enjoys complete mine wide wireless radio coverage using portable radios, a tribute to Mr. Isburgs' work).

UHF systems also enjoy several other electrical characteristics over all other technologies, as few are here listed;

1. Decreased Body Absorption.

It is a proven fact that a body absorbs radio frequency energy. A hand or body mounted VHF radio will degrade a radio signal up to 26 dB where a UHF radio will absorb at a factor of 16 dB = 10 times less! (6) The end result is 10x better reception and transmission from the same radio used in the different bands. (10)

2. Lower Reflection Coefficient.

Where a signal is not-line-of-sight, (around a corner or behind a stoppage) from the transmitting element, (amplifier and cable network) the signal to the target portable will be absorbed. Lower frequency VHF signals will absorb up to 500x more than UHF signals in the same mine structure, reducing the signal to unusable levels where the UHF signal will be sufficient to allow communications.

3. Compact Point Antenna Use

Radiating elements of a VHF antenna will exceed 6 ft in length, requiring a large ungainly sized antenna, (like a large roof mount TV antenna) to mount in a narrow gallery. UHF antennas on the other hand are compact (24"x 12"x 2" or smaller), high gain, (10X) and can be easily mounted.

UHF antenna's can be used anywhere, providing many coverage options and the ability to beam the signal for enhanced radio coverage - like down a trackway. These bands are capable of transiting *beyond a damaged or fire ridden zone* to rescue crews or even to the surface.

One patented system employs a tapped radiator element and/or directional elements on the fixed cable network providing 500x more radiated energy than emitted from a leaky cable. (11)

Summing the above signal enhancements, UHF equipment offers improved coverage along the line of 50 dB, where 30 dB = 1000X more talk energy than all other wireless technologies.

4. Wireless data collection capabilities

The UHF band allows easy integration of wireless data equipment as many manufacturers' have chipsets available to accomplish this task at UHF. Also due to the nature of UHF range, wireless sensors for methane, CO, rock mechanics and SCADA functions are now a reality in mines. This wireless data highway can include tagging and position location.

Distribution Techniques used in UHF

Now that research, physics and experience has shown these upper bands most effective in mines, how do we get the signal in there? It was recently stated that "We can talk to the moon but we can't talk 200ft underground". Actually, a more correct statement would be; "We can talk to the moon but we can't talk to the back side of the moon", relating to RF signal distribution in underground mines.

DAS

Known as the **D**istributed **A**ntenna **S**ystem, this type of antenna and amplifier network is required to ***positively*** distribute a Radio Frequency signal underground from a surface or u/g source. In mining, the source is a radio repeater or "mobile relay", both are defined by the FCC (Federal Communications Commission). (12)

The "Mobile Relay" radio rebroadcasts any received signal in the mine and retransmits, on a different channel, almost at the same instant, the same audio received into the mine network mine-wide. Two frequencies are used, one to receive and one to retransmit. The net result is all communications are instantly relayed through the DAS network of active components, passives, antenna's and coax in the mine to effected portable units with excellent reliability.

FO/RF

This network uses fiber optic cable to interconnect remote transceivers in the mine to create "cells". Each cell has a coverage area or zone. These zones can be expanded with a combination of DAS interconnection. If a mine already employs an Ethernet FO network underground, radio cells can be installed on it.

Current digital handset signaling capabilities

Wireless FM commercial 2-way radios are currently available with many digital signaling enhancements. *Man-down, Radio-Check, Hot Mic, Lone Worker* and *Emergency Alert* to mention a few.

These capabilities include technologies that are built-in to portables and compatible with a number of advanced computer aided display and command capabilities. A number of these systems are in use in U/G mines daily, resulting in a safer workplace where all workers are accounted for and assured a quick response if an accident occurs. None of these safety enhancements, acting to serve the US miner in day to day activities, are achieved with paging or tagging systems as spelled out in the current version of the WV law.

New wireless tag system

A new tagging system not requiring a reader is under development and is operable. More information is forthcoming on this exciting technology. Shouldn't our people have the best?

Do Unto Others -

If personally found in emergency circumstances one would desire the latest most reliable approach to wireless communications available. At a cost of less than $500 per man for a state-of-the-art powerful UHF band portable, and a supporting infrastructure, this option is achievable for all to benefit from, not only in an emergency but to make working u/g a far more efficient and positive experience for operators and miners alike day to day.

A buried phone line to the refuge chamber is what would work best in a coal mines for those able to reach that location. This same line can remote control a base radio.

Summary

Any of these current technologies mentioned may be employed and used creatively to provide ***reliable*** wireless radio coverage in a mine. *All* systems have limitations. They cannot reach every corner of a mine in reasonably designed configurations. Complete 100% mine-wide coverage in large or aging mines would require complicated and expensive installations with limited return in usefulness and potentially defeat their purpose to maintain them in safe order.

No mine is impervious to communication interruption, no less than if wireless is lost in a city hit by a hurricane, flood or earthquake. Reasonable redundancy and useful radio coverage in underground mines will make a dramatic reduction in injuries and death, as proved many times over in current installations world-wide.

A miner with a rugged, UHF long range personal radio has a powerful safety tool in time of need. Deployment of wireless technologies (like multiple wireless methane sensors and late technology wireless communications) that can ***prevent*** a disaster is a more ***proactive*** approach to safety enhancement in coal or any mine. It is a travesty that the US government is spending billions of dollars slinging expensive equipment into outer space when thousands of men and women work every day in inner space without wireless communications.

Funding, misinformation, approval issues and knowledge gaps are the real issues separating the mining industry from enjoying the efficiency and safety enhancements of wireless 2-way and data communications.

Mines are varied in nature and structure. *Although well meaning, this law is too narrow and makes impossible demands on the mining community*. It siphons resources in the wrong direction and stifles a more creative state of- the-art ***proactive*** approach to solve the problems and meet the need.

In conclusion, the WV law will force many mines to purchase outdated systems proven to be of little use in the day to day activities of the mine, with questionable effectiveness to be considered a safety of life apparatus. In the event of disaster, the choice forced upon the industry will be second rate and likely dysfunctional at the point of greatest need; not for the operator, not for the government**, but for the people underground**.

Wireless communications is a great step forward in mining, and my hat is off to West Virginia for kicking over this bucket in favor of using wireless to support the hard working, brave folks working underground, so let's move forward, God grant you wisdom.

S. B. Trapper
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