CANMET Mining and Mineral Sciences Laboratories

Summary Study of Underground Communications Technologies

Final Project Report

by Pierre Laliberté, Eng.
Experimental-mine

Project: 603478-00-0
Report CANMET-MMSL 09-004(TR)

Version: May 2009

Natural Resources Canada Ressources naturelles Canada

Canada

DISCLAIMER

Any determination and/or reference made in this report with respect to any specific commercial product, process or service by trade name, trademark, manufacturer or otherwise shall be considered to be opinion; CANMET-MMSL makes no, and does not intend to make any, representations or implied warranties of merchantability or fitness for a particular purpose nor is it intended to endorse, recommend or favour any specific commercial product, process or service. The views and opinions of authors expressed herein do not necessarily state or reflect those of CANMET-MMSL and may not be used for advertising or product endorsement purposes.

TABLE OF CONTENTS

FIGURES

TABLES

SUMMARY

There is a multitude of underground communication technologies available on the market today. Some of these technologies are based on proven principles that have been in place for more than a decade, while others are based on new technologies originally designed for surface use. Given this wide range of options, some mining companies are somewhat overwhelmed by and very wary of these new technologies. Company personnel do not always have the time and resources to sift through the vast body of information and make an enlightened choice.

The main objective of this project was to inventory and briefly evaluate underground communications technologies as well as related technologies and make the information available to the mining industry. The second objective was to identify the underground communications requirements of the mining industry in order to take research in the direction needed to meet users' expectations.

A survey of 13 mining companies was carried out in the summer of 2008. The results of that survey are presented at the end of this report. The findings suggest that the level of knowledge of new underground communication technologies varies considerably. It also appears that the mining industry is still reluctant to use these new technologies even knowing they are reliable. Finally, 8 of 11 respondents reported that their current underground communications needs are being met by manufacturers.

The results of this project will give the industry a better understanding of underground communication technologies, vehicle and personnel tracking, anti-collision systems and remote control systems. The project will highlight the characteristics of each technology.

Mining industry personnel will benefit from the information gathered and will have greater insight into the technical advantages and limitations of the various technologies offered by manufacturers.

INTRODUCTION

In the wake of a series of coal mine accidents in the United States, the American government enacted legislation (the Miner Act of 2006) requiring mines to put in place sturdy, redundant communication systems and a system for locating miners underground. After that legislation was passed, a number of existing manufacturers came forward to demonstrate the features of their underground communications systems. In addition, many new companies also came up with prototypes or finished products to show that their system could meet the requirements of the Miner Act. In some cases, the companies had no experience in the mining sector and none of their personnel had ever been in an underground mine.

Each section of this report presents and defines a type of communications technology. The advantages and limitations of that technology are identified, and a description of the various systems offered by different manufacturers is provided.

A number of communication systems were tested in American coal mines by the ***West Virginia Office of Miners' Health, Safety and Training, Emergency Communications and Tracking***. Some of the available findings are presented in this report. The complete reports are available on the Web site, the link also is provided in the References section of this report.

Very Low Frequency Through-the-earth Communications (VLF or ULF)

Description

This type of communications system uses the principle of propagation of an electromagnetic or magnetic wave at a very low frequency (3 kHz to 30 kHz) or ultra low frequency (300 Hz to 3 kHz) through-the-earth (TTE). Generally, the system uses a very large loop antenna deployed on the surface or underground and underground receivers capable of receiving the signal from the antenna. The antenna can be made by connecting each conductor on a cable in series to create a multi-turn loop. Most of these systems are unidirectional.

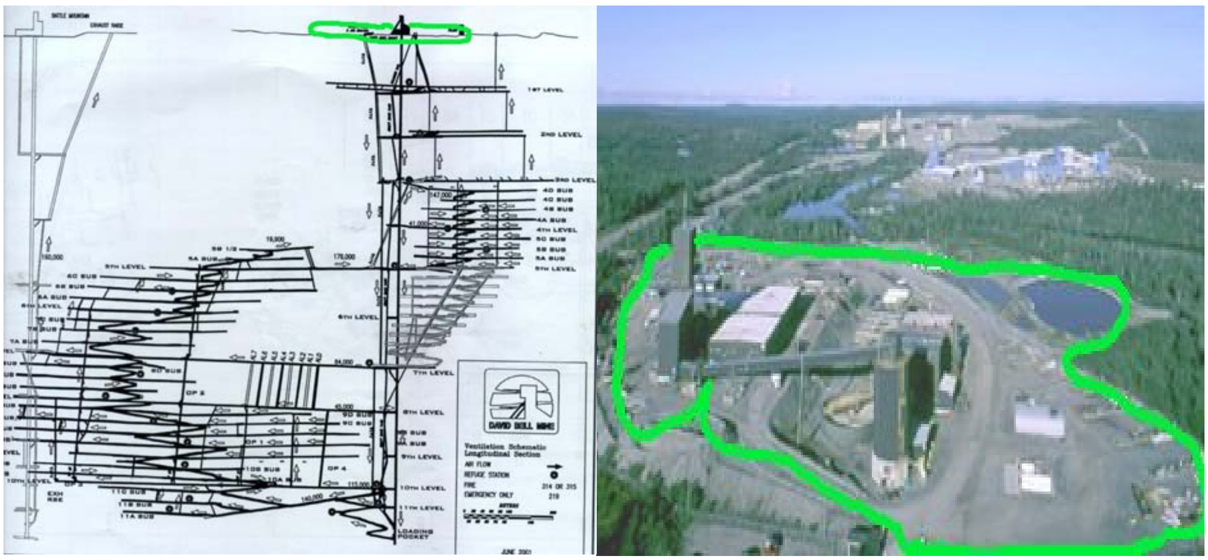

Figure 1 – Surface Loop Antenna

Advantages

- Some systems require no underground infrastructure except the receivers.
- Surface antenna can be deployed fairly quickly in an emergency.
- Voice communication possible with some systems (Transtek and MISL).
- Line of sight not required because the system is through the earth.

Limitations

- Communication is often unidirectional from the surface to the underground receivers, which means there is not always confirmation of reception.
- Signal cannot transmit and receive simultaneously (semi-duplex) most of the time.
- Sensitive to interference from electrical equipment.
- Can interfere by induction with existing communications and control systems.
- Surface antenna up to 12 km in circumference can be complicated to deploy.
- System requires up to 1.2 kW of power to transmit.
- Surface antenna must be in line in order to cover the entire mine, which is sometimes difficult on a slope or in an area that is hard to access.
- Coverage impossible to predict, and dead spot or shadow area where there is no signal.
- Antennas to repeat the signal underground or to interface with other frequencies have the potential to break and can be damaged.
- Limited communication distance.
- Very limited data transfer capacity.

- Almost impossible to transmit voice communications (except Transtek and MISL).
- Systems often not portable (Transtek).
- Very little information on the Web from some companies.

Manufacturers

Magneto-Inductive Systems Limited (www.magnetoinductive.com), now **Ultra Electronics Maritime Systems** (www.ultra-uems.com), has developed a communications system (**MI Rock Phone**) that uses a digitally modulated 5 kHz VLF magnetic wave to communicate through the earth. The system comprises a surface transceiver (**Rock Phone**) with a loop antenna and an underground transceiver that also has a loop antenna. The Rock Phone allows two-way communication. A portable receiver (Rock Phone Receiver) can be connected to the transceiver to view text messages and data or for voice communication in receive mode only. The battery powers the unit for approximately 20 hours on a single charge. The communication system can be interfaced with a mine's existing communications systems, such as a leaky feeder. Very little information is available on the company's Web site.

Tests in the catacombs of Paris showed that the system is capable of transmitting voice over a distance of 180 m (590.5') and text messages over 300 m (984'). The audio quality was very good from the surface to the catacombs and satisfactory from the catacombs to the surface. The data transfer rate in the tests was 2400 bps.

Figure 2 – Rock Phone, Rock Phone Receiver and MISL 3 m Loop Antenna

Mine Site Technologies (MST) (www.minesite.com.au) offers the **PED (Personal Emergency Device)** system, which uses 400 Hz to 1000 Hz ULF frequencies to transmit through the earth. A software installed on a computer on surface is used as interface to send commands to the system. A modulator board receives data by serial link and converts them to a 0-20 mA current loop. A headend boosts the signal and injects it into the surface loop antenna. It can take up to 1200 watts of power to transmit the ULF signal. The placement of the loop antenna is crucial to the performance of the communications system. Generally, the bigger the loop (maximum of 12 km), the better the performance. One or more antennas with an underground repeater system can be installed so that the signal is rerouted where necessary because of the depth of the mine. The system is unidirectional.

MST claims that more than 200 systems have been installed in mines since 1990, and the average communication distance through the earth is between 800 m (2624') and 1100 m (3609'). For example, one mine in Ontario, Canada, with a surface antenna 1400 m (4593') in circumference is covered to a depth of 1000 m (3281').

A number of accessories capable of receiving ULF signals underground are available. Miner's cap lamp (**Personal Receiver** or **BeltPED**) can receive ULF signals and display 32-character text messages. **AutoPED** offers the same features for occupants of vehicles. **ControlPED** allows remote control of pumps, fans and other equipment. Finally, **BlastPED** is a remote blasting system. All of these accessories can only receive ULF signals and are therefore unidirectional. Installing the loop antenna underground so that it is closer to the receivers appears to be the norm. A great deal of information is available on the company's Web site.

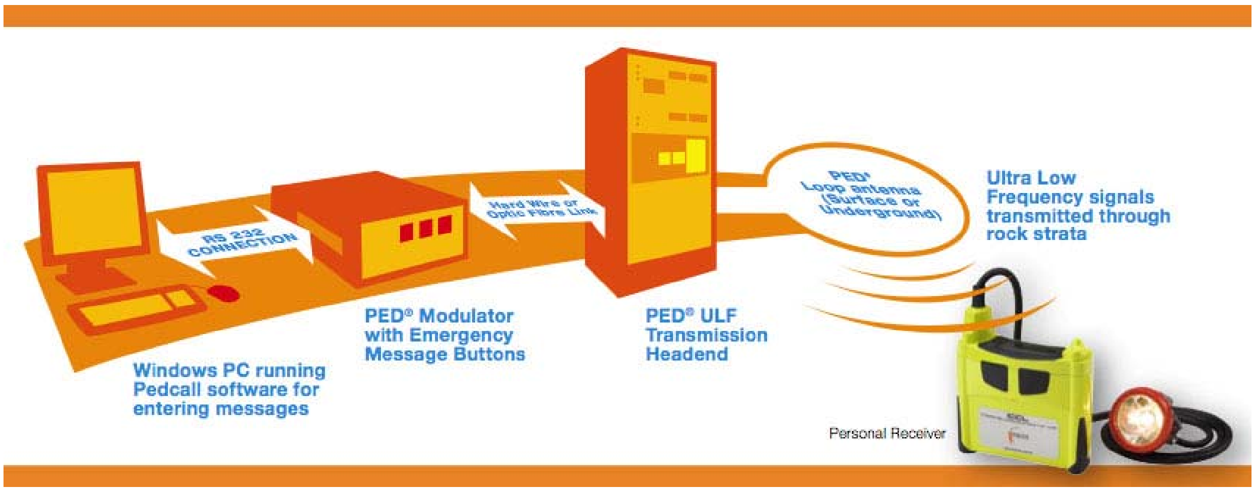

Figure 3 – PED System and Personal Receiver from Mine Site Technologies

Figure 4 – AutoPED, ControlPED and BlastPED from Mine Site Technologies

Mine Site Technologies is currently developing the next generation of the company's PED system, which will be bidirectional. The surface system will be essentially the same, but a portable version will also be available for emergencies. The system will allow fixed stations to be installed in underground refuge stations, but only text messaging will be available for bidirectional communication. The loop antenna can be installed outside the refuge station. The power of the system had to be reduced in order to obtain MSHA approval for coal mines and other potentially explosive environments. The system should nevertheless function to a depth of 600 m (1968'). A version for conventional mines offering deeper coverage should also be available. The surface system will be able to communicate with three underground stations. Each underground station will be able to act as a repeater and retransmit to a deeper station.

The second phase of development will be a portable system that underground mine workers will be able to carry with them and will have the capacity to communicate with the PED systems in the refuge stations, which will act as repeaters/amplifiers to the surface. The new PED system has been tested in Patriot Coal Federal's #2 Mine in West Virginia with the presence of representatives of MSHA, NIOSH and Consol Energy. Clear, bidirectional voice communication was maintained at the 230 m (755') and 335 m (1099') levels of the mine.

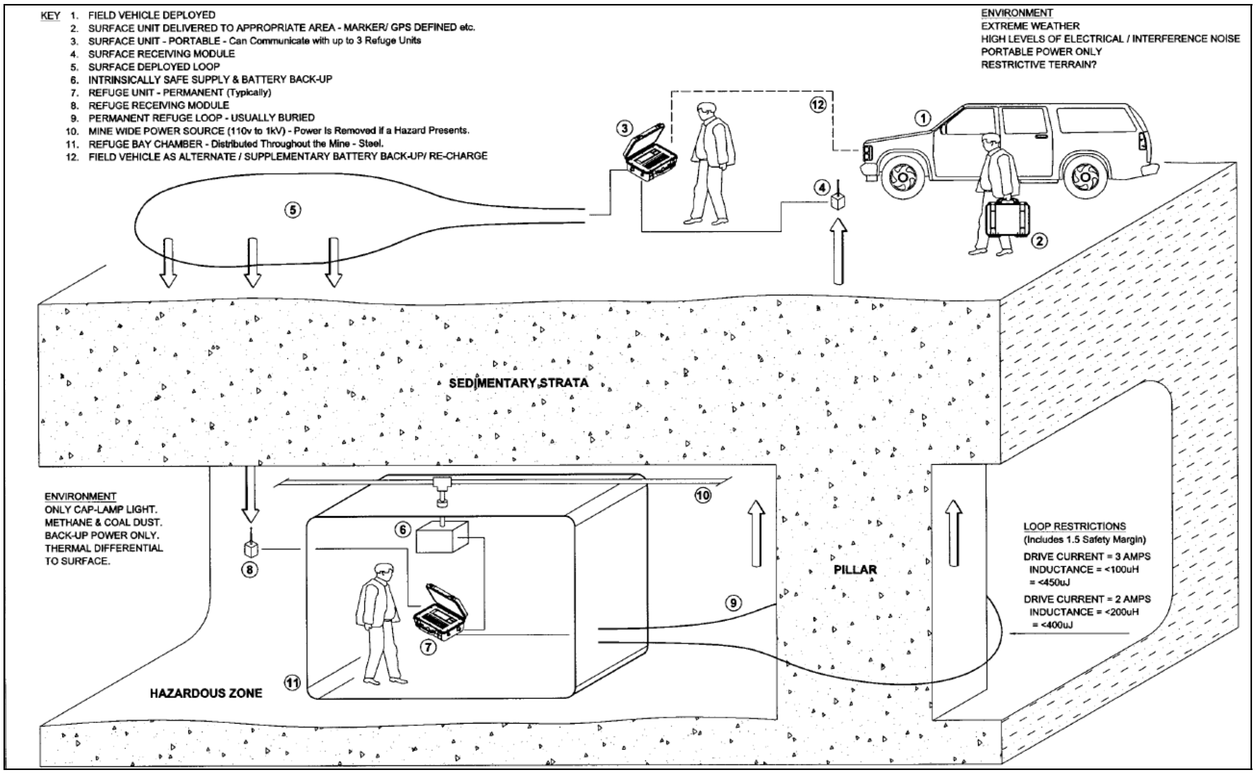

Figure 5 – Portable Bidirectional PED from Mine Site Technologies

Transtek (www.transtekcorp.com) offers the **TeleMag** system, which uses 3000 Hz to 8000 Hz VLF frequencies to transmit through the earth. DSP filtering technology that eliminates noise induced by harmonics ensures communication up to 1000' (305 m) deep. Because it is not portable, TeleMag uses transceivers to convert to portable radios. Transtek says that its portable radios are able to communicate to a depth of 600' (183 m) from the transceivers. The system is bidirectional but semi-duplex. That means it cannot transmit and receive simultaneously. No technical information about TeleMag is available on the Transtek Web site.

Tests conducted in 2006 at the NIOSH facilities in Lake Lynn, Pennsylvania, showed a maximum bidirectional communication distance of 280' (85 m). The antenna, installed on the surface and underground, was 60' (18.3 m) in diameter. A horizontal displacement of 170' (52 m) of the underground receiver resulted in a communication loss from below ground to the surface. The portable radios could not be more than about 100' (30.5 m) from the TeleMag transceiver.

Figure 6 – TeleMag System from Transtek

Recent discussions with Transtek officials yielded additional information about the development of the system. With additional funding from NIOSH, Transtek is developing the next version of the TeleMag. The new version will be tested in an American coal mine in 2009 and should meet NIOSH requirements for system power in potentially explosive environments. The system should be able to transmit voice in both directions over a distance of more than 600’ (183 m) using DSP digital compression. Transtek’s ultimate goal is to be able to transmit up to 1200’ (366 m) through the earth. The surface and underground antenna will have a circumference of approximately 180’ (55 m).

Kutta Technologies (www.kuttaconsulting.com) offers the **Subterranean Wireless Electronic Communication System (SWECS)**. Originally developed for the American army, the system permits voice communication, text messaging and transmission of electronic files. Kutta claims that the system can penetrate up to 800’ (244 m) of rock. Medium frequency (MF) radios form a mesh communication network underground. A non-mobile interface provides the link to the surface using through-the-earth VLF frequencies. The MF radio system (DRUM 100 and 200) is described in the ***Medium Frequency (MF) Communications*** section of this report. The manufacturer’s Web site includes technical information about the system.

Tests conducted in 2006 at Consol Energy’s McElroy Mine in West Virginia showed that the prototype was unable to penetrate to a depth of 500' (152 m) or 600' (183 m). Tests at the Consol Energy’s Enlow Fork Mine in Pennsylvania produced more positive results and bidirectional text messages were sent to depths of 580' (177 m) and 631' (192 m) at a rate of 20 to 30 characters per minute with a 20% error rate. In subsequent tests, unidirectional text messages were sent to a depth of 900' (274 m) at a rate of 2 or 3 characters per minute with a 50% error rate. It remains to be seen how voice, even digitally compressed, can be transmitted at such a low data rate.

Figure 7 – Prototype and SWECS from Kutta Technologies

Vital Alert (www.vitalalert.com) offers the **Canary Mine Messenger** system, which operates at VLF frequencies of 3 kHz to 30 kHz and uses ferrite rods with amplifiers as an antenna instead of a loop antenna. **Canary 1** is capable of sending text messages at a rate of only 32 characters in 30 seconds. **Canary 2** allows bidirectional voice communication using digital compression. Vital Alert claims that its system can reach through-the-earth communication distances of 9000’ (2743 m). There is no information on the company’s Web site.

Tests conducted in 2007 in a mine used as a NIOSH test site in Lake Lynn, Pennsylvania, showed that the Canary 2 system had a communication distance of approximately 370' (113 m). The system is sensitive to electrical interference, and the quality of the audio signal was disappointing. An ACU-1000 system from Raytheon was used as the interface between the Vital Alert VLF system and Sprint i325 UHF radios.

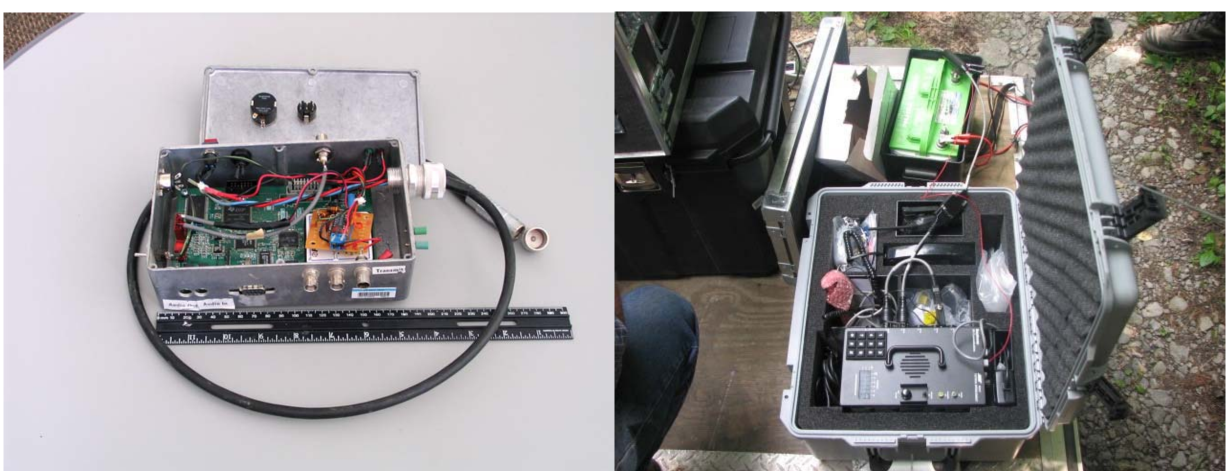

Figure 8 – Canary 2 System from Vital Alert

Recent discussions with Vital Alert officials yielded additional information about the development of this system. It appears that the new system, which will be hitting the market in 2009, will be capable of transmitting voice more than 100 m (328') using DSP digital compression (MELPe). It may be possible to send text messages over distances of more than several hundred metres. The transmission rate could be as high as 2400 bps. The portable system has a power rating of 10 watts, while the fixed system has a rating of 100 watts. The frequencies used are between 2000 and 6000 Hz. The commercial name of the product has yet to be revealed.

The **MinerTrack** system from **Gamma Services International** (www.gsimining.com) is also offered by **Geosteering Mining Services LLC** (http://geosteeringminingservices.com). It uses a system of UHF tags at 900 MHz called PAD (Personal Alarm Device) to locate personnel. PAD is also part of the collision detection system called **TramGuard** and transmits its unique identification by UHF to the master field generator (MFG). The MFG transmits to the surface through the earth using very low frequencies (VLF). Very little information is available on the manufacturer's Web site.

Tests conducted in 2006 at Consol Energy's McElroy Mine in West Virginia showed that the prototype was unable to penetrate 500' (152 m) into the earth. However, communication between the PADs and the MFG at 900 MHz went as far as 1012' (308 m). In other tests, penetration was 270' (82 m).

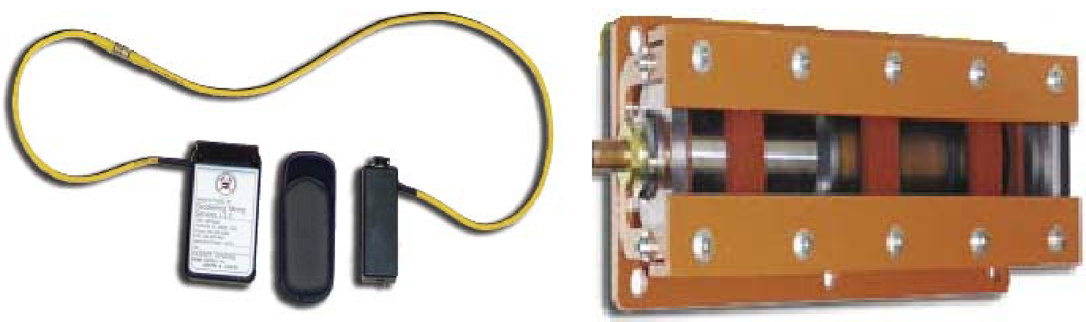

Figure 9 – PAD and MFG from Gamma Service International

Mine Radio Systems (www.mineradio.com) used to offer the **FlexAlert** system, but there is no longer any information about the product on the manufacturer's Web site. According to company officials, the system is no longer in production, but new research on ways to improve it is currently being done.

Summary

Table 1 – Summary of VLF/ULF Communications

Company	Description	Advantages	Limitations
Gamma Services International & Geosteering Mining Services	MinerTrack : UHF Tag at 900 MHz (PAD) must be carried by worker. Tag transmits in UHF to the MFG (Master Field Generator), which transmits to surface through the earth using VLF.	Good range of communication between the PAD and the MFG (308 m).	VLF communication distances fairly limited (82 m). Very little information on manufacturer's Web site.
Kutta Technologies	Subterranean Wireless Electronic Communication System (SWECS): VLF communication through rock and MF communication underground.	Uses portable MF radios, providing greater mobility. Voice communication possible.	Fairly limited communication distances (192 m to 274 m). Very slow communication (2 to 30 characters per minute). SWECS not available for mining applications.
Magneto-Inductive Systems Limited (Ultra Electronics Maritime Systems)	MI Rock Phone : VLF of 5 kHz and digital modulation. Maximum data transfer rate of 2400 bps. MI Rock Phone on surface and MI Rock Phone or MI Rock Phone Receiver underground.	Capable of transmitting voice and data. Loop antenna can be small in some cases (3 m in diameter).	Audio quality deteriorates rapidly with distance. Limited communication distances. Antennas installed underground may be susceptible to breakage.
Mine Site Technologies	PED : ULF of 400 Hz to 1000 Hz. Loop antenna on surface can be up to 12 km in circumference. Up to 1.2 kW of power required. Personal pager system in miner's cap lamp.	200 installations worldwide. Long communication distance (800 m to 1100 m). Many signal receivers offered. Future system will offer bidirectional voice communication.	Antennas installed underground may be susceptible to breakage. Surface antenna up to 12 km in circumference. Shadow zones. Unidirectional communication. No voice communication at present time.
Transtek	Telemag : VLF of 3000 Hz to 8000 Hz. DSP filtering technology to eliminate noise induced by harmonic waves. Uses transceivers to convert to portable VHF/UHF radios.	Bidirectional voice communication but semi-duplex. Uses portable VHF/UHF radios, providing greater mobility.	Communication distances fairly limited (85 m). Not portable. Underground antenna and transceivers susceptible to breakage. Sensitive to electrical interference.
Vital Alert	Canary Mine Messenger System (Canary 1 and 2) : Frequencies between 3 kHz and 30 kHz. Uses ferrite rods as antennas.	Voice communication bidirectional but semi-duplex. Capable of transmitting voice and data. Uses portable UHF radios, providing greater mobility. Future system will offer text communication over several hundred meters at 2400 bps.	Fairly limited communication distances (113 m). Very slow communication (32 characters in 30 seconds. Sensitive to electrical interference. Quality of audio signal disappointing. Future system will have voice communication over a distance of slightly more than 100 m. No information on manufacturer's Web site.

MF or Medium Frequency Communications

Description

This type of communications system uses frequencies between 300 kHz and 3000 kHz. This band of frequencies couples readily to metal structures and cables and propagates and emanates from them easily. The structure becomes the antenna and means of conveyance. AM radio is in this range of frequencies.

Advantages

- Couples readily to metal structures or cables, propagating over very long distances.
- Very acceptable distance even without metal structures or conductors.
- Medium frequencies can be used to communicate with isolated miners.
- Signal turns around corners well.
- No communication cable to be installed if there are existing metal structures.
- Less sensitive to electrical interference.
- Capable of transmitting voice and data.

Limitations

- Antennas and radio can be very bulky.
- Analog version (DRUM 100 from Kutta) does point to point only.
- MF repeaters have the potential to break and can be damaged.
- Not approved by MSHA and may never be because it is too powerful.
- May be dangerous to use with blasting line made of electric wires because signal will couple to it.
- Metal structure or cable must be insulated to achieve good signal propagation.

Manufacturers

Kutta Technologies (www.kuttatech.com) has developed two communication systems. **DRUM 100** (Digital Radio for Underground Miners) is an analog point-to-point communications system that uses a frequency of 470 kHz. It therefore only permits communication between two users at a time. It can interface with a VHF or UHF Leaky Feeder communications system by means of a repeater (DRUM 100 Repeater). In the presence of a continuous metal structure, it can cover up to two miles (10560’ or 3219 m) without a repeater. The manufacturer’s Web site contains technical information about the system.

Kutta Technologies claims that the signal propagates better in conductors that are not grounded. Dedicated signal cables are suggested. Electrical power supply cables are normally grounded at each box or cabinet and, therefore, are not a good medium for propagation. Water and compressed air pipes are often suspended from chains screwed into the rock and also would not be a good conductor for the MF signal. Rails and other non-insulated structures are also considered poor conductors for the signal. Measures would also have to be taken to ensure safety with a blasting line made of wires because the MF signal will couple to it and could trigger the detonator.

DRUM 200 uses digital compression and multiple frequencies to permit two or more communications at the same time on the same medium. The system is capable of transmitting text messages and establishing an ad hoc mesh network. It can also interface with a Leaky Feeder VHF or UHF system using a repeater (DRUM 100 Repeater).

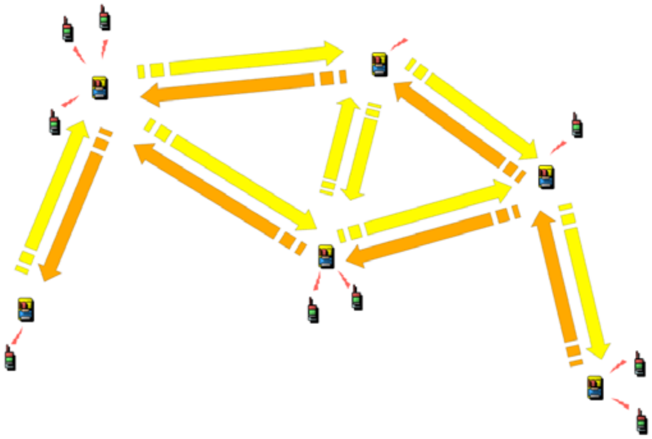

Figure 10 – Mesh Network from Kutta Technologies

Figure 11 – DRUM 100/200 and Repeater from Kutta Technologies

Tests conducted in April 2006 at Consol Energy's McElroy Mine in West Virginia showed that the prototype was capable of communicating over a distance of 5387' (1642 m) using a loop antenna 1.5 m (5') in diameter. A ferrite rod antenna also produced conclusive results. The distance was limited by the fact that the personnel had reached the limit of the work site, not because the signal was lost.

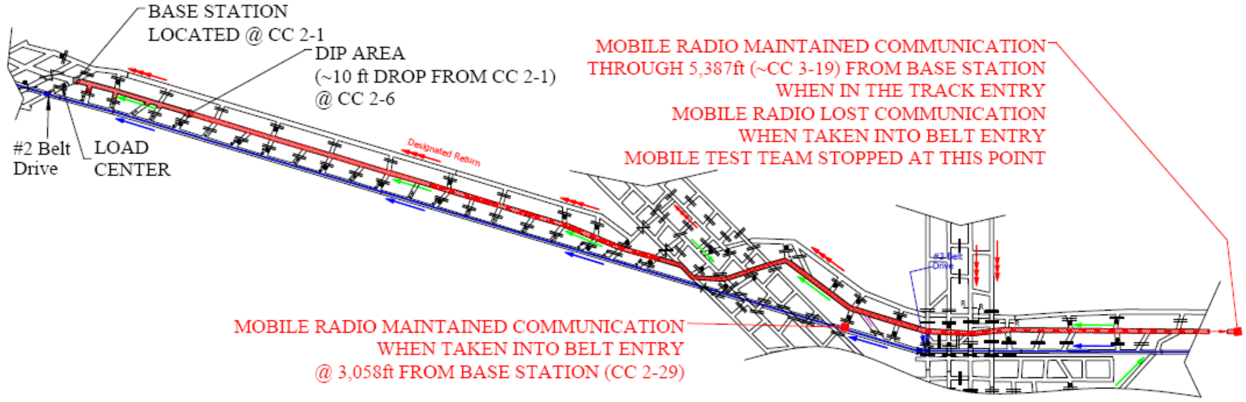

Figure 12 – McElroy Mine Test Site

Additional tests conducted in May 2006 at Consol Energy's Enlow Fork Mine in Pennsylvania showed that the prototype was capable of communicating over a distance of 11600' (3536 m) by propagating along water supply pipes, rails and electrical power supply cables. A distance of 9000' (2743 m) was also achieved along an operating coal conveyor. Without an electrical conductor, audible but poor-quality communications were transmitted to a maximum of 900' (274 m).

CONSPEC (www.conspeccontrolsinc.com) offers a similar solution. Its communications system operates on medium frequencies (280 kHz to 520 kHz) and uses loop antennas to induce the signal in any metal structure or other conductor. Like Kutta Technologies, CONSPEC claims that the signal propagates better in conductors that are not grounded. Dedicated signal cables are recommended. Electrical power supply cables are normally grounded at each box or cabinet and, therefore, are a good medium for propagation. Water and compressed air pipes are often suspended from chains screwed into the rock and also would not be a good conductor for the MF signal. Rails and other non-insulated structures are also considered to be poor conductors for the signal.

CONSPEC claims that if the loop antennas are touching the conductor, the MF signal can travel up to 15000' (4572 m). If the antennas are 8' (2.4 m) away from the conductor, the communication distance drops to 3000' (914 m). A repeater system is available. The manufacturer's Web site provided technical information about the various components of this communications system.

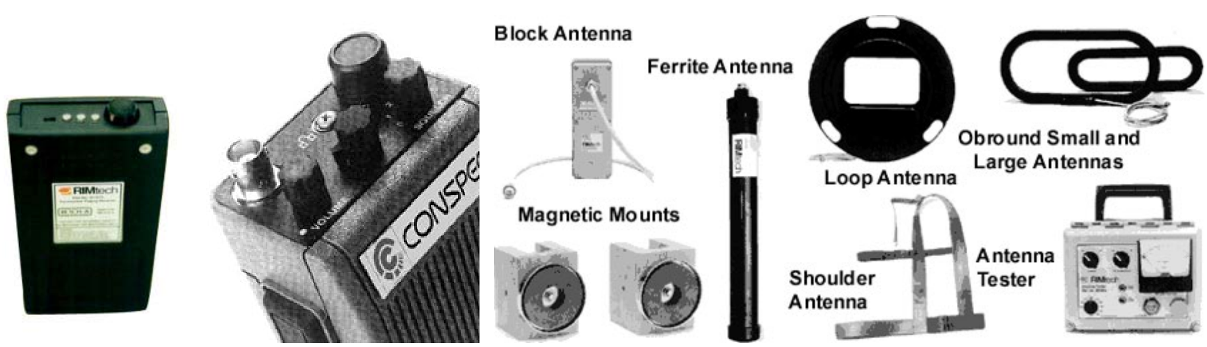

Figure 13 – Pager, Portable Radio and Miscellaneous Antennas from CONSPEC

Summary

Table 2 – Summary – MF Communications

Company	Description	Advantages	Limitations
CONSPEC	Communications system using frequencies between 280 kHz and 520 kHz. Portable radios and loop antennas	Long communication distances (theoretical) where antenna is touching the insulated conductor (4572 m). Distance of 914 m if antenna is 8' from insulated conductor.	Does not appear to propagate well when conductor is grounded. Shorter communication distances without metal conductors or if antenna is far from conductor.
Kutta Technologies	DRUM 100 and 200 radios : DRUM 100 has a power of 5 W at 470 kHz. DRUM 100 repeater converts UHF/VHF to MF at 470 kHz, 5 W.	Long communication distances (1642 m to 3536 m). DRUM 200 version capable of two or more voice and data communications through a digital mesh network. Interface with VHF/UHF Leaky Feeder communications system.	Analog version (DRUM 100) point to point only. Does not appear to propagate well when conductor is grounded. Shorter communication distances without metal conductors.

VHF Leaky Feeder Communications

Description

This type of communications system normally uses a coaxial cable shielded in such a way that part of the signal from the centre cable is able to pass through. This type of cable is called a Leaky Feeder cable or radiating cable. The system was first introduced two decades ago and is widely used in underground mines. It is very reliable and easy to repair. The portable radios used to communicate over the cable are very sturdy and designed for an underground mine environment. The VHF frequencies range from 30 MHz to 300 MHz.

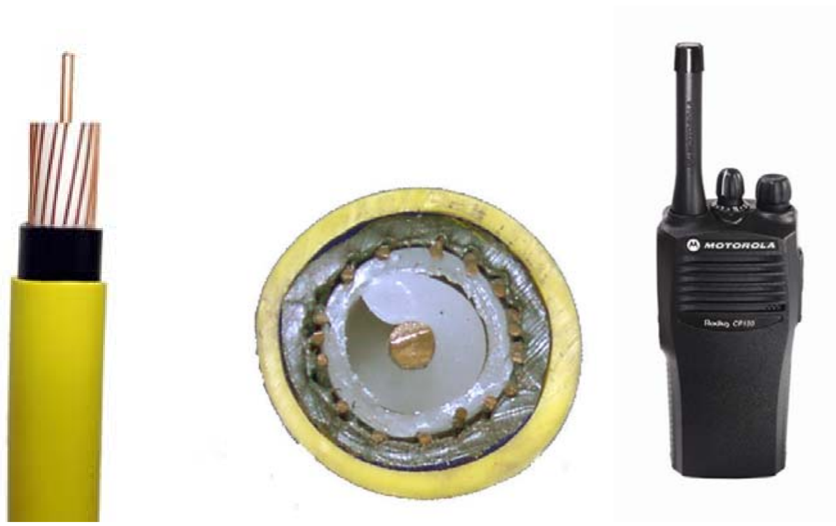

Figure 14 – VHF Leaky Feeder and Radio

Advantages

- System is well known, reliable and ensures clear voice communication.
- Uses commercial radios readily available on the market.
- Capable of bidirectional carriage of voice, video and data.
- Remote diagnostic of amplifiers (some models).
- Vehicle and personnel tracking system (some models).
- Option of Ethernet network on Leaky Feeder cable through CMTS (some models).
- Leaky Feeder cable seems to have less loss (dB/100’) at VHF frequencies.
- Acceptable distance between amplifiers approximately 1500’ (457 m).
- Many are MSHA approved.

Limitations

- VHF frequencies can limit options for increasing transmission capacity.
- Dependent on a cable that can be damaged, causing communication to be lost.
- Distances between Leaky Feeder cable and radios relatively short in general and limited to direct line of sight.
- Leaky Feeder cable can be expensive to install.
- Repeaters have to be installed at regular intervals to maintain signal quality.
- Backup power supply needed in case of electrical power failure.

Manufacturers

Varis Smart Underground Communications, (www.varismine.com), now owned by **Becker Mining Systems** (www.becker-mining.com), offers a complete VHF Leaky Feeder communications system (**Smart Com**). The frequencies used for voice communication range from 145 MHz to 174 MHz. According to the technical specifications, the spacing between amplifiers must be approximately 500 m (1640') and the spacing between electrical power supplies must be 8000 m (26247'). Electrical power is supplied to the amplifiers through the Leaky Feeder cable. The guaranteed coverage distance between the cable and the VHF radios is 30 m (98'), but distances of 150 m (492') have been recorded. The system is capable of carrying 16 voice or data channels and 8 video channels simultaneously.

Varis also offers an Ethernet solution using cable modem technology (CMTS & DOCSIS 2.0) on a Leaky Feeder cable. The transfer capacity is 54 Mbps downstream and 31 x 1 Mbps upstream. Remote diagnostic of the system and amplifiers is possible. The attenuation of the Leaky Feeder cable used by Varis is 21 dB/500 m or 1.28 dB/100' at 185 MHz. A great deal of technical information is available on the manufacturer's Web site.

Figure 15 – Varis Leaky Feeder Connection and Amplifier

Tests conducted at Arch Coal's Mountain Laurel Coal Mine in West Virginia showed that VHF frequencies do not usually go through concrete block walls very well (site 7C). It was nevertheless possible to attain distances between 400' (122 m) and 480' (146 m) on the Leaky Feeder cable by going around several coal pillars (site 10D). The roof heights for the tests were between 6' (1.83 m) and 7' (2.13 m).

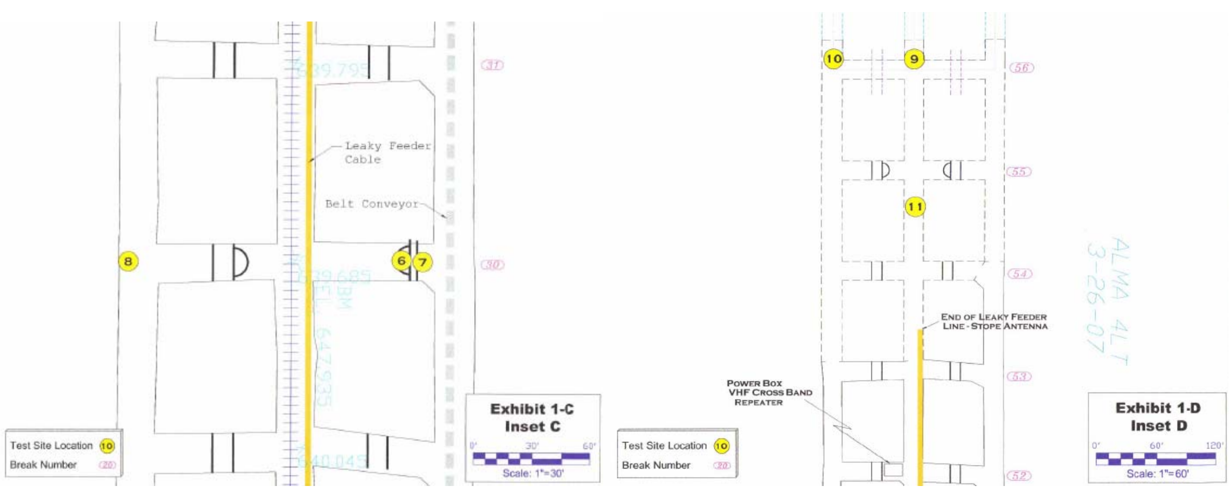

Figure 16 – Test Sites 7C and 10D at Mountain Laurel Mine

Mine Site Technologies (www.minesite.com.au) offers **VDV**, a complete VHF Leaky Feeder communications system. The frequencies used for voice communication range from 146 MHz to 220 MHz. According to the technical specifications, the spacing between amplifiers must be approximately 350 m (1148’). Electrical power is supplied to the amplifiers through the Leaky Feeder cable. No information about the specifications of the Leaky Feeder system offered by MST is available. The Leaky Feeder cable ends with a CATV connector.

MST does not offer a Leaky Feeder Ethernet solution, but it does offer a solution on another communications system called Impact (see Wi-Fi Communications section). VDV’s system, however, can carry telemetry data and video signals. Diagnostic of the system can be done locally or remotely using a software application. The manufacturer’s Web site provides little technical information about this system.

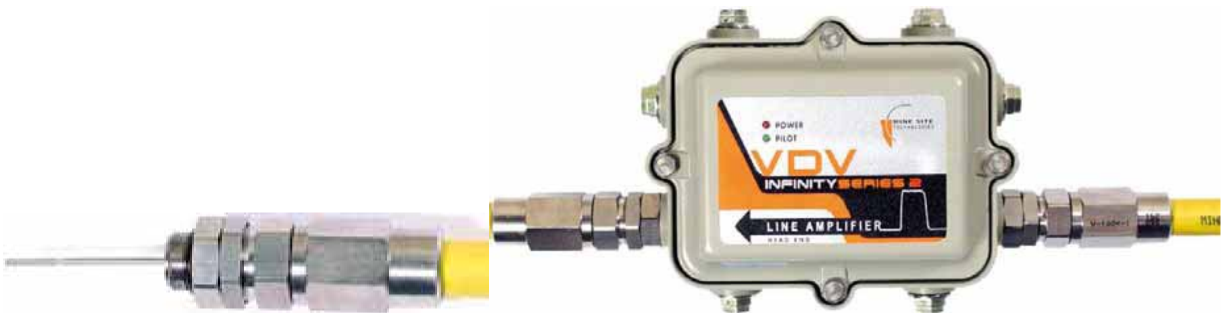

Figure 17 – MST CATV Connector and Amplifier

Mine Site Technologies also offers miner’s cap lamps called **ICCL** (Integrated Communication Cap Lamp) with integrated VHF or UHF radios. The lithium-ion battery is good for 12 hours and is very lightweight. The radio integrated into the battery is very well protected and less bulky than having to carry a battery and a radio separately. A radio tagging option for tracking personnel is available as an option.

Figure 18 – ICCL Miner’s Cap Lamp with Integrated Radio from Mine Site Technologies

Tests conducted at Magnum Coal’s Remington Mine in West Virginia showed that VHF frequencies do not usually go through concrete block walls or coal pillars very well when the roof is only 84’’ (2.13 m) high. The signal from a portable radio was unable to travel a distance of 100’ (30.5 m) toward the Leaky Feeder cable. However, when the roof was higher (274’’ or 6.96 m), the VHF signal found a path to the Leaky Feeder cable more easily; in that instance, the Leaky Feeder cable and the portable radio were 120’ (36.6 m) apart.

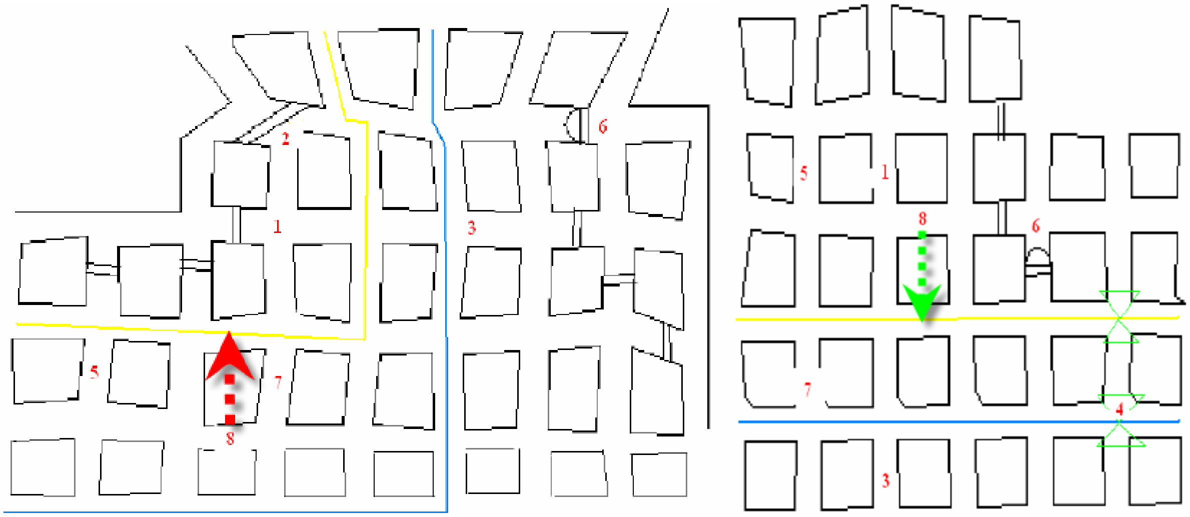

Figure 19 – Tests through Pillars with Roof Heights of 84'' and 274'' at the Remington Mine

In tests with a roof height of 274'' (6.96 m), maximum line-of-sight distances of 150' (45.7 m) from the Leaky Feeder cable and 120' (36.6 m) around several coal pillars were recorded. However, in tests with a roof height of 84'' (2.13 m), the maximum line-of-sight distance from the Leaky Feeder cable was 70' (21.3 m), but the system was unable to go around one pillar.

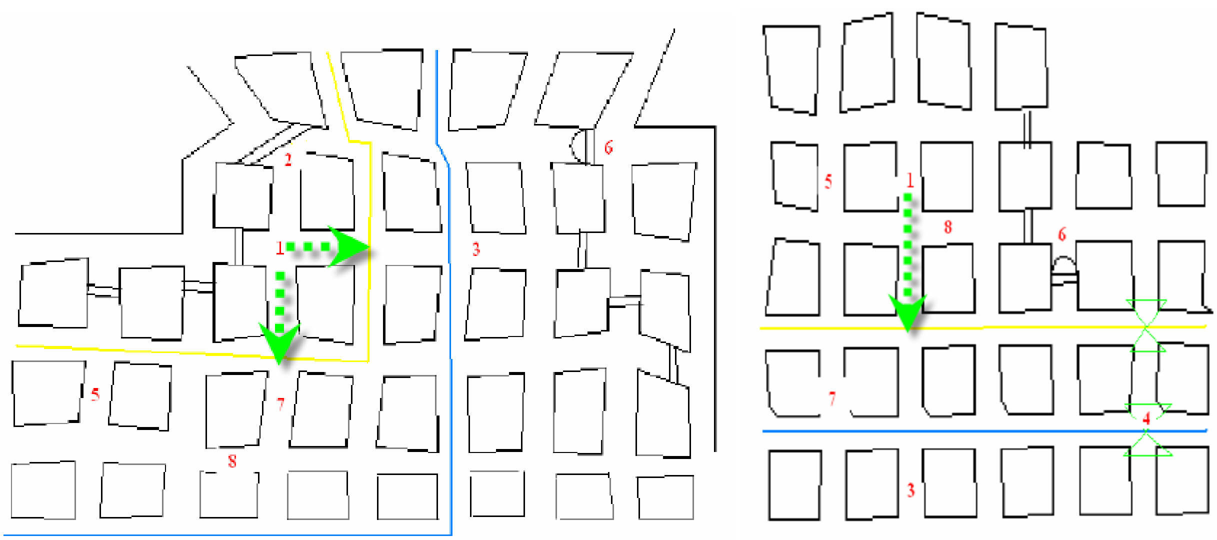

Figure 20 – Line-of-sight Test with Roof Heights of 84'' and 274'' at the Remington Mine

Mine Radio Systems (MRS) (www.mineradio.com) offers **FLEXCOM**, a complete VHF Leaky Feeder communications system. The frequencies used for voice communication range from 150 MHz to 175 MHz. According to the technical specifications, the spacing between amplifiers must be approximately 350 m (1148') and the spacing between electrical power supplies must be 3500 m (11483'). Electrical power is supplied to the amplifiers through the Leaky Feeder cable. The Leaky Feeder cable used by MRS has an attenuation of 4.3 dB/100 m or 1.31 dB/100' at 160 MHz. The system is capable of carrying 32 voice or data channels and 16 video channels simultaneously.

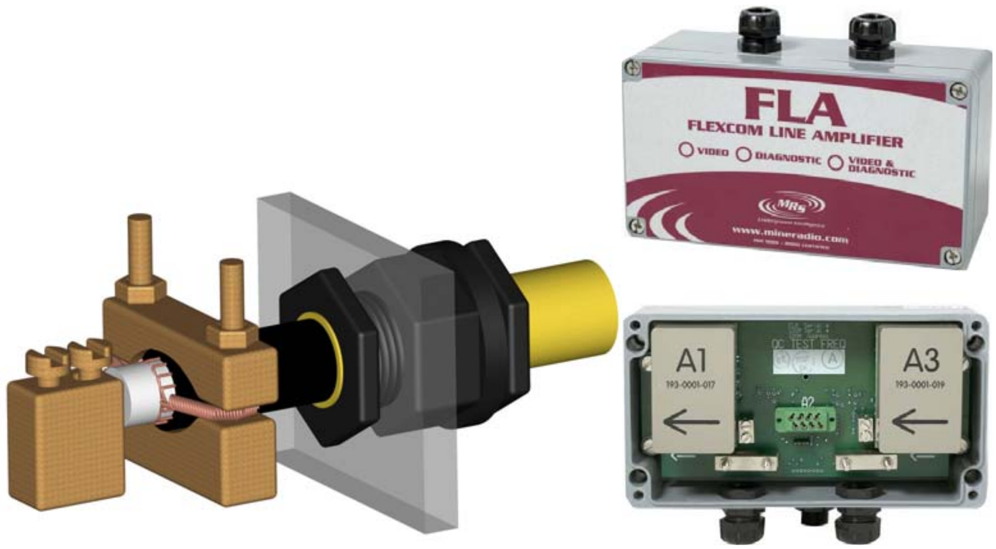

Figure 21 – FLEXCOM Leaky Feeder Connection and Amplifier from MRS

Mine Radio Systems also offers the **MULTICOM** system, which was previously manufactured by **El-Equip**. MULTICOM is a complete VHF Leaky Feeder communications system. The frequencies used for voice communication range from 155 MHz to 174 MHz. According to the technical specifications, the spacing between amplifiers must be approximately 350 m (1148’) and the spacing between electrical power supplies must be 3500 m (11483’). Electrical power is supplied to the amplifiers through the Leaky Feeder cable. The Leaky Feeder cable used by MRS has an attenuation of 5.71 dB/100 m or 1.74 dB/100'. The system is capable of carrying 32 voice or data channels and 16 video channels simultaneously. Remote diagnostic of amplifiers is available as an option.

Figure 22 – MULTICOM Leaky Feeder Connection and Amplifier with Diagnostic Option from MRS

Finally, MRS offers an Ethernet solution (**FLEXCOM CMTS**) using cable modem technology (CMTS & DOCSIS) on a Leaky Feeder cable. The transfer capacity is 30 Mbps downstream and 10 to 30 Mbps upstream, depending on whether one, two or three channels are being used. The system is capable of carrying 32 voice or data channels on the VHF part. The Ethernet via cable modem part can accommodate VoIP phone, video and data transmission and can track and locate equipment and personnel. A great deal of information is available on the manufacturer’s Web site.

Figure 23 – CMTS and FLEXCOM CMTS Amplifier from MRS

Tests of the FLEXCOM system conducted at Arch Coal's Cumberland River Coal Mine in Virginia showed that VHF frequencies do not usually go through concrete block walls very well. A maximum distance of 250' (76 m) from the Leaky Feeder cable, even going around several pillars, was attained with a roof height of 9' (2.74 m). Communication distances dropped to between 80' (24.4 m) and 220' (67 m) when the roof height was between 5.5' (1.68 m) and 6' (1.83 m).

MineCom (www.minecom.com) offers a complete VHF or UHF Leaky Feeder communications system. The VHF frequencies used for voice communication are not specified. According to the technical specifications, the spacing between amplifiers must be between 350 m (1148') and 500 m (1640'), depending on the model chosen. Electrical power is supplied to the amplifiers through the Leaky Feeder cable. MineCom does not offer an Ethernet solution using cable modem technology (CMTS & DOCSIS) on the Leaky Feeder cable. Local and remote diagnostic of the system and amplifiers are available as options. The local diagnostic feature appears to be more complete than those offered by competitors. Up to 11 DEL are used to check the amplifiers simply by walking or driving past the amplifier. The Leaky Feeder cable used by MineCom has an attenuation of 4.2 dB/100 m or 1.27 dB/100' at 160 MHz and is filled with foam. The foam keeps water out of the cable. The system is capable of carrying 8 to 64 voice and data channels and 16 video channels.

MineCom appears to be one of the only manufacturers to offer an optional system of completely redundant amplifiers where the amplification direction can change (Smart Reverse System). If the Leaky Feeder cable breaks, the isolated amplifiers will change the amplification direction so that the signal takes an alternate route.

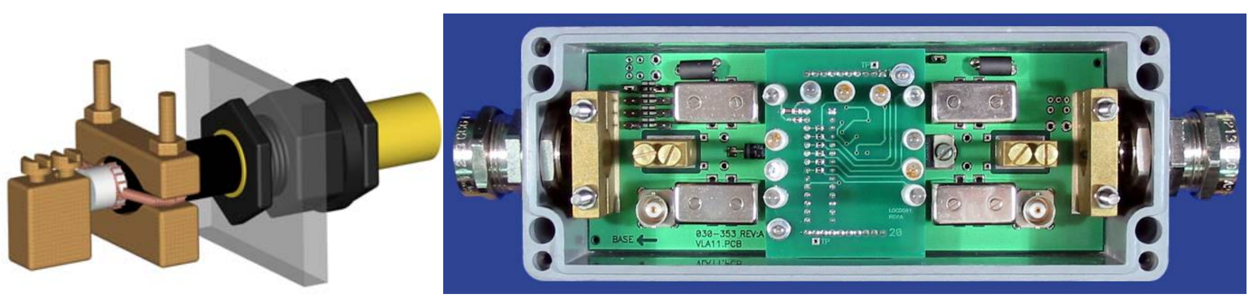

Figure 24 – Leaky Feeder Connection and Amplifier from MineCom

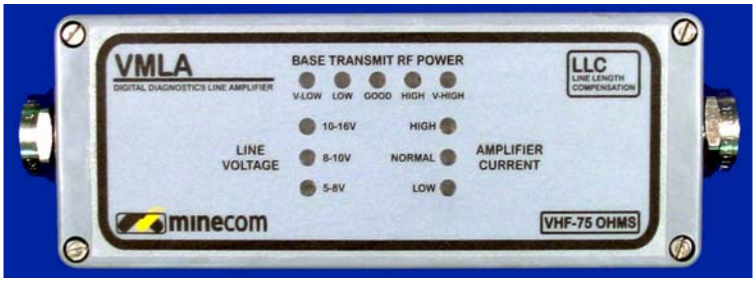

Figure 25 – Amplifier with Integrated Diagnostic from MineCom

VHF tests conducted at Alex Energy's Jerry Fork Eagle Coal Mine showed that the MineCom system barely covered distances between 80' (24.4 m) and 100' (30.5 m) from the Leaky Feeder cable around one pillar. The roof height for the tests was 75'' (1.9 m).

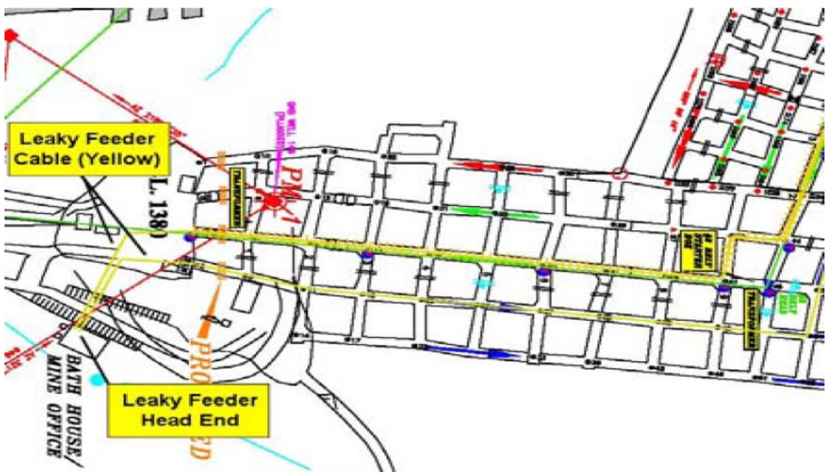

Figure 26 – Jerry Fork Mine Test Sites

Becker Mining Systems (www.becker-mining.com) offers **BECKERCOM**, which is a complete VHF or UHF Leaky Feeder communications system. The VHF frequencies used for voice communication are not specified. According to the technical specifications, the spacing between amplifiers must be 350 m (1148'). Electrical power is supplied to the amplifiers through the Leaky Feeder cable. Becker does not offer an Ethernet solution using cable modem technology (CMTS & DOCSIS) on the Leaky Feeder cable. Local and remote diagnostic of the system and amplifiers are available as options. No specifications are provided for the Leaky Feeder cable used by Becker. The communications system can carry up to 64 voice and data channels and video signal.

No independent tests of Becker's VHF system could be found, but Becker claims that a radio communication can be established up to 50 m (164') away from the Leaky Feeder cable. That is one quarter of the distance attained with Becker's UHF system.

In 2006, **Becker Mining Systems** purchased **Varis Smart Underground Communications**.

Figure 27 – Amplifier with Integrated Diagnostic from Becker

Tunnel Radio of America (http://new.tunnelradio.com) offers a VHF or UHF Leaky Feeder communications system (**ULTRACOMM**). The VHF frequencies used for voice communication range from 152 MHz to 175 MHz. According to the technical specifications, the spacing between amplifiers must be between 335 m (1099') and 488 m (1601'). Electrical power is supplied to the amplifiers through the Leaky Feeder cable. The company claims that the coverage distance between the feeder and the VHF radios is 400' to 700' (122 m to 213 m), more than any competitor. Tunnel Radio of America does not offer an Ethernet solution using cable modem technology (CMTS & DOCSIS) on the Leaky Feeder cable. Local diagnostic of the amplifiers and remote monitoring software are available as options. The Leaky Feeder cable used by Tunnel Radio of America has an attenuation of 4.92 dB/100 m or 1.5 dB/100' at 150 MHz. The communications system can carry 4 to 8 voice and data channels. No independent tests of Tunnel Radio of America's VHF system could be found.

Figure 28 – Head Unit and Amplifiers from Tunnel Radio of America

Jannatec Radio Technologies (http://jannatec.com) is not a supplier of communications systems, but does offer VHF and UHF radios integrated into a miner's cap lamp called **Johnny Light**. The Ni-MH battery is good for 14 hours and is very lightweight. The radio integrated into the battery is very well protected and less bulky than having to carry a battery and a radio separately. Radio tagging for tracking personnel or personnel working alone is available as an option.

Figure 29 – Johnny Light Miner's Cap Lamp with Integrated Radio from Jannatec

NL Technologies (www.nltinc.com) does not offer any VHF communications systems, but does offer VHF and UHF radios integrated into a miner's cap lamps called **GIIIR**. The Ni-MH battery is good for 12 hours and is very lightweight. The radio integrated into the battery is very well protected and less bulky than having to carry a battery and a radio separately.

Figure 30 – GIIIP Miner's Cap Lamp with Integrated Radio from NL Technologies

Additional Notes

It should be noted that there are better-quality Leaky Feeder cables than the ones currently offered by manufacturers of underground communications systems. Attenuation or longitudinal loss is the loss of RF signal over the length of the feeder. The greater the attenuation, the closer together the amplifiers will have to be. Coupling loss is the loss between the Leaky Feeder cable and a transceiver located at a given distance from the cable. The lower the coupling loss, the greater the leakage will be around the feeder; however, there will be more longitudinal loss. The table below compares Leaky Feeder cables in the VHF range.

Table 3 – VHF Leaky Feeders

Manufacturer	Model	Attenuation (dB/100')	Coupling Loss (dB)
Varis	RNG-500	1.28 @ 185 MHz	
MRS	P-177-16-MSHA	1.31 @ 160 MHz	65 @ 150 MHz
MineCom	MCA1000 VLFC	1.28 @ 160 MHz	75.7 @ 150 MHz
Tunnel Radio of America		1.5 @ 150 MHz	65 @ 150 MHz @ 20'
Times Microwave Systems	T-RAD-600	1.34 @ 150 MHz	54 @ 150 MHz @ 6.5'
Times Microwave Systems	T-RAD-900	0.88 @ 150 MHz	58 @ 150 MHz @ 6.5'
AFL Telecommunications	LCX-20D	0.7 @ 150 MHz	65 @ 150 MHz @ 4.92'
Radio Frequency Systems	RLF114-50JA	0.32 @ 150 MHz	62 @ 150 MHz @ 6.5'
Radio Frequency Systems	RLK78-50JA	0.46 @ 150 MHz	56 @ 150 MHz @ 6.5'
Trilogy AirCell	AR114J50	0.28 @ 150 MHz	61 @ 150 MHz @ 6'
Andrew	RCT5-LT-1-RNT	0.48 @ 150 MHz	78 @ 150 MHz @ 6.5'
Andrew	RCT6-LTC-1A-AX	0.33 @ 150 MHz	67 @ 150 MHz @ 6.5'

It should be noted that there is no mention of the price, weight or diameter of Leaky Feeder cables. Most of the Leaky Feeder cables offered by communications system manufacturers are approximately 5/8'' (15 mm) in diameter and weigh 0.18 lb/foot (0.27 kg/m). Better cables can be up to 1 5/8'' (41 mm) in diameter and weigh as much as 0.87 lb/foot (1.3 kg/m). It is safe to assume that the price of those Leaky Feeder cables is directly proportional to their performances.

RFS (Radio Frequency Systems) offers a cable called Vario that is sold in predetermined lengths. The numbers of slots where the RF signal leaks increase as the end of the cable is reached. This means that coupling loss is reduced as the end of the cable is reached, providing more constant radio coverage.

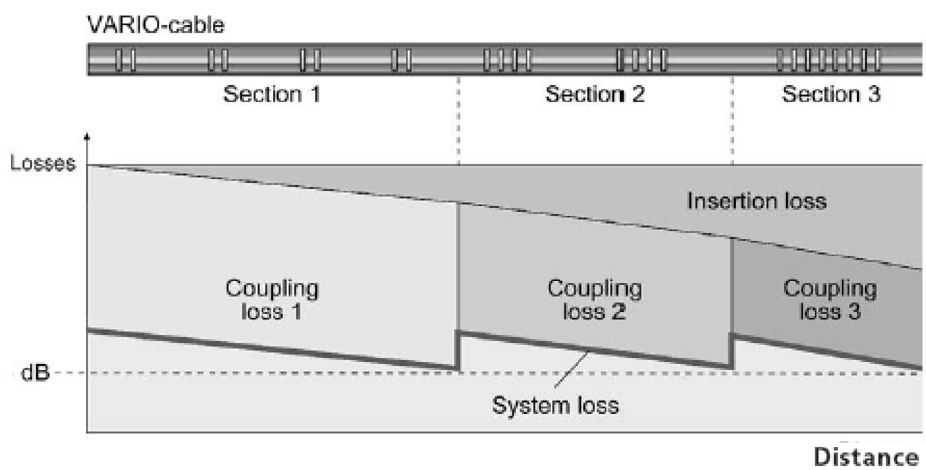

Figure 31 – Details of the Vario Cable from RFS

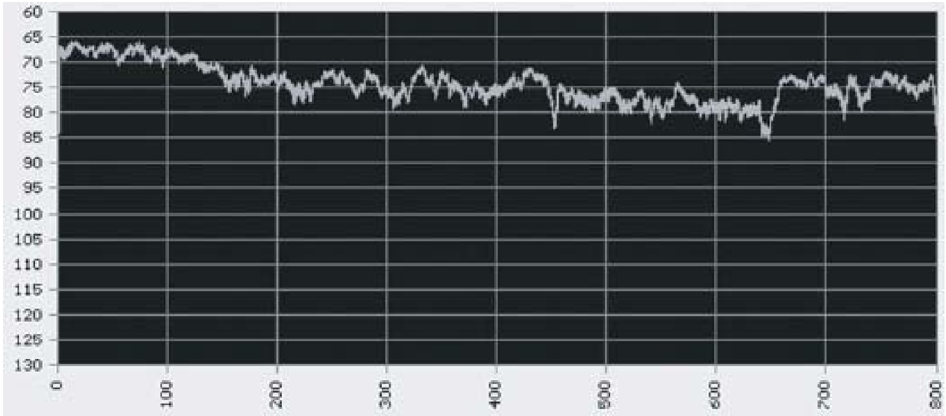

Figure 32 – Measurement of Radiated Signal Relative to Length of the Vario Cable from RFS

Summary

Table 4 – Summary – VHF Communications

Company	Description	Advantages	Limitations
Becker Mining Systems	Frequencies not specified. 350 m between amplifiers. Up to 64 voice channels.	Local diagnostic of amplifiers. Remote diagnostic of amplifiers optional. Up to 64 voice channels.	No Ethernet solution via cable modem (DOCSIS). Fairly short distances between portable radios and Leaky Feeder (50 m).
Mine Radio Systems	Flexcom and Flexcom CMTS. Frequencies between 150 MHz and 175 MHz. 350 m between amplifiers and 3500 m between power supplies. Up to 32 voice, data and video channels.	Remote diagnostic of system and amplifiers. Cable modem Ethernet solution (DOCSIS) optional. Voice, data and video capability.	Fairly short distances between portable radios and Leaky Feeder (67 m to 76 m).
Mine Site Technologies	VDV. Frequencies between 146 MHz and 220 MHz. 350 m between amplifiers. Up to 16 voice, data and video channels	Remote diagnostic of system and amplifiers. Cable relatively easy to repair. Voice, data and video capability.	No Ethernet solution via cable modem (DOCSIS). Very short distances between portable radios and Leaky Feeder (36 m). Cable connection expensive.
MineCom	Frequencies not specified. 350 to 500 m between amplifiers.	Local diagnostic of amplifiers. Remote diagnostic of amplifiers optional. Fully redundant system optional. Leaky Feeder cable filled with dielectric foam. Up to 64 voice channels.	No Ethernet solution via cable modem (DOCSIS). Very short distances between portable radios and Leaky Feeder (30.5 m).
Tunnel Radio of America	Ultracomm. Frequencies between 152 MHz and 175 MHz. 333 m to 485 m between amplifiers	Remote diagnostic of system and amplifiers optional. Maximum distance between radios and Leaky Feeder 122 m to 213 m.	No Ethernet solution via cable modem (DOCSIS). Only 4 to 8 voice communication channels.
Varis Smart Underground Communications	Smart Com. Frequencies between 145 MHz and 174 MHz. 500 m between amplifiers and 8000 m between power supplies. Ethernet via CMTS. Maximum guaranteed distance between radios and Leaky Feeder 30 m. Up to 16 voice channels and 8 video channels.	Long distances between portable radios and Leaky Feeder (146 m). Remote diagnostic of system and amplifiers. Voice, data and video capability. Ethernet solution via cable modem (DOCSIS) optional.	16 voice communication channels.

UHF Leaky Feeder Communications

Description

This type of communications system often uses a coaxial cable shielded in such a way that part of the signal from the centre cable is able to pass through. This type of cable is called a Leaky Feeder or radiating cable. The VHF version of this type of system was first introduced two decades ago and is widely used in underground mines. It is very reliable and easy to repair. The portable UHF radios used to communicate over the cable are very sturdy and designed for an underground mine environment. The UHF frequencies range from 300 MHz to 3000 MHz.

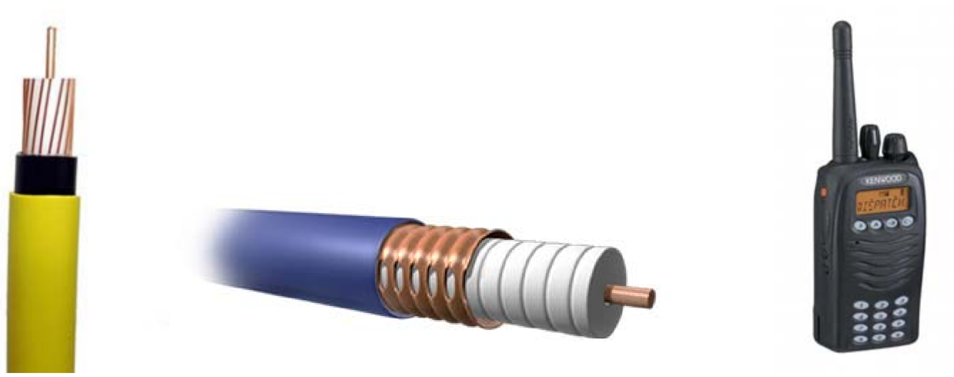

Figure 33 - Leaky Feeder Cables and UHF Radio

Advantages

- Frequencies between 450 MHz and 1000 MHz propagate better in tunnels.
- Makes it possible to move away from the working face.
- Can be less expensive over the lifespan of the mine because of the greater coverage.
- UHF frequencies well known and wide range of equipment and parts available.
- UHF frequencies less absorbed by the body than VHF frequencies (9 dB vs 25 dB).
- UHF frequencies less sensitive to noise.
- UHF frequencies turn around corners better than VHF frequencies.

Limitations

- Loss in dB/100’ greater in UHF Leaky Feeder cables than VHF:
    - 1.34 dB/100’ at 150 MHz
    - 2.22 dB/100’ at 450 MHz
    - 3.35 dB/100’ at 900 MHz.
- Remote diagnostic optional (UltraComm from Tunnel Radio of America).
- Initial cost of UHF equipment may be higher.

Manufacturers

MineCom (www.minecom.com) offers a complete VHF or UHF Leaky Feeder communications system. The UHF frequencies used for voice communication are not specified. According to the technical specifications, the spacing between amplifiers must be between 350 m and 500 m, depending on the model chosen. Electrical power is supplied to the amplifiers through the Leaky Feeder cable. MineCom does not offer an Ethernet solution using cable modem technology (CMTS & DOCSIS) on the Leaky Feeder cable. Local and remote diagnostic of the system and the amplifiers are available as options. The Leaky Feeder cable used by MineCom has an attenuation of 6.1 dB/100 m or 1.86 dB/100' at 450 MHz and is filled with foam. The foam keeps water out of the cable. The communications system is capable of carrying 8 to 64 voice and data channels and 16 video channels.

MineCom appears to be one of the only manufacturers to offer an optional system of completely redundant amplifiers that can change direction. If the Leaky Feeder cable breaks, the isolated amplifiers will change direction so that the signal takes an alternate route.

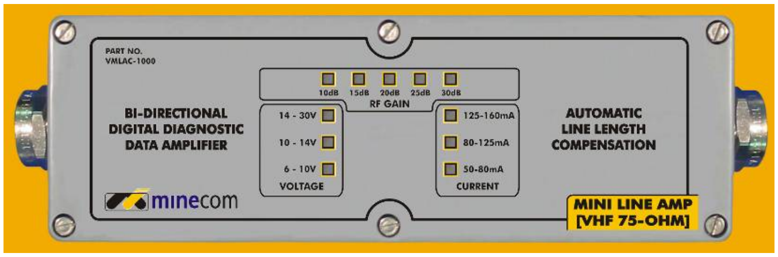

Figure 34 – Bidirectional Amplifier with Integrated Diagnostic from MineCom

UHF tests conducted at Alex Energy's Jerry Fork Eagle Mine shows that the MineCom is able to cover maximum distances of 200' (61 m) from the Leaky Feeder cable going around several pillars. The average roof height in the test site was 75'' (1.9 m). Other tests in XMV's Mine #32 showed maximum distances of 75' (22.9 m) and 90' (27.4 m) from the Leaky Feeder cable in a mine where the work areas were only 40" high (1 m) high.

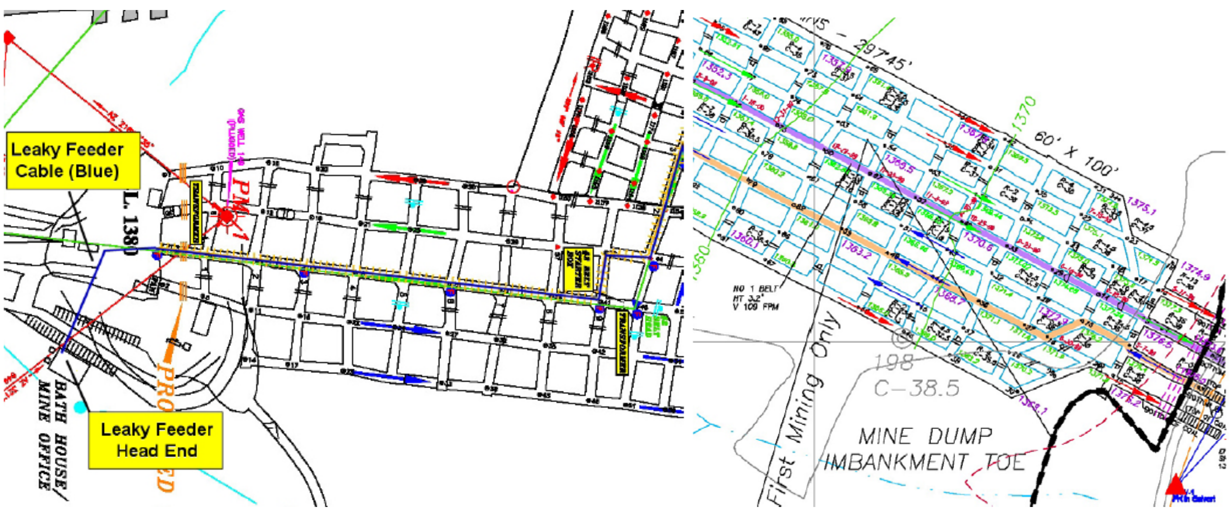

Figure 35 – Jerry Fork Eagle and #32 Test Sites

Becker Mining Systems (www.becker-mining.com) offers **BECKERCOM**, which is a complete VHF or UHF Leaky Feeder communications system. The UHF frequencies used for voice communication are not specified. According to the technical specifications, the spacing between amplifiers must be 350 m (1148'). Electrical power is supplied to the amplifiers through the Leaky Feeder cable. Becker does not offer an Ethernet solution using cable modem technology (CMTS & DOCSIS) on the Leaky Feeder cable. Local and remote diagnostic of the system and amplifiers are available as options. No specifications are provided for the Leaky Feeder cable used by Becker. Becker claims that UHF radio communication is possible up to 200 m (656') from the cable, compared with 50 m (164') in VHF. The communications system can carry up to 64 voice and data channels and video signal.

Figure 36 – Combiner/Splitter and UHF Amplifier from Becker

UHF tests conducted at Consolidation Coal's Loveridge Mine in West Virginia showed that the BECKERCOM is able to cover maximum line-of-sight distances of 300' (91 m) from the Leaky Feeder cable. The average roof height at the test site was 114'' (2.9 m).

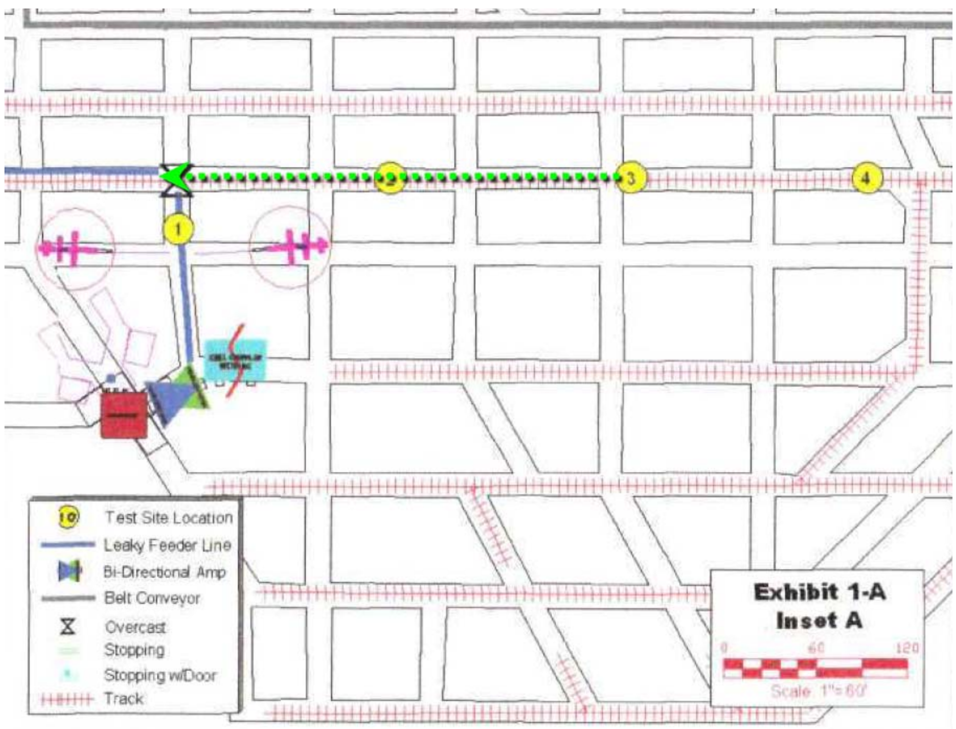

Figure 37 – Loveridge Mine Test Sites

Other tests conducted at Patriot Coal's Rocklick Mine in West Virginia showed communication distances of 950' (290 m) to 1100' (335 m) between two UHF radios without the Leaky Feeder cable. The average roof height at the test site was 120'' (3 m).

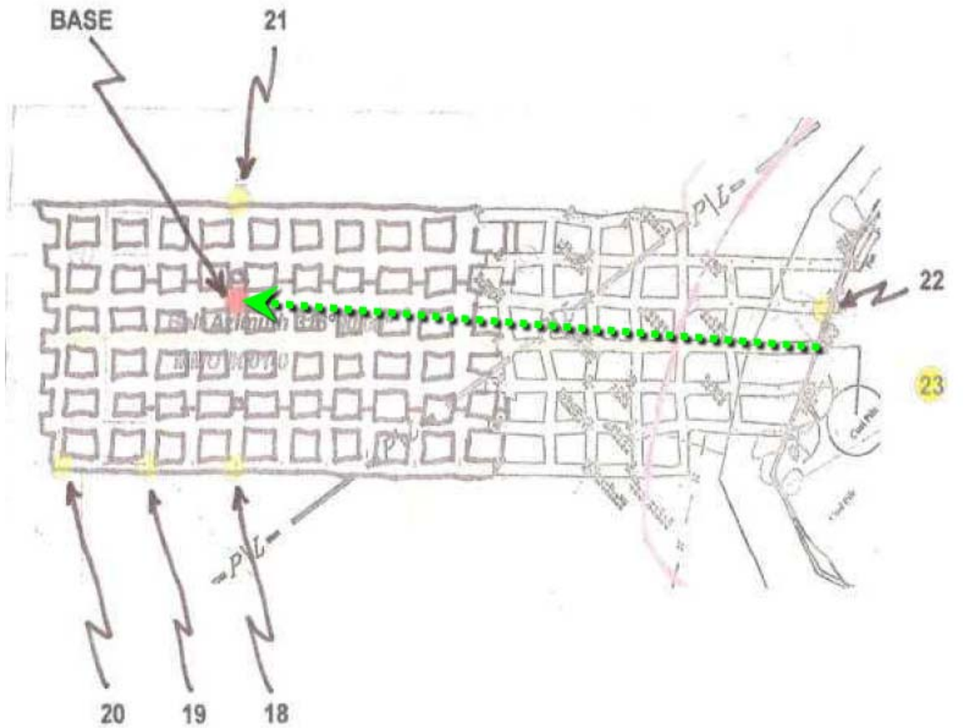

Figure 38 – Rocklick Mine Test Sites

Tunnel Radio of America (http://new.tunnelradio.com) offers a VHF or UHF Leaky Feeder communications system (**ULTRACOMM**). The UHF frequencies used for voice communication range from 448 MHz to 470 MHz. According to the technical specifications, the spacing between amplifiers must be between 1100’ (335 m) and 1600’ (488 m). Electrical power is supplied to the amplifiers through the Leaky Feeder cable. The company claims that the coverage distance between the feeder and the UHF radios is 2000’ (610 m), more than any competitor. Tunnel Radio of America does not offer an Ethernet solution using CMTS cable modem technology (DOCSIS) on the Leaky Feeder cable. Local diagnostic of the amplifiers and remote monitoring software are available as options. The Leaky Feeder cable used by Tunnel Radio of America has an attenuation of 5 dB/100 m or 1.5 dB/100' at 500 MHz. The communications system can carry 4 to 8 voice and data channels and 6 to 32 video channels.

Tests conducted at the International Coal Group’s Imperial Mine showed maximum communication distances between a radio and the Leaky Feeder cable of 220’ (67 m) going around several pillars and even through a concrete block wall. Other tests showed communication distances of 1000’ (305 m) between two UHF radios without the Leaky Feeder cable. The average roof height at the test site was 72’’ (1.83 m).

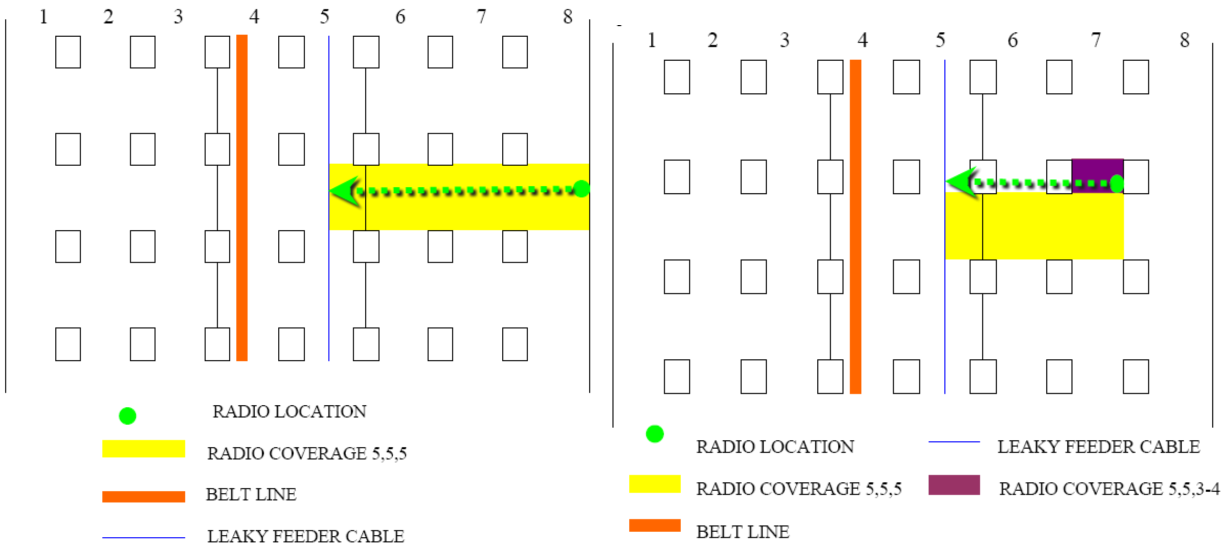

Figure 39 – Imperial Mine Test Sites

Tests conducted at XMV's #35 Mine showed maximum communication distances between a radio and the Leaky Feeder cable of 80' (24.4 m) in a mine with a work area only 32'' (0.81 m) to 44'' (1.1 m) high.

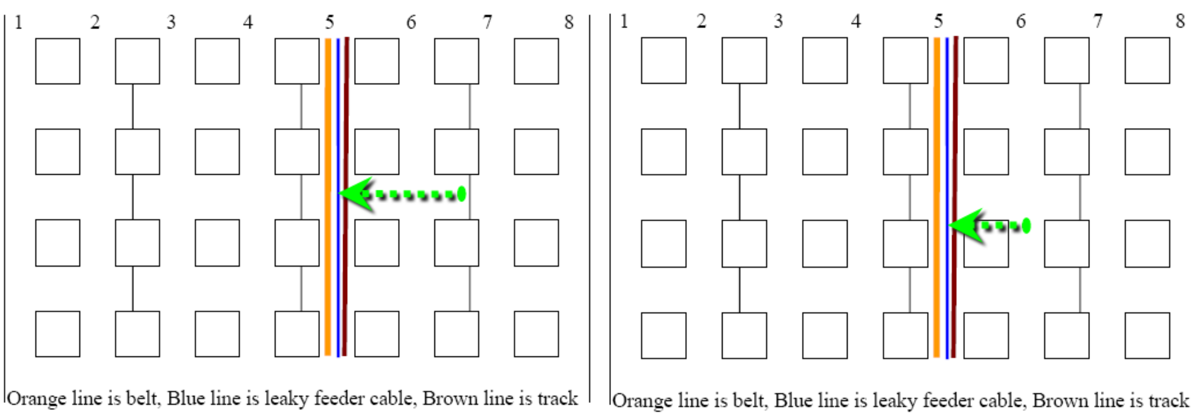

Figure 40 – #35 Test Sites

Other tests conducted at the Horse Creek Eagle Mine showed maximum communication distances between a radio and the Leaky Feeder cable of 140' (42.7 m) around several pillars and even through a concrete block wall in a mine with a work area only 50'' (1.27 m) to 60'' (1.52 m) high.

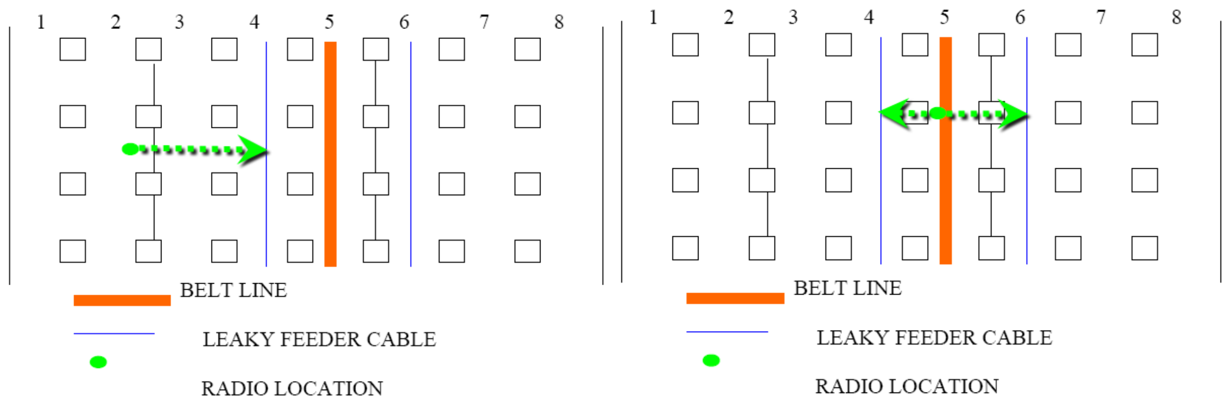

Figure 41 – Horse Creek Eagle Test Sites

Jannatec Radio Technologies (http://jannatec.com) and **NL Technologies** (www.nltinc.com) offer VHF and UHF radios integrated into miner's cap lamps. A description of the lamps is given in the previous section.

Additional Notes

As in the case of VHF systems, there are better-quality Leaky Feeder cables than the ones currently offered by manufacturers of underground communications systems. Attenuation or longitudinal loss is the loss of RF signal over the length of the cable. The greater the attenuation, the closer together the amplifiers will have to be. Coupling loss is the loss between the Leaky Feeder cable and a transceiver located at a given distance from the cable. The lower the coupling loss, the greater the leakage will be around the cable; however, there will be more longitudinal loss. Table 5 compares Leaky Feeders in the UHF range.

As in the **VHF Communications** section, it should be noted that there is no mention of the price, weight or diameter of the Leaky Feeder cables. Most of the cables offered by communications system manufacturers are approximately 5/8'' (15 mm) in diameter and weigh 0.18 lb/foot (0.27 kg/m). Better cables can be up to 1 5/8'' (41 mm) in diameter and weigh as much as 0.87 lb/foot (1.3 kg/m). There is a strong chance that the price of these cables is very high.

Table 5 – UHF Leaky Feeder Cables

Manufacturer	Model	Attenuation (dB/100’)	Coupling Loss (dB)
MineCom	MCA2000 ULFC	1.86 @ 450 MHz	77 @ 450 MHz
Tunnel Radio of America		1.5 @ 500 MHz	65 @ 500 MHz @ 20’
Times Microwave Systems	T-RAD-600	2.22 @ 450 MHz	61 @ 450 MHz @ 6.5’
Times Microwave Systems	T-RAD-900	1.56 @ 450 MHz	62 @ 450 MHz @ 6.5’
AFL Telecommunications	LCX-20D	1.22 @ 450 MHz	65 @ 450 MHz @ 4.92’
Radio Frequency Systems	RLFU158--50JA	0.47 @ 450 MHz	67 @ 450 MHz @ 6.5’
Trilogy AirCell	AR114J50	0.54 @ 450 MHz	61 @ 450 MHz @ 6’
Andrew	RCT6-LTC-1A-AX	0.7 @ 450 MHz	66 @ 450 MHz @ 6.5’
Times Microwave Systems	T-RAD-900	2.27 @ 900 MHz	69 @ 900 MHz @ 6.5’
AFL Telecommunications	LCX-20D	1.77 @ 900 MHz	60 @ 900 MHz @ 4.92’
AFL Telecommunications	WBLCX-20D	1.2 @ 900 MHz	78 @ 900 MHz @ 4.92’
Radio Frequency Systems	RLFU158--50JA	0.77 @ 900 MHz	65 @ 900 MHz @ 6.5’
Trilogy AirCell	AR114J50	0.86 @ 900 MHz	61 @ 900 MHz @ 6’
Andrew	RCT6-LTC-1A-AX	1.31 @ 900 MHz	59 @ 900 MHz @ 6.5’
Siemens	IWLAN RCoax	5.18 @ 2400 MHz	
AFL Telecommunications	WBLCX-20D	2.3 @ 2400 MHz	65 @ 2400 MHz @ 4.92’
Radio Frequency Systems	RLKU158-50JA	1.68 @ 2400 MHz	61 @ 2400 MHz @ 6.5’
Trilogy AirCell	AR114J50	1.56 @ 2400 MHz	61 @ 2400 MHz @ 6’
Andrew	RCT6-S-1-RNT	1.60 @ 2400 MHz	65 @ 2400 MHz @ 6.5’
Siemens	IWLAN RCoax	8.54 @ 5850 MHz	

Summary

Table 6 – Summary – UHF Communications

Company	Description	Advantages	Limitations
Becker Mining Systems	BECKERCOM. Frequencies used not specified. 350 m to 500 m between amplifiers.	Remote diagnostic of amplifiers optional. Good distances between portable radios and Leaky Feeder cable (91 m to 200 m). Up to 64 voice, data and video channels. UHF frequencies perform better than VHF where roof is low.	No cable modem Ethernet (DOCSIS) solution.
MineCom	Frequencies used not specified. 350 m to 500 m between amplifiers.	Remote diagnostic of amplifiers optional. Offers a completely redundant system as an option. Leaky Feeder cable filled with dielectric. 64 voice communication channels. Good distances between portable radios and Leaky Feeder cable (61 m). UHF frequencies perform better than VHF where roof is low.	No cable modem Ethernet (DOCSIS) solution.
Tunnel Radio of America	Ultracomm. Frequencies used between 448 and 470 MHz. 335 m to 488 m between amplifiers. Distance between portable radios and Leaky Feeder cable up to 610 m.	Remote diagnostic of amplifiers optional. Good distances between portable radios and Leaky Feeder cable (67 m). 6 to 32 video channels. UHF frequencies perform better than VHF where roof is low.	No cable modem Ethernet (DOCSIS) solution. Only 4 to 8 voice communication channels.

Distributed Antenna Systems

Description

This type of system comprises a non-radiating coaxial cable used as a transmission medium and distributed antenna where radio communication is required. A distributed antenna system can also incorporate cable modem technology (CMTS & DOCSIS) in order to permit wired Ethernet network connection or through wireless access points (Wi-Fi).

Advantages

- High data rate for voice, data and video.
- Wide range of equipment and parts available at frequencies from 600 MHz to 900 MHz.
- UHF frequencies generally propagate four times better than VHF.
- Easy to install and repair.
- Proven CATV technologies.
- Uses DOCSIS standard for Ethernet network.
- Option to upgrade to DOCSIS 3.0, which would increase capacity to 160 Mbps (to be verified).
- Non-radiating cable can be hidden or protected behind pipes or structures.
- Wi-Fi access points can be added.

Limitations

- Coaxial cable infrastructure has the potential to break.
- Higher purchase cost.

Manufacturers

Cattron-Theimeg/Siamtec (www.siamtec.com) offers the DAS (Distributed Antenna System) communications system. The DAS was designed to operate in the frequency range of 600 MHz to 900 MHz. The non-radiating coaxial cable can be run behind compressed air and water pipes and even fed through drill holes for greater protection. An antenna is installed wherever UHF radio communication is needed. Power sources, connectors and splitters can be purchased from a CATV equipment suppliers.

Siamtec claims that its system offers greater transmission capacity than Leaky Feeder cable and that the type of antenna used permits radio communication distances up to 1 km (3281’). This is certainly, because the fixed antenna is polarized in the same direction as the antennas on the portable radios.

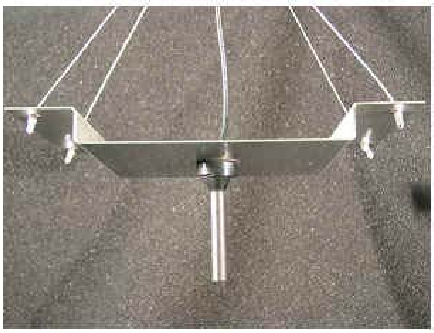

Figure 42 – UHF Antenna from Cattron-Theimeg/Siamtec

Electrical power to the bidirectional amplifiers is supplied through the coaxial cable. Two models of amplifier are available. One covers radio communications only, while the other also covers the frequencies required for DOCSIS 1.1 and 2.0 cable modem technology.

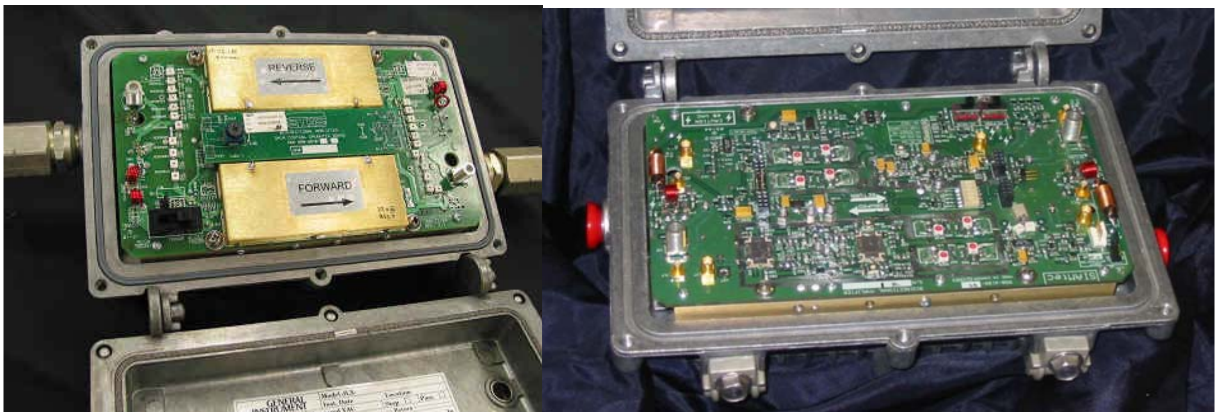

Figure 43 – SDBA and SDBA 2 Amplifier from Cattron-Theimeg/Siamtec

As many as six CMTS 1500 (Cable Modem Termination System) can be installed on the SIAMnet system. The CMTS 1500 transmits information at a maximum rate of 42 Mbps downstream. The maximum upstream data rate of the CM-300A cable modem is 10.24 Mbps per channel. No more than 8 channels are available. With 6 CMTS, a flow of up to 250 Mbps downstream and 150 Mbps upstream can be attained. No information of independent tests is currently available.

Figure 44 – CMTS 1500 and Cable Modem from Cattron-Theimeg/Siamtec

GG Automation (www.ggautomation.com) offers a system that uses a non-radiating coaxial cable to carry the DOCSIS cable modem signal only. The company does not offer a distributed antenna system for voice communication using UHF/VHF radios. The GG Automation system will therefore be discussed in detail in the following Wi-Fi Communications section.

Additional Notes

Recent developments in cable distribution and high-speed cable modem Internet service have resulted in a new standard: DOCSIS 3.0. This technology makes it possible to attain transmission rates of 145 Mbps to 160 Mbps downstream and 120 Mbps upstream by bonding four channels. The equipment also supports DOCSIS 2.0. The same frequencies of 88 to 860 MHz downstream and 5 to 42 MHz upstream are used. This suggests that the existing coaxial cable and amplifiers could support the new standard, DOCSIS 3.0.

Figure 45 – Arris C4 CMTS and Motorola BSR6400 with DOCSIS 3.0

Wi-Fi Communications

Description

This type of communications system uses a network of wireless access points connected to one another by an optical fibre or by an Ethernet cable network. Clients, such as moving equipment and personnel, communicate with the access points through a wireless Wi-Fi network, and the access points route the information onto the network cable or optical fibre. The frequency of access points is normally around 2.4 GHz, and the standards used are usually 802.11 b, 802.11 g and, more recently, 802.11 n, which uses antenna and signal diversity to improve its performance in terms of transfer rate and communication distance.

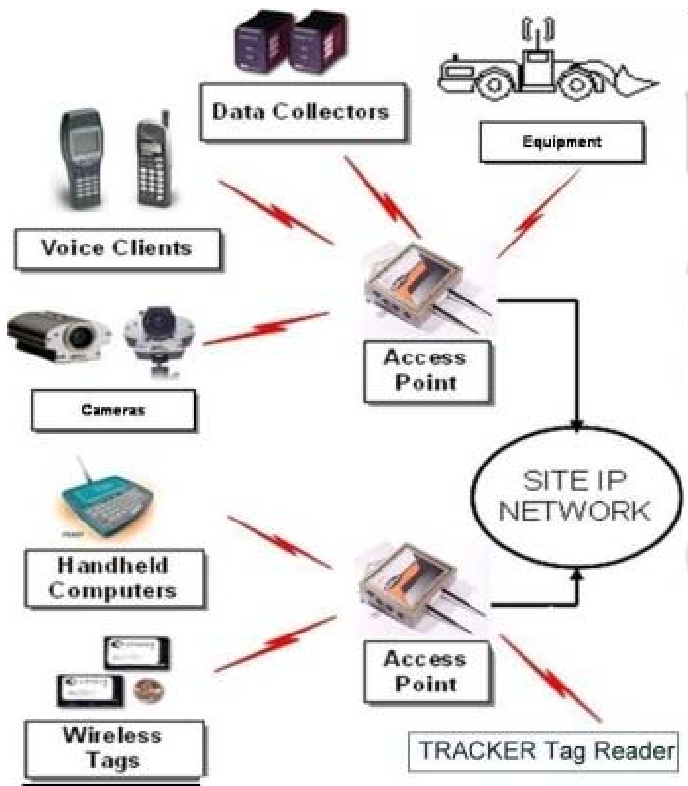

Figure 46 – Wi-Fi Network

Advantages

- High data rate capacity (voice, data, and video).
- Open architecture: many pieces of hardware can hook to the Wi-Fi signal.
- Can be used to track personnel and equipment.
- Locations can be pinpointed with great accuracy depending on the Wi-Fi tag used (Ekahau).
- Some Wi-Fi radio tags are very small and affordable.
- Can carry Voice over Internet Protocol (VoIP).
- Can carry text messaging, Internet access and access to the company's network.
- 2.4 GHz radiating cables seem very promising.

Limitations

- Few commercial VoIP telephones are sturdy enough for an underground mine environment.
- Location resolution is often limited to the distance between two access points.
- The infrastructure requires network and power supply cables that are susceptible of breaking.

Manufacturers

Mine Site Technologies (MST) (www.minesite.com.au) offers the **ImPact** system. The access points are powered and linked by means of a specialized cable that has connectors at both ends and contains electrical wires and optical fibres. The connector seems to be quite difficult to assemble, and the company offers predetermined lengths of cable (50 m, 100 m and 200 m) with connectors at both ends. Each MST access point can have one or two wireless access cards, including a four-port optical fibre switch (10/100/1000 Mbps) and four RJ45 10/100 Mbps (Power Over Ethernet) ports. The access points have radio coverage (Wi-Fi) of approximately 350 m (1148') on each side and can be approximately 600 m (1968') apart on the optical fibre. The wireless access cards can support 802.11 a/b/e/g standards and offer a transfer rate of up to 54 Mbps. Diagnostic can be done through the front of the access point.

Figure 47 – Wi-Fi Access Point and Connector from Mine Site Technologies

The ImPact system offers VoIP using an IP telephone, laptop computer or personal digital assistant (PDA) with Wi-Fi access. The system also offers personnel and equipment tracking using Wi-Fi radio tags. Finally, the system can be used to monitor moving equipment using a system that can be installed on the equipment communication network and thus monitor tonnage or the status of specific vehicles for preventive maintenance purposes.

Figure 48 – VIP (Vehicle Intelligence Platform) System from Mine Site Technologies

Figure 49 – SpectraLink i640 VoIP Telephone

Mine Site Technologies also offers a mesh network solution called the **Breadcrumb System** from **Rajant** (www.rajant.com). The system uses different types of nodes capable of serving as Wi-Fi access points using the 802.11 b protocol at 2.4 GHz. It can be connected to the ImPact system. The Breadcrumb System will be described in detail in the next **Mesh Networks** section.

NL Technologies (www.nltinc.com) offers a Wi-Fi communication system with nodes linked by optical fibre. Wireless access points, Ethernet switches, radio tag readers and even programmable logic controllers are available as options on each NLT node. The system offers VoIP communication and text messaging via Wi-Fi. The system also offers personnel and equipment tracking with Wi-Fi or RFID tags. The wireless access card can support 802.11 b (11 Mbps) and 802.11 g (54 Mbps) standards. NLT offers very little technical information about this product on its Web site.

Figure 50 – Text Messaging in Lamp Battery and VoIP Telephones from NL Technologies

Text messaging and VoIP tests conducted in Peabody Energy’s 20 Mile Coal Mine and Mine #2 in the United States showed communication distances between 2400’ (731 m) and 3000’ (914 m) in front of a very directional (helical) antenna. The communication distance was 350’ (107 m) behind the directional antenna and 250’ (76 m) on the sides. The roof height at the test sites ranged from 6’ (1.83 m) to 8’ (2.44 m). It should be noted that only some test scenarios were carried out. No testing of penetration through coal pillars or concrete block walls was attempted.

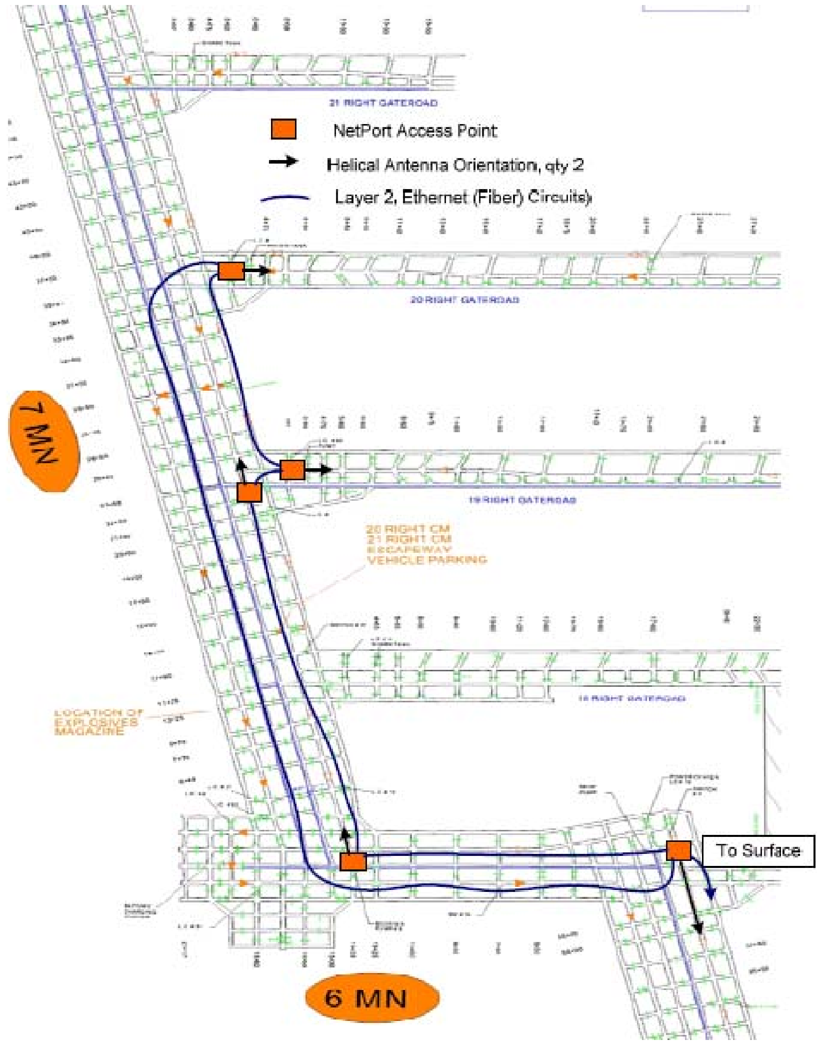

Figure 51 – Test Sites at Peabody Energy's 20 Mile Coal Mine

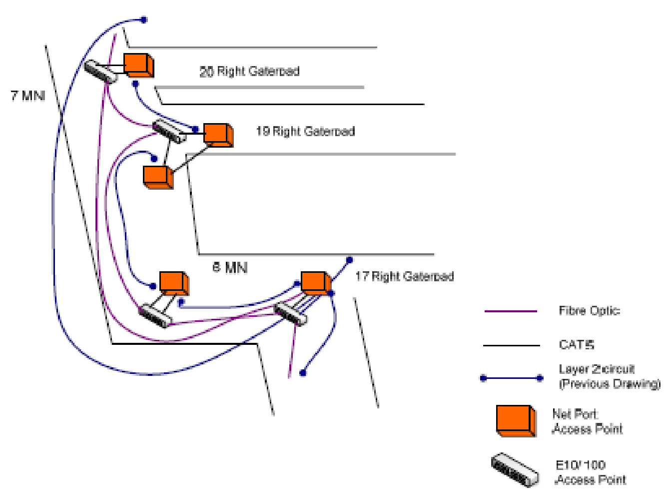

Figure 52 – Configuration of the NLT System at the Test Site

GG Automation (www.ggautomation.com) offers a hybrid coaxial cable and optical fibre system (**HFC Network**). The communications system is based primarily on the use of DOCSIS cable modem technology over a non-radiating cable that can be installed near structures, compressed air and water supply pipes or even fed through drill holes. GG Automation uses standard CATV distribution equipment from Lindsay Broadband Inc. An access point (WAZU) is needed wherever Wi-Fi communication is needed. The access point is also capable of distributing the Ethernet network through the integrated cable modem. Among the solutions offered by GG Automation are Wi-Fi VoIP communication, personnel and equipment tracking using Wi-Fi tags and industrial automation. Little technical information is available on the manufacturer's Web site.

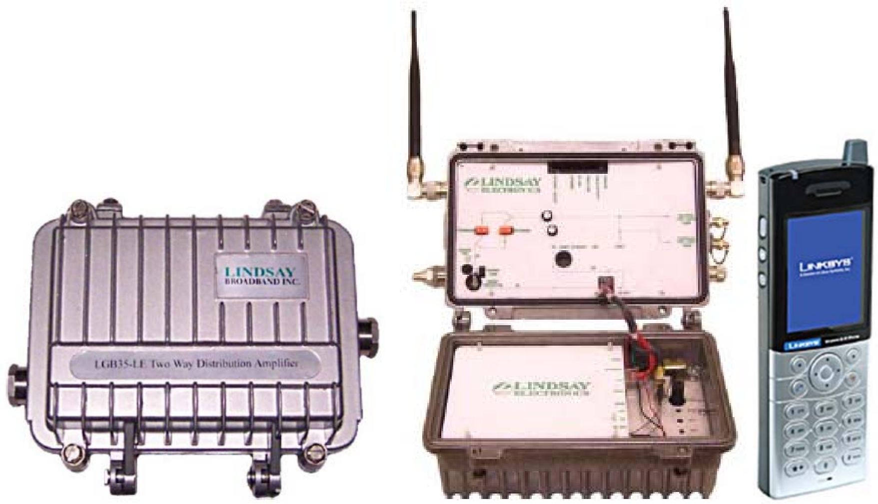

Figure 53 – Amplifier, Wi-Fi Access Point and VoIP Telephone from GG Automation

Hard-Line Solutions (www.hard-line.com) offers an Ethernet/Wi-Fi communication network called **Mine Area Net**. The wired Ethernet part is either optical fibre or RJ45 twisted pair wires. The Wi-Fi part offers a flow rate of 11 to 54 Mbps. Among the solutions offered by HLS are Wi-Fi VoIP, personnel and equipment tracking using Wi-Fi tags, vehicle and equipment remote control, video and vehicle status monitoring (DDEC Interface) and industrial automation. Little technical information is available on the manufacturer's Web site.

Figure 54 – Wi-Fi Access Point and VoIP Telephone from Hard-Line Solutions

Siemens (www.automation.siemens.com) also offers a communication network comprising Wi-Fi industrial access points (**Scalance**) linked by a cable or optical fibre network. The access points can optionally be linked by a wireless network at 5.8 GHz to make them more reliable. Even though the access points are connected by a wireless link, they do not constitute a mesh network.

Siemens is the only company that offers Wi-Fi coverage by antenna and radiating cable at 2.4 GHz and 5.8 GHz. The 5.8 GHz version is used only for very close applications and could not potentially be used in underground communications applications. The cable has a loss of 17 dB/100 m (5.18 dB/100') at 2.4 GHz and 28 dB/100 m (8.54 dB/100') at 5.85 GHz. Compared with VHF and UHF Leaky Feeder cables, the losses are three to six times greater in the Siemens radiating cable because of the frequencies used. It can be concluded that this system will require more closely spaced amplifiers. Siemens apparently does not offer amplifiers for radiating cables; instead, the radiating cable is used in sections of a specific length, each connected to an access point. The radiating cable serves as the antenna for the access point. This makes it possible to cover greater distances with the cable; regularly spaced access points have to be installed and connected by Ethernet cable, optical fibre or wireless link at 5.8 GHz (see Figure 55). Table 7 compares the Siemens cable with other, higher-performance radiating cables. The table does not indicate the larger diameter and greater weight of the cables that perform best or the cost per unit of length, which is bound to be higher.

Table 7 – Radiating Cables at 2.4 GHz and 5.85 GHz

Manufacturer	Model	Attenuation (dB/100')	Coupling Loss (dB)
Siemens	IWLAN RCoax	5.18 @ 2400 MHz	
AFL Telecommunications	WBLCX-20D	2.3 @ 2400 MHz	65 @ 2400 MHz @ 4.92'
Radio Frequency Systems	RLKU158-50JA	1.68 @ 2400 MHz	61 @ 2400 MHz @ 6.5'
Trilogy AirCell	AR114J50	1.56 @ 2400 MHz	61 @ 2400 MHz @ 6'
Andrew	RCT6-S-1-RNT	1.60 @ 2400 MHz	65 @ 2400 MHz @ 6.5'
Siemens	IWLAN RCoax	8.54 @ 5850 MHz	

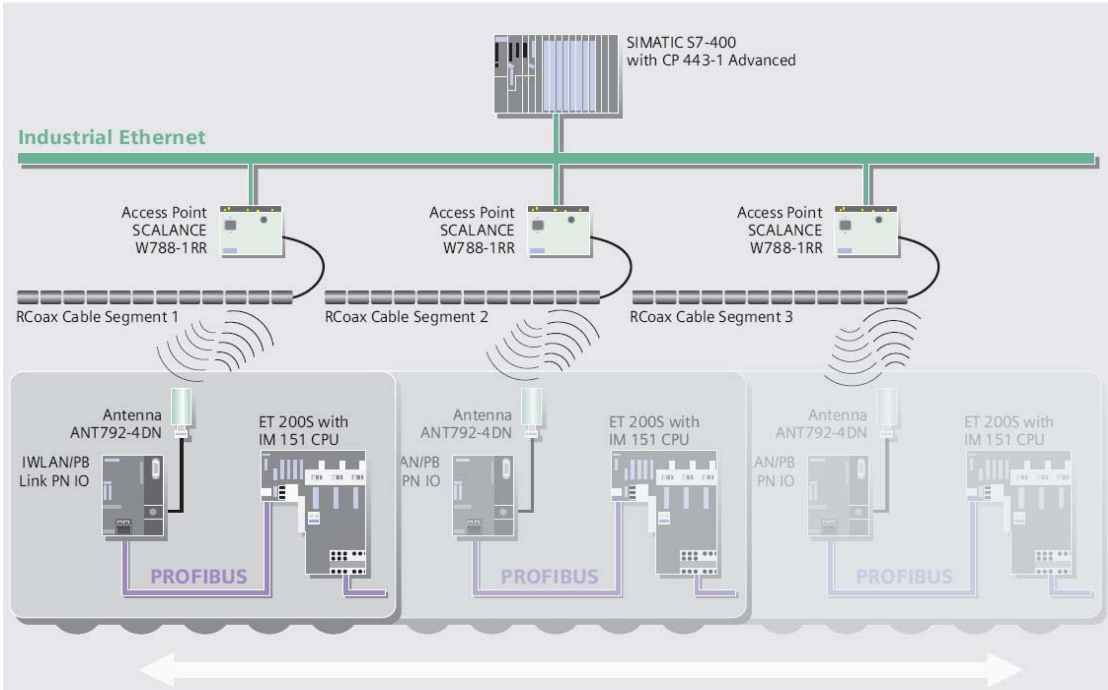

Figure 55 – Typical Radiating Cable Configuration offered by Siemens

The Siemens' radiating cable does not emit its signal 360° around itself, but within a range of 90° to 120°. It therefore has to be meticulously installed so that it emits and receives radio signals in the direction of the tunnel or mining site where they are needed. It has to be held in place by a specially designed bracket. Special attention is needed to ensure that the cable does not move when underground blasting is being done.

Figure 56 – Radiating Cable and Bracket from Siemens

Siemens offers several models of wireless access points. Model W786 is the one recommended for high-demand industrial applications. It can function from -40°C to +70°C and has an IP65 protection rating. It is available with integrated antennas or up to six SMA connectors for external antennas. It can be connected by an RJ45 cable network at 10/100 Mbps or by optical fibre. It can be powered through the Ethernet network (PoE) and an external source simultaneously. However, it cannot be used as a single

Wi-Fi access point. It absolutely must be operated through a Siemens network controller called HiPath Controller. HiPath manages all access points as well as the quality of service (QoS) of the wireless network. The transfer rate with wireless links is from 1 to 54 Mbps.

Figure 57 – Wi-Fi W786 Industrial Access Point and HiPath Controller from Siemens

Model W788 is the one recommended for mid-demand industrial applications. It can function from -20°C to +60°C and has an IP65 protection rating. It is available with two or four SMA connectors for external antennas depending on whether it has one or two internal radios. It can be connected by RJ45 cable network at 10/100 Mbps. It can be powered through the Ethernet network (PoE) and an external source simultaneously. It can be used as an access point without the HiPath Controller. The transfer rate with wireless links is from 1 to 54 Mbps.

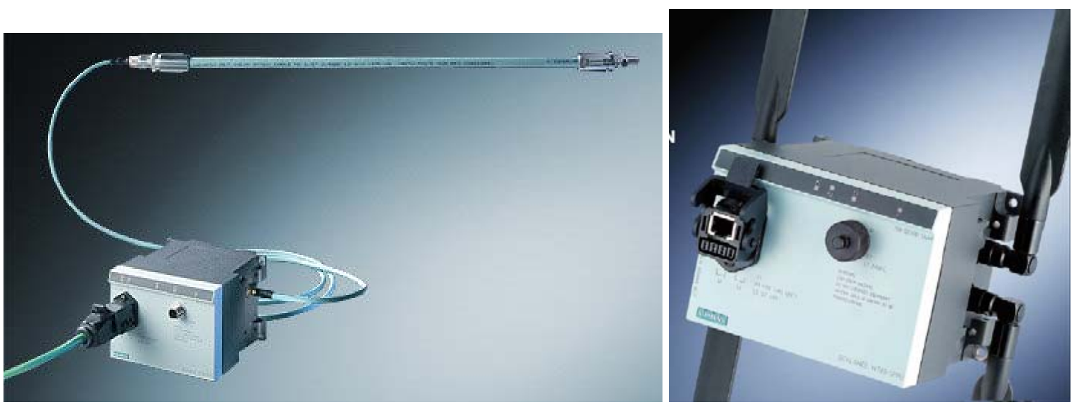

Figure 58 – Wi-Fi W788 Industrial Access Point from Siemens

Siemens offers VoIP solutions over wired and wireless networks. A great deal of technical information is available on Siemens' Web site.

Figure 59 – Wi-Fi VoIP Telephones from Siemens

Active Control Technology (www.activecontrol.com) offers a mesh network called **ActiveMine** based on **MeshDynamics** (www.meshdynamics.com) technology. The nodes can communicate with one another at 2.4 GHz or 5.8 GHz; the choice is up to the user. The system offers Wi-Fi communication technology for client applications but will be described in detail in the **Mesh Networks** section.

iPackets International (www.ipackets.com) offers a mesh network communications system called **iPMine**. The network nodes (iPMine-ZAP) are connected to one another by a Wi-Fi network at 2.4 GHz, although connection using RJ45 twisted-pair wires is available as an option. Because it is primarily a mesh network, it will be described in detail in the **Mesh Networks** section.

Subterracom Wireless Solutions (www.subterracom.com) offers a mesh network communications system called **SubterraMine**. The system offers Wi-Fi communication, but because it is primarily a mesh network, it will be described in detail in the **Mesh Networks** section.

Hannah Engineering (http://hannahengineering.com) offers a mesh network from **Proxim Wireless** (www.proxim.com). The system comprises Wi-Fi access points (**ORiNOCO AP-4000M**) arranged in a mesh network. Once again, because the system is primarily a mesh network, it will be described in detail in the next section.

Summary

Table 8 – Summary – Wi-Fi Communications

Company	Description	Advantages	Limitations
GG Automation Inc	HFC Network. Coaxial cable and optical fibre system to distribute communication. Access points installed where W-Fi communication is needed.	Proven CATV technologies and equipment (Lindsay Broadband). Open standard for access points and cable modem. Non-radiating coaxial cable easy to install and repair and capable of being hidden behind pipes or structures.	Only a few mines are equipped with this system.
Hard-Line Solutions	Mine Area Net. Optical fibre and wired Ethernet network. Access points installed where Wi-Fi communication is needed. HLS offers wireless VoIP, video, personnel and equipment tracking and remote vehicle diagnostic.	Transfer rate between 11 and 54 Mbps	Optical fibre difficult to install and repair.
Mine Site Technologies	ImPact. Wi-Fi network and optical fibre communication system. Access points can have one or two wireless access cards, includes a four-port optical fibre switch (10/100/1000 Mbps) and four RJ45 ports 10/100 Mbps Power Over Ethernet. Supports standards 802.11 a/b/e/g.	10/100/1000 Mbps port. Diagnostic of access points can be done from the front panel. Data rate of 54 Mbps. Access points have radio coverage (Wi-Fi) of approximately 350 m on each side and can be spaced approximately 600 m on optical fibre. Extension of Wi-Fi network via Breadcrumb mesh network	Optical fibre and connectors difficult to install and repair. Predetermined lengths of cable with connectors at both ends have to be purchased.
NL Technologies	Wi-Fi network, optical fibre and CAT-5 cable communication system. Each NLT node can have a wireless access point, an Ethernet switch, a radio tag reader and a programmable logic controller. Supports standards 802.11 b/g.	Loop can be made with optical fibre for redundancy. Data rate of 54 Mbps. Communication distances up to 914 m in front of directional antenna. Distance of 107 m behind antenna and 76 m on sides.	Optical fibre difficult to install and repair.
Siemens	Scalance. Access points connected by optical fibre, CAT-5 cable or wireless network at 5.8 GHz.	Wi-Fi coverage via radiating cable at 2.4 GHz very promising. Option of linking access points by cable or fibre and/or wireless for greater sturdiness. Data rate of 1 to 54 Mbps. Very sturdy access points.	Cable emits signal in range of 90 to 120 degrees only and has to be installed in such a way that it covers the tunnel and does not move. Many access points needed because there is no amplifier.

Mesh Networks

Description

A mesh network is a wired or wireless network in which each host is connected to the hosts adjacent to it but which has no central hierarchy; the resulting structure resembles a net. This eliminates sensitive spots which, in the event of a network failure, sever the connection in part of the network. If one host is out of service, its neighbours will take a different route. For that reason, a mesh network is very reliable.

Mesh networks are characterized by fast, simple deployment, a great deal of flexibility in terms of coverage and, because of their structure, a high tolerance for failures and interference, which significantly reduces the cost of installation and operation. Mesh network solutions reproduce the architecture of the Internet and optimize it for wireless. Most mesh networks offer an access point at 2.4 GHz and nodes communicate with each other at 5.8 GHz or 2.4 GHz. Some mesh networks use frequencies in the 900 MHz range for node-to-node communication.

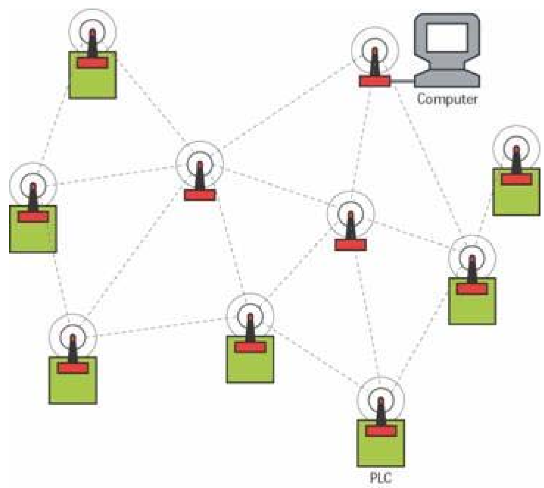

Figure 60 – Mesh Network

Advantages

- Propagation over fairly good distances.
- Location function available as an option.
- High data transmission capacity.
- Apparently immune to interference.
- Some nodes can run on batteries.

Limitations

- Location function accurate to closest node.
- Location function using strength of RF signal very inaccurate.
- Network dependent on radio link that can be interrupted.
- If the nodes use the same frequency for Tx and Rx, the bandwidth of a linear mesh network will be divided by 2^n, where n is the number of nodes.
- If the nodes use the same frequency for Tx and Rx, the latency can be quite large depending on the number of nodes.

Mine Site Technologies offers a mesh network solution, the **Breadcrumb System** from **Rajant** (www.rajant.com), that uses different types of nodes capable of serving as Wi-Fi access points using 802.11 b protocol at 2.4 GHz. Information is sent from one node to another on the same frequency as the access point. In this configuration, the maximum transfer rate is 11 Mbps. Some nodes are equipped with two radio systems at 2.4 GHz (2.402 GHz to 2.472 GHz) and some can be battery powered.

BreadCrumb LX is a node with one 802.11b access point at 2.4 GHz (2.402 GHz to 2.472 GHz) and a link to the other 802.11a nodes at 5 GHz (5.20 GHz to 5.825 GHz). In that configuration, the transfer rate can be as high as 54 Mbps.

Figure 61 – BreadCrumb SE, LX and ME from Rajant and VoIP Telephone from Zyxel

Tests conducted at the Mountain View Mine operated by Mettiki Coal (Alliance Resource Partners) in West Virginia showed voice communication distances of up to 160’ (48.8 m) from the closest node. Voice communication and Wi-Fi location detection distances of 750’ (229 m) were attained by going through several nodes. The average roof height in the test area was 8.5’ (2.6 m).

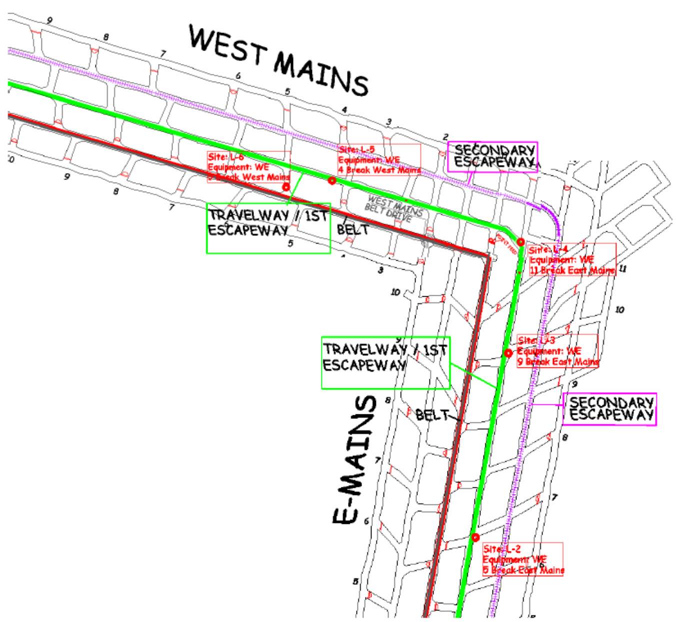

Figure 62 – One of the Test Sites at the Mountain View Mine

Newtrax Technologies (www.newtraxtech.com) is one of the only manufacturers to offer a truly wireless mesh network solution because it uses nodes (Infrastructure Device) capable of running for two years on two D batteries and using frequencies of 902 to 928 MHz that are well suited for an underground mine environment. Each node is able to communicate over distances of 100 m (328') to 400 m (1312'). Depending on the number of nodes the signal has to pass through, the transmission rate will be between 1 kbps to 38.4 kbps with a latency of 0.5 to 2 seconds per hop from node to node. It quickly becomes clear that this system cannot carry voice communications or video signals. The system allows a node to send information to another node in the mesh network without going through the gateway. That makes the network more efficient and prevents gateway bottlenecks. Newtrax offers nodes that can be installed on vehicles or carried by personnel for tracking and location purposes and nodes for controlling equipment. The system is able to interface with all existing communications systems.

Figure 63 – SCADA RTU, Node and Gateway from Newtrax

MeshDynamics (www.meshdynamics.com) offers a number of mesh network solutions (**MD4000**) for the commercial and industrial sectors. The nodes are able to communicate with one another at 2.4 GHz or 5.8 GHz, depending on what the user chooses. Four wireless access cards can be installed in each wireless node. As a rule, two cards are used for backhaul at 5.8 GHz and two cards provide wireless access at 2.4 GHz. MeshDynamics appears to have done extensive research and development in order to optimize the performance of its mesh network. The transfer rate is 22 Mbps and the latency is 1 to 2 ms per node through a maximum of 18 wireless nodes. Each node has two Ethernet ports for the user that provide a power supply on the RJ45 cable (PoE). A serial port can even be included on one of the wireless access cards.

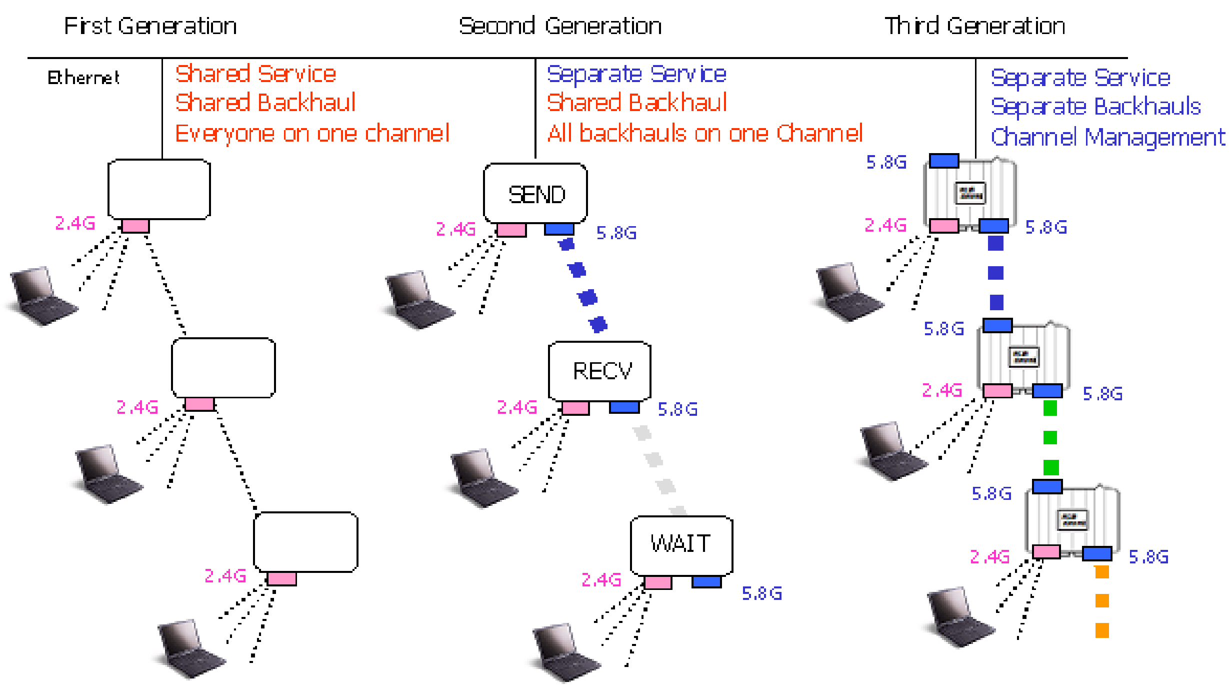

Figure 64 – Difference between Generations of Mesh Networks from MeshDynamics

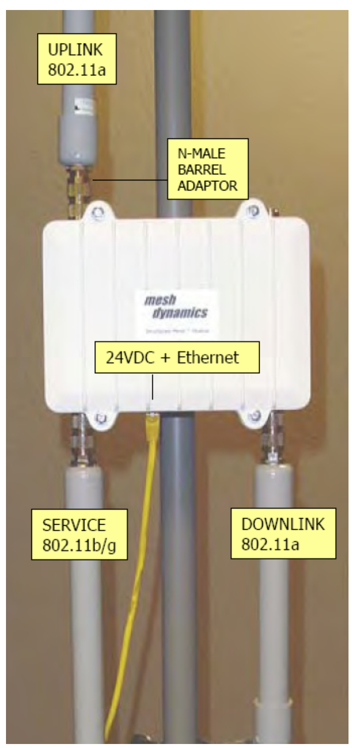

Figure 65 – Mesh Node from MeshDynamics

Video transmission tests were conducted in an unidentified longwall coal mine, and the MD4000 system was able to transmit a high-quality signal at 15 frames/s from a video camera and even control the three camera axes (PTZ). The latency generated by each of the 14 nodes used was between 1 and 2 ms. The average data rate over the network was 18 Mbps.

Other voice and video transmission and personnel location tests were conducted in a room-and-pillar mine. The MD4000 system was deployed over a distance of approximately 3 miles (4828 m) with 14 wireless nodes powered by an uninterruptible power supply. This resulted in an average distance of 345 m (1132') between nodes. Wireless VoIP telephones and a PBX telephone system were used. The quality of the voice communication was excellent all the way to the end of the wireless mesh network.

The designated integrator for this technology for mining applications is **Active Control Technology** (www.activecontrol.com).

Active Control Technology (www.activecontrol.com) offers a mesh network called **ActiveMine** that is based on **MeshDynamics** (www.meshdynamics.com) technology. The nodes are able to communicate with one another at 2.4 GHz or 5.8 GHz, depending on what the user chooses. Four wireless access cards can be installed in each wireless node. As a rule, two cards are used for backhaul at 5.8 GHz and two cards provide wireless access at 2.4 GHz for client applications. The 5.8 GHz connection is able to provide a transfer rate of up to 54 Mbps with latency of 1 to 3 ms per node. The nodes can function for four days on back-up power.

Active Control Technology appears to have done extensive research in order to select the best antennas for the application. A combination of Omni directional and directional antennas (patch and sector) is used to cover a level or worksite. In addition, the company uses various software (Site Survey and Network Management System) to plan and check deployment of the mesh network. The software makes it possible to verify signal strength, the number of nodes seen by each node and the current data transfer rate at each location.

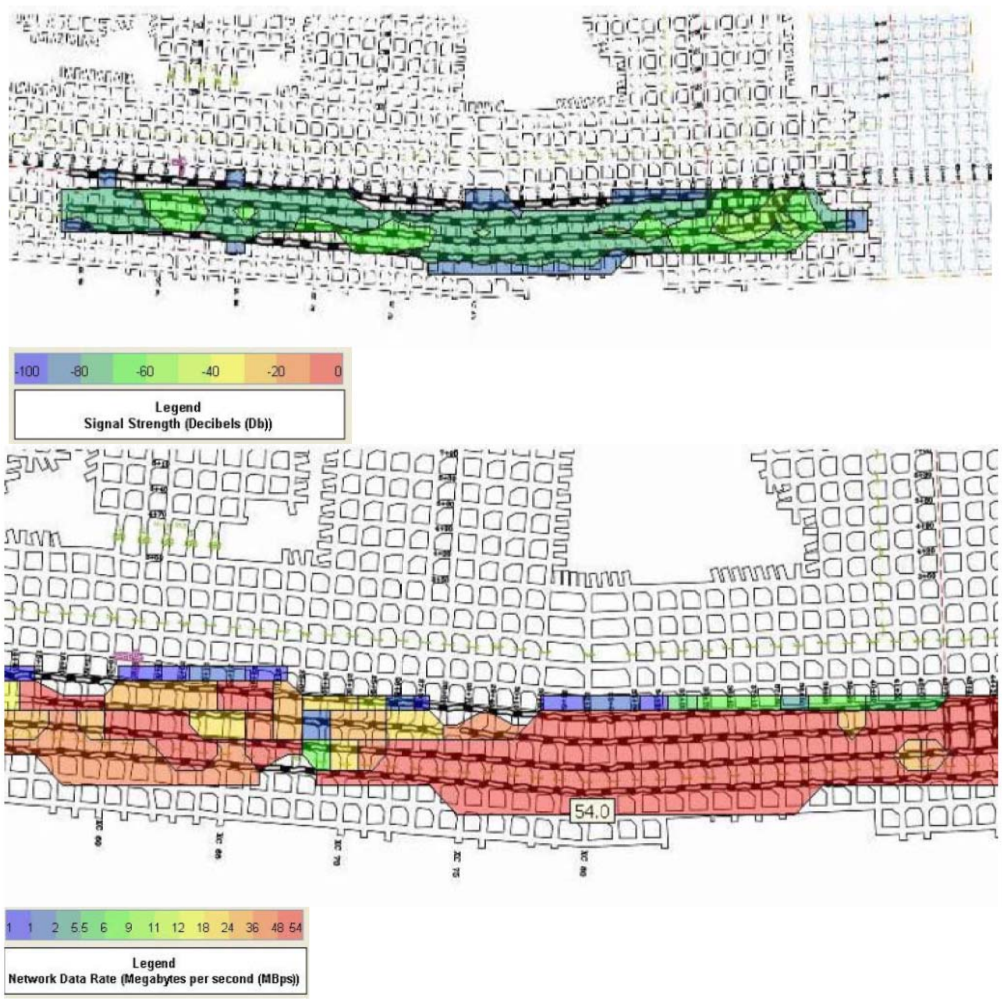

Figure 66 – Verification of Network Deployment using Site Survey

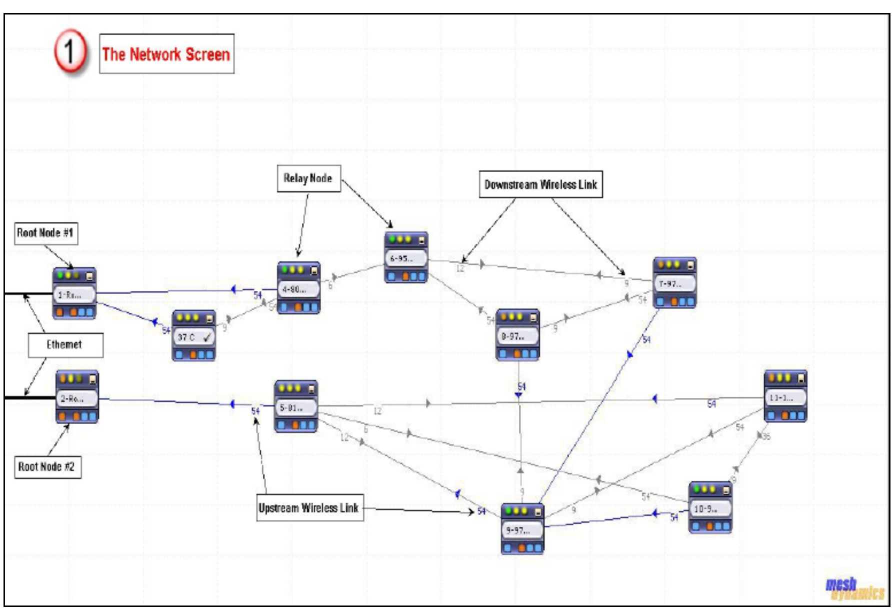

Figure 67 – Mesh Network Management using Network Management System

The system offers wireless VoIP and real-time tracking accurate to within tens of feet using Ekahau tags. The system nevertheless uses optical fibre and cable. The system is set up in such a way that nodes cut off from the rest of the mesh network can ensure radio communication in the cut-off area without a headend. Personnel tracking cannot operate in that mode, which is called Starfish. Very little information is available on Active Control Technology's Web site.

Figure 68 – Mesh Network Node from MeshDynamics

Tests were conducted at International Coal Group's Viper Mine in Illinois in May 2007. A Wi-Fi VoIP telephone (Spectralink i-640) was able to communicate up to 1190' (363 m) from a line-of-sight node with very good quality of communication. The communication distance dropped to between 70' (21.3 m) and 140' (42.7 m) when the telephone entered the crosscuts. Using part of the 11-node mesh network, it was possible to establish communication over the entire work area – 4200' (1280 m) – with minimum latency. Ekahau tags allowed location up to 1750' (533 m) from a wireless node. The average roof height was 6' (1.83 m).

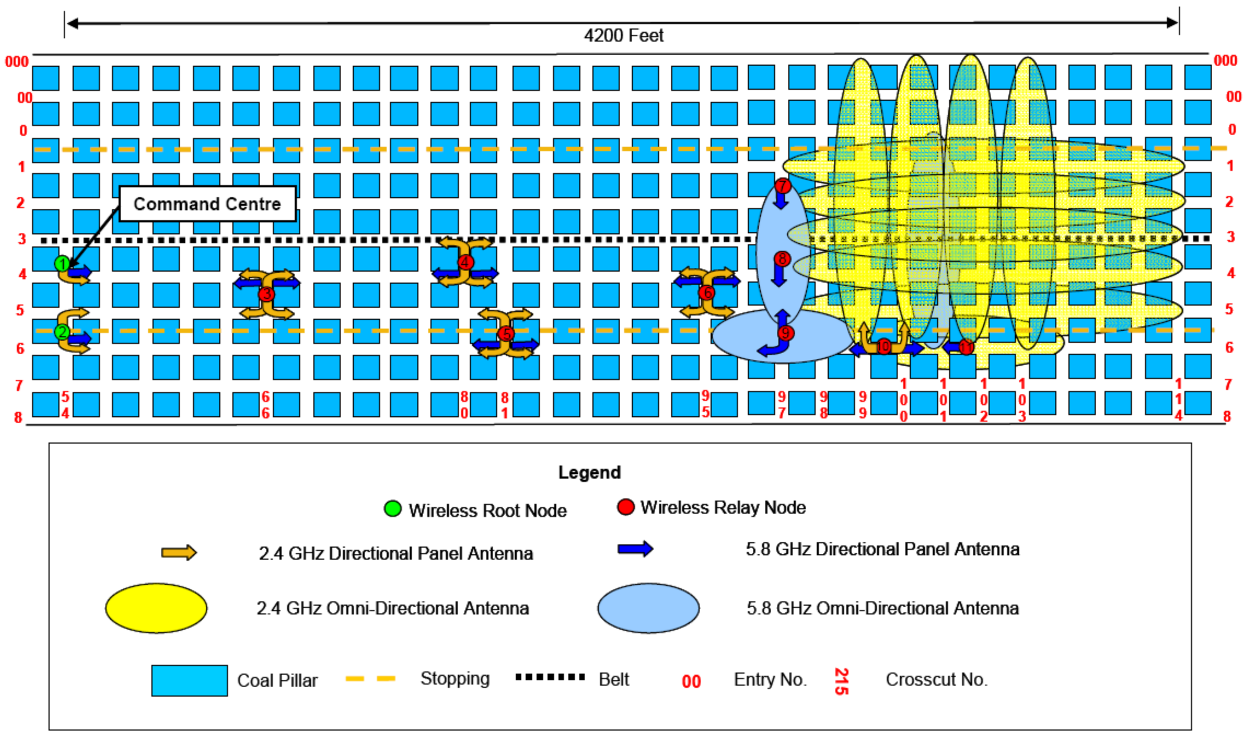

Figure 69 – Test Site at the Viper Mine

iPackets International (www.ipackets.com) offers a mesh network communications system called **iPMine**. The system does not permit voice communication or video transmission, only text messaging. The network nodes (iPMine-ZAP) are connected to one another by a Wi-Fi network at 2.4 GHz, but connection using RJ45 twisted-pair wires is available as an option. They do not have an independent network at 5.8 GHz like some competitors. The surface communication distance can range from 450 m (1476’) at 11 Mbps to 1200 m (3937’) at 1 Mbps. The system can reach 54 Mbps. No information about the underground communication distance is available. A network node can have up to four Wi-Fi access cards (802.11 b). The system is used primarily for text messaging and personnel location. Mine workers wearing a Wi-Fi radio tag (iPMine-M8) are able to receive text messages on the LCD screen of the iPMine-M8 and send SOS messages using the buttons on the tag.

Figure 70 – iPMine-ZAP Node and iPMIne-M8 from iPackets International

Subterracom Wireless Solutions (www.subterracom.com) offers a system similar to the one offered by iPackets International, namely a mesh network communications system called **SubterraMine**. However, the Subterracom system permits wireless VoIP voice communication and video transmission, although there is no information about those features on the manufacturer's Web site. The network nodes (Subterra-ZAP) are connected to one another by a wireless 5.8 GHz network, but connection using RJ45 twisted-pair wires is available as an option. The system can reach 54 Mbps. No information about the underground communication distance is available. A network node can have two, four or six Wi-Fi access cards (802.11 a/b/g). The system is used primarily for text messaging and personnel location, according to the Web site. Mine workers wearing a Wi-Fi radio tag (Subterra-M8) are able to receive text messages on the LCD screen of the Subterra-M8 and send SOS messages using the buttons on the tag.

Figure 71 – Subterra-ZAP Node and Subterra-M8 from Subterracom Wireless Solutions

Tests conducted at Campbells Creek #7 Mine in West Virginia, which is operated by Magnum Coal (Patriot Coal), showed that text messages could be sent up to 1900' (579 m) to a Subterra M8 and voice communication up to 800' (244 m) between two VoIP telephones, but no mention is made of the number of nodes used. It can be deduced by measuring the test site plan that almost all of the mesh network nodes were used. According to other tests, the maximum distance between a Subterra M8 and a node at 2.4 GHz appears to be 350' (107 m) without line of sight. It can be deduced from scale measurement of the test site plan that nodes are able to communicate with one another at 5.8 GHz at a maximum distance of approximately 900' (274 m).

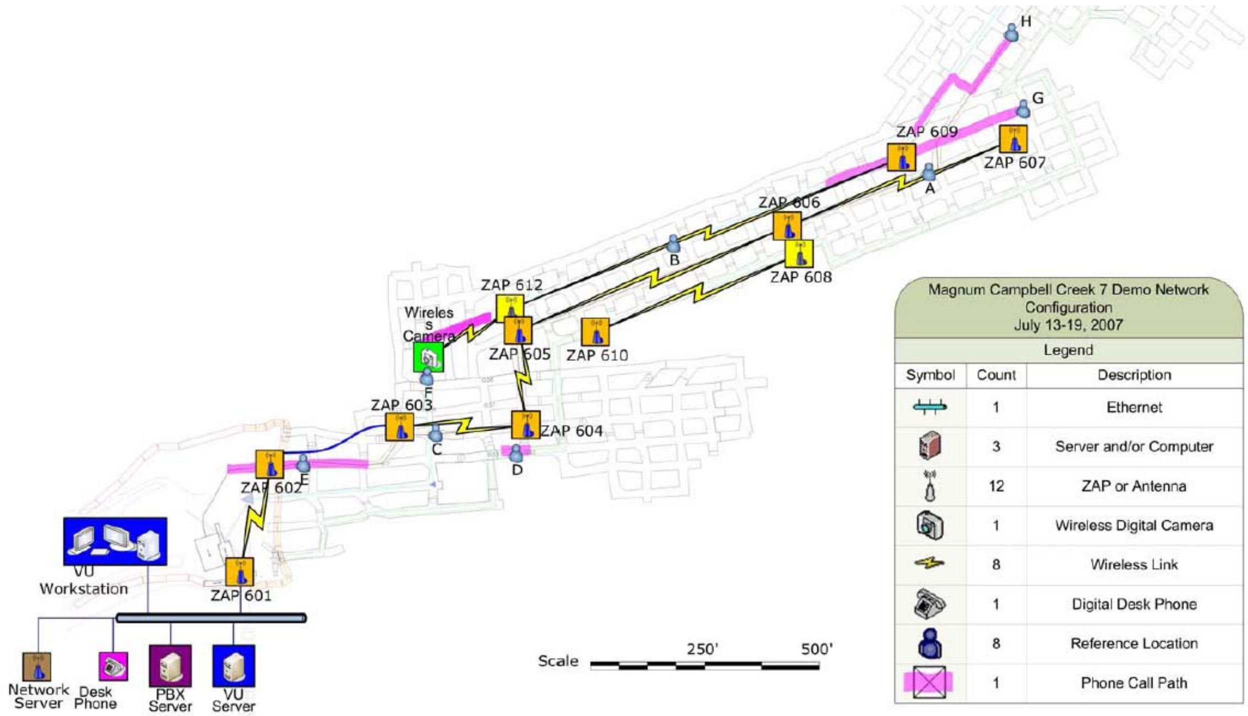

Figure 72 – Test Site at Campbells Creek #7 Mine

Hannah Engineering (http://hannahengineering.com) tested a mesh network from **Proxim Wireless** (www.proxim.com) in May 2007 at the Roblee Coal Company's Tallmans Run #1 Mine. The system comprises meshed wireless **ORiNOCO AP-4000M** access points integrated into the underground communications system **WITS** (Wireless Integrated Technology System) from Hannah Engineering. No information about the system is available on Hannah Engineering's Web site. The nodes or access points have two wireless communication systems. One is used to communicate with another node in order to establish the mesh network at frequencies between 5.15 GHz and 5.85 GHz, and the other is used as an access point for Wi-Fi clients at 2.4 GHz. The system supports 802.11 a/b/g protocols and has a data transfer capacity up to 30 Mbps.

Figure 73 – ORiNOCO AP-4000M Wireless Access Point from Proxim Wireless

In tests conducted at Roblee Coal's Tallmans Run #1 Mine in West Virginia, clear communication was established between a VoIP telephone and a wireless access point (at 2.4 GHz) over a distance of 900' (274 m). The average roof height was 60'' (1.52 m).

Figure 74 – Wi-Fi VoIP Telephone Communication over 900' at the Tallmans Run #1 Mine Test Site

It was also possible to establish a connection at 5.8 GHz between two wireless access points over a distance of 1680' (512 m). Clear communication could be established between a VoIP telephone at 2.4 GHz and one of the wireless access points using the connection at 5.8 GHz. The average roof height was 60'' (1.52 m).

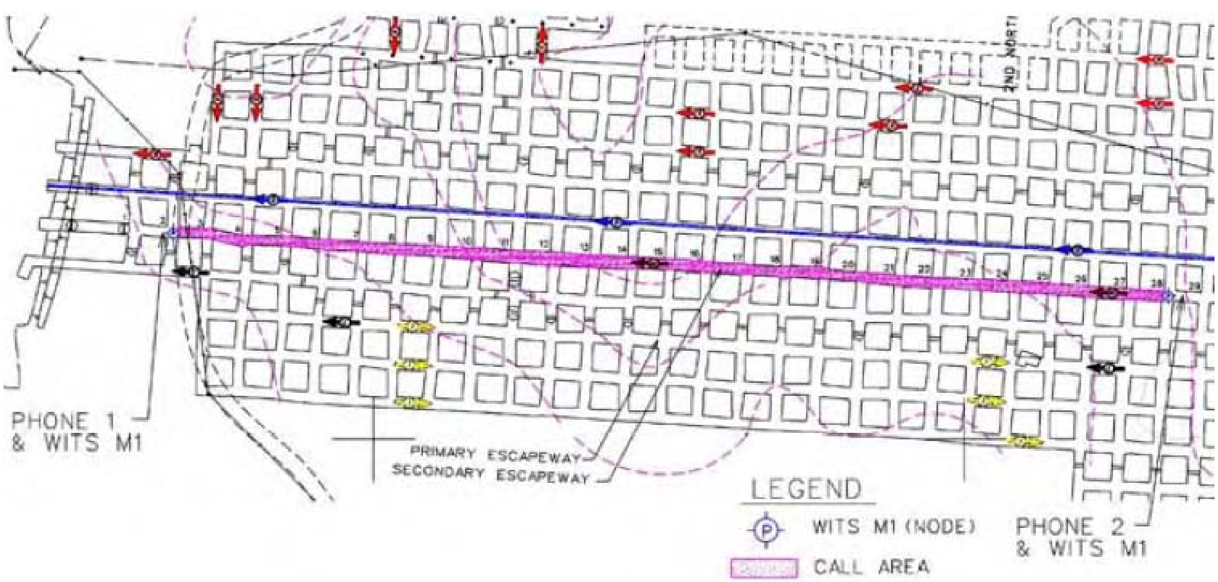

Figure 75 – 5.8 GHz Connections over 1680' at the Tallmans Run #1 Mine Test Site

Venture Design Services (http://ventureminetracer.com) offers the **MineTracer**, a system that uses wireless access points arranged in a mesh network and low-power (10 mW) ZigBee 802.15.4 technology at 2.4 GHz manufactured by Helicomm (www.helicomm.com). The wireless access points are powered through an electrical cable, but their low power requirement allows them to run on batteries for 48 to 96 hours in the event of a power failure.

The wireless access points have an external indicator lamp that changes colour depending on the status of the location system. A green light means that the system is in normal operating mode. A flashing yellow light means that someone has sent an SOS. Once officials at the surface start the response process, the yellow light stops flashing but remains on. The red light is used only for emergency evacuation of the mine.

A maximum of three subnetworks, each with 25 wireless access points, can be connected to a subnet controller. The subnet controller sends information to the surface through an RS-485 serial link over a twisted-pair wire. A subnetwork cannot cover more than 5280’ (1609 m) with a maximum of 25 wireless access points. This means that no wireless access point can be more than 211’ (64 m) from another access point, which is a very short distance. The manufacturer actually recommends that there be an access point every 150’ (45.7 m). The system therefore seems to need a large number of access points and several subnet controllers to ensure a strong mesh network. In a linear configuration, the loss of one access point cuts the rest of the wireless network off from the subnet controller and therefore the surface. In addition, a serial communication cable is required for each subnet controller. This cable could be exposed to breaking.

This mesh network is fairly slow (12 kbps), and Venture Design Services guarantees data refresh every 20 to 30 seconds. The network is essentially used for text messaging from the surface to mobile communication devices. Personnel can confirm receipt of messages and call for help using a button on the mobile device. The company points out that the system is able to carry wireless voice communications, but only between two nodes (150’ or 45.7 m), which is not very practical. The manufacturer offers a personnel tracking system that will be described in the **Equipment and Employee Tracking Systems** section.

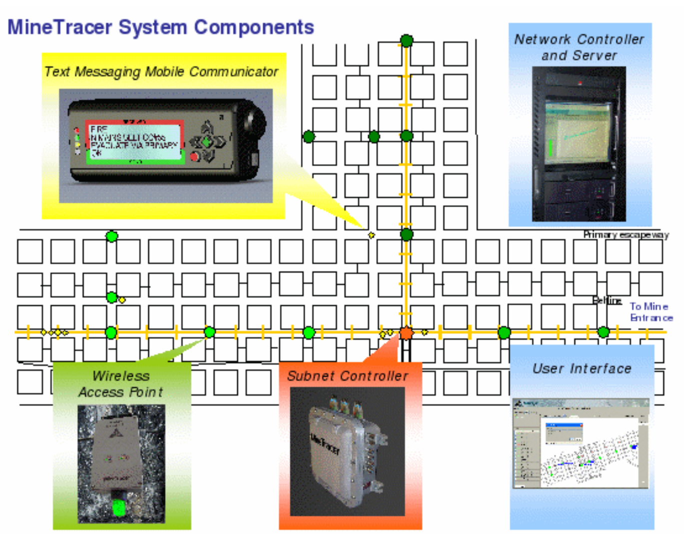

Figure 76 – Configuration of the MineTracer Wireless Network

Figure 77 – MineTracer Subnet Controller and Wireless Nodes

Tests conducted at the Skyline Coal Mine in Utah, the Mountain Laurel Coal Mine in West Virginia and the Big Branch coal Mine in West Virginia in the United States showed line-of-sight radio tag detection distances of approximately 300’ (91 m) to 700’ (213 m). Those values are two thirds smaller where there was no line of sight. MSHA recommends a maximum of 270’ (82 m) between a wireless access point and a radio tag and 370’ (112.8 m) between two access points if the system is to be reliable. One test even showed almost no reading of a tag worn by the driver of a vehicle moving at a speed of 19 km/h between 0’ and 70’ (21.3 m) away from an access point. Measurement of the scale plan of the test site shows that the nodes were installed approximately 300’ (91 m) apart. The average roof height was 96’’ (2.44 m).

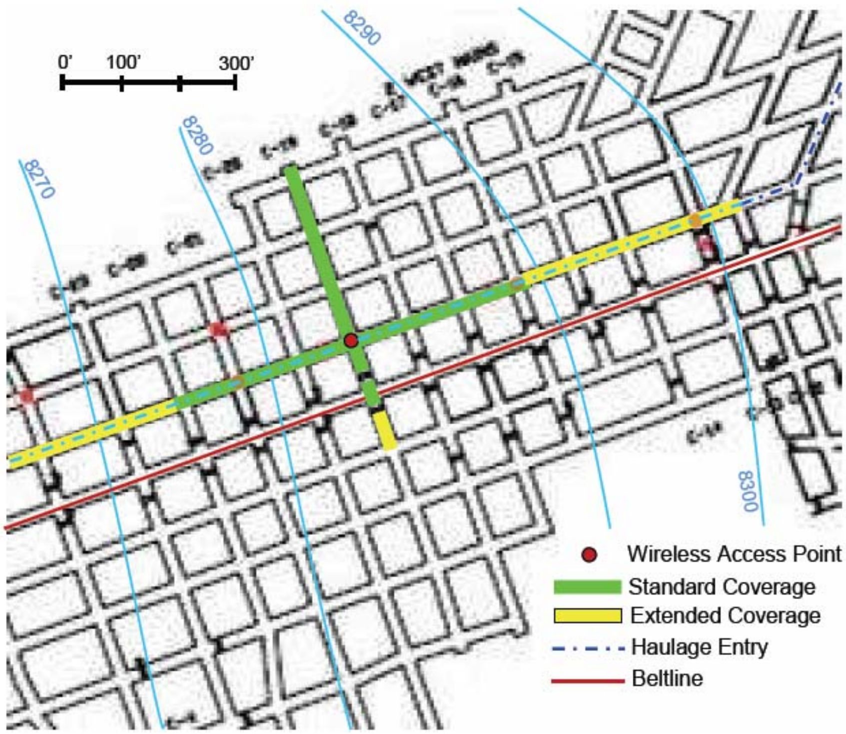

Figure 78 – Test Site at the Skyline Mine

L3-Communications (www.l-3com.com) offers a mesh network communications system called **ACCOLADE** that uses the mesh network technology developed by **Innovative Wireless Technologies** (www.iwtwireless.com). Very little information about the product is currently available on the manufacturer's Web site. The nodes communicate with one another through radio links and a gateway that directs communications to the mine's existing communications network. A location system is also being developed and will be described in the **Equipment and Employee Tracking Systems** section.

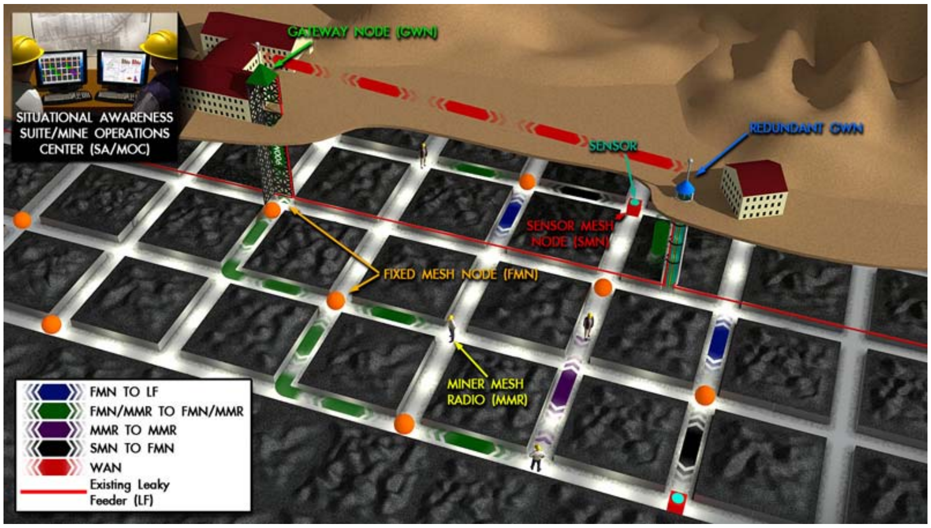

Figure 79 – Configuration of the ACCOLADE Wireless Network from L3-Communications

Figure 80 – Wireless Node and VoIP Telephone from L3-Communications

Summary

Table 9 – Summary – Meshed Networks

Company	Description	Advantages	Limitations
Active Control Technology Inc	ActiveMine. Wi-Fi and mesh communications network based on MESHDYNAMICS technology. Mesh network nodes can communicate at 2.4 GHz or 5.8 GHz and have up to 4 wireless access cards. Nodes have 2 RJ45 PoE Ethernet ports.	Different radio frequencies for Tx and Rx gives a transfer rate of 22 Mbps with latency of 1 to 2 ms per node through 18 nodes. 4 different radio frequencies per box possible. Nodes can run on back-up power for 4 days. Voice communication remains functional if network is cut off. Communication distance between a node and a Wi-Fi phone is 363 m.	Uses optical fibre and Power Over Ethernet. More nodes there are, slower the network may be depending on confirmation. Communication distance drops rapidly with no line of sight.
Hannah Engineering & Proxim Wireless	WITS. Mesh network with nodes operating with 2 radios. Network at 5.8 GHz and access point at 2.4 GHz . 802.11a/b/g protocols supported.	Transfer rate up to 30 Mbps. Network is at 5.8 GHz and access point are at 2.4 GHz. Wireless VoIP voice communication. 512 m between two nodes. 274 m between VoIP phone and node.	No information on Hannah Engineering's Web site.
iPackets International	iPMine. Personnel tracking system through Wi-Fi mesh network. Text messaging. Node can have up to 4 802.11 b wireless access cards.	Bidirectional communication. iPMine-M8 has message confirmation and SOS functions.	iPMine-M8 is somewhat bulky to carry. No voice communication. No video. Mesh network and access points on same frequency. No link at 5.8 GHz.
L-3 Communication	ACCOLADE. Advanced Configurable Communications and Location Awareness Design. Location system integrated into system. Can be connected to Leaky Feeder communication system.	L3 Communications claims to have attained communication distance of 2000' with no line of sight. Bidirectional communications system (voice and data) by mesh network.	Very little information on L -3 Communications' Web site.
Mesh Dynamics	MD4000. Nodes in mesh network able to communicate at 2.4 GHz or 5.8 GHz and hold up to 4 wireless access cards. Nodes have two RJ45 Power over Ethernet ports.	Different radio frequencies for Tx and Rx allow faster speed: 22 Mbps with latency of 1 to 2 ms per node through 18 nodes. Four different radio frequencies per box possible.	
Newtrax Technologies	Very low power mesh network can run on batteries for long periods. UHF frequencies (902-928 MHz). Nodes can be powered by two D cells for more than 2 years and do not require electrical wiring. Optional 10-year external battery.	Real wireless network. Fast installation. Compatible with all communication systems (Leaky Feeder VHF/UHF, RS-485, Ethernet, Wi-Fi). Communication distance from 100 m to 400 m. Information can be transmitted from node to node without going through a headend or gateway.	Data transmission fairly slow because each node has to be awakened in order to transmit to another node (1 kbps to 38.4 kbps). Latency 0.5 to 2 seconds per hop. No voice communication. Communication over Leaky Feeder from 1200 bps to 9600 bps.
Mine Site Technologies & Rajant	Breadcrumb System. Most nodes operate with two Wi-Fi radios at 2.4 GHz. Portable BreadCrumb ME2 node has only one Wi-Fi 802.11b radio. Fixed LX node has one 802.11b Wi-Fi radio at 2.4 GHz and one 802.11a radio at 5 GHz. One model of node can run on batteries for a few hours. Wireless VoIP communication.	System quickly deployable in the event of an accident. Ad hoc mesh network. Data transfer rate of 54 Mbps with one node at 2.4 GHz and another at 5 GHz.	Signal does not turn around corners very well. Voice communication distance approximately 49 m. Data transfer rate drops to 11 Mbps where nodes with only one radio at 2.4 GHz are used.
Subterracom Wireless Solutions	SubterraMine. Communications system via Wi-Fi and mesh network. Text messaging. Up to 4 802.11a/b/g wireless access cards in one node.	Bidirectional communications. Wireless VoIP phone possible. Network supports video transmission. Network is at 5.8 GHz and access points are at 2.4 GHz. Redundant access points possible. Frequency appears to turn very well around pillars in work areas. 274 m between nodes and 107 m between M8 and node.	Subterra-M8 is somewhat bulky to carry.
Venture Design Services & Helicomm	MineTracer. Tracking and location tag system and Zig-Bee mesh network at 2.4 GHz and low power. Subnet Controller queries up to 75 nodes and transmits data to surface via RS-485 signal over twisted-pair wire.	Bidirectional communication. User has SOS button. Nodes can run on backup power for 48 hours. Distance between radio tags and access points up to 213 m.	Access point every 46 m to make network sturdy. Text communication only. Voice communication between only two nodes (46 m) is questionable. Communication between personnel impossible. Network very slow: 12 kbps and refresh rate between 20 to 30 seconds. RS-485 network (DX-Bus) to surface. Network architecture debatable.

Ultra Wide Band (UWB) Communications

Description

UWB communication is based on the emission of very short pulses over a very wide band of frequencies that can range from 3.1 GHz to 10.6 GHz. UWB uses very little power, and the signal is often below the noise threshold. UWB pulses are easily differentiated from one another when there is interference caused by multiple wave paths and are therefore suitable for communication in underground mines and especially for tracking and location applications. A UWB signal can penetrate several metres into the earth, and some companies use UWB as ground-penetrating radar to locate buried cables and pipes.

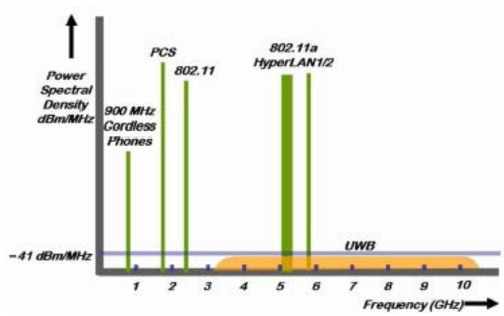

Figure 81 – UWB Signal compared with Other Signals

Cancellation of the signal by multipath waves occurs when the wave of the transmitted signal becomes partly or fully out of phase with the signal transmitted directly. This reduces the amplitude at the receiver. With very short pulses, a signal transmitted directly has time to reach the receiver and rebound even before the multipath signals come along to cancel out the signal. Conventional signals like Wi-Fi (802.11b/g) become very distorted in terms of wave shape and loss of signal strength. Figure 82 illustrates the advantage of UWB signals over Wi-Fi signals.

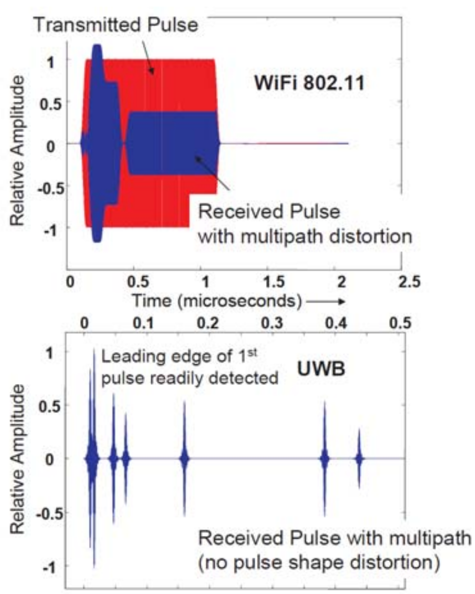

Figure 82 – UWB Signal compared with Wi-Fi

Figure 83 shows the limitation of data transfer rate over distance. According to many Internet sources, UWB offers a very high transfer rate over short distances, but the rate drops very quickly as the distance increases. With the exception of location, it appears that applications which use UWB technology are only for equipment that are very close together, like Bluetooth applications.

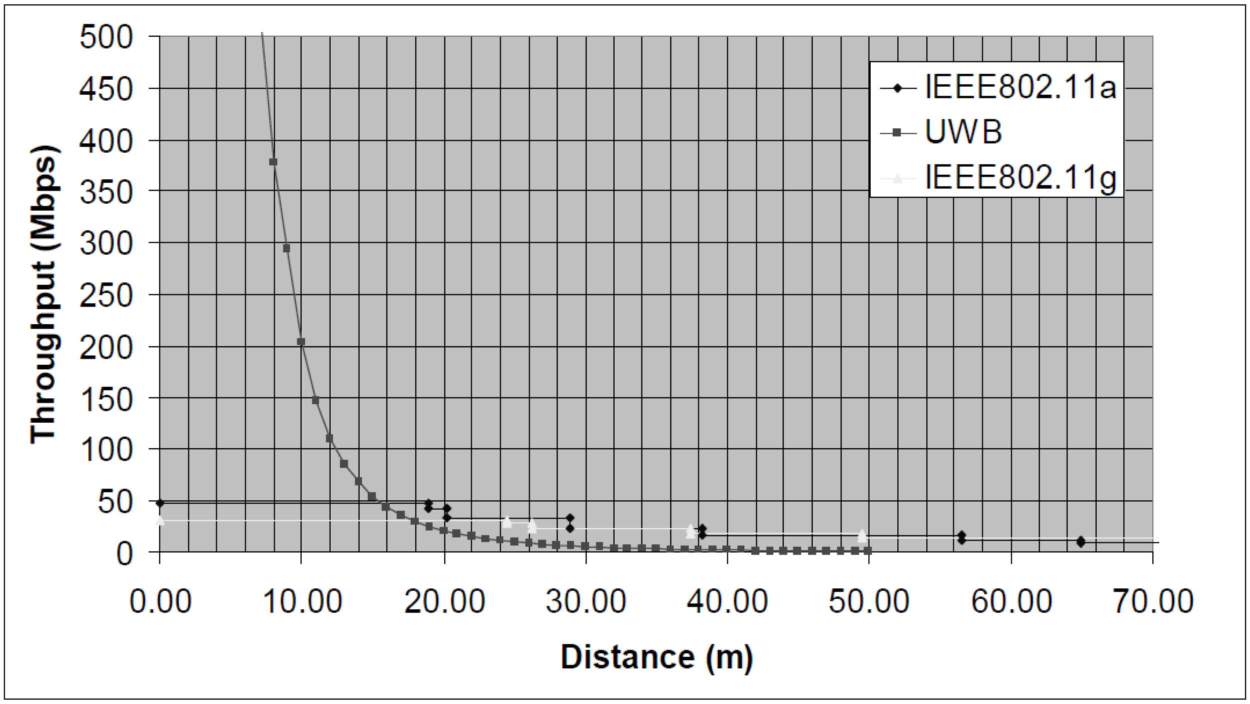

Figure 83 – Transfer Rate versus UWB Distance compared to 802.11a/g

Advantages

- Very long propagation distances because of the wave guide effect of underground tunnels.
- Accuracy of location can reach one centimetre.
- High data rate capacity.
- Appears to be unaffected by interference and multipath.
- Uses very little energy and is very efficient.

Limitations

- Directional antenna to obtain wide range.
- Few commercial products available for the mining industry.

In 2006, **Concurrent Technologies Corporation** (www.ctc.com) tested a radio communications system called **Time Domain UWB** (www.timedomain.com). The tests were conducted at Consol Energy's McElroy Mine in West Virginia. Communication was spread over frequencies from 3.1 GHz to 7.3 GHz, and the modulation used was by pulse position. The radio power used was approximately -3 dBm (500 uW), which is extremely low. The system is capable of transmitting voice and data and measuring the distance between two radios by measuring the travel time of pulses.

Data transmission with directional antennas was established over a distance of 1200' (366 m) uninterrupted and up to 2000' (610 m) with occasional dead spots. The distance was nevertheless 950' (290 m) with omnidirectional antennas. Software connected to one of the transceivers was able to measure the distance from the other transceiver with accuracy of 10' (3 m) over a distance of 1000' (305 m) and 21' (6.4 m) between 1000' (305 m) and 2000' (610 m). Other voice communication transmission tests over distances between 1382’ (421 m) and 1679’ (512 m) were successfully completed.

Figure 84 – Time Domain UWB System from Concurrent Technologies Corporation

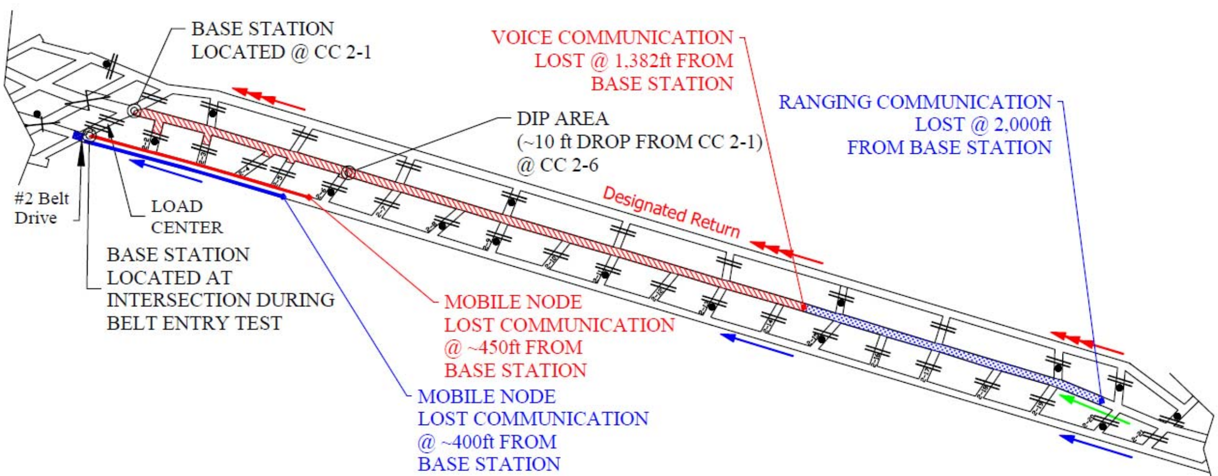

Figure 85 – Test Site in an Entry at the McElroy Mine

Communication tests with no line of sight were conducted, and it appears that UWB signal readily turn well around corners. Communication between an entry and a crosscut was established up to 70’ (21.3 m). As soon as the other radio came into the adjacent entry, the UWB signal was lost. The UWB signal does not go through coal pillars.

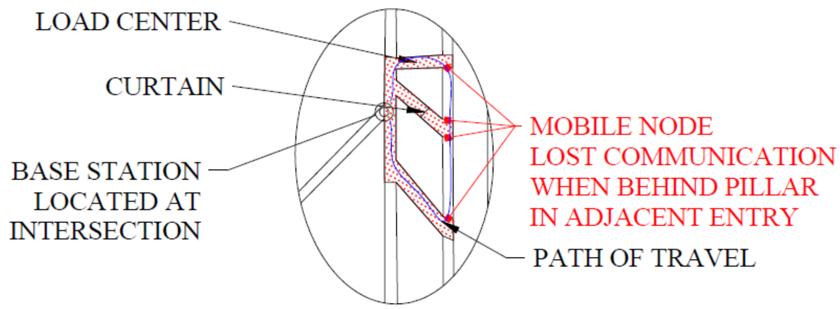

Figure 86 – Adjacent Entry Test Site in the McElroy Mine

Other communication tests with no line of sight were conducted, and it appears that UWB signal readily turn around corners. Communication was established up to 384' (117 m) in an entry with an S curve.

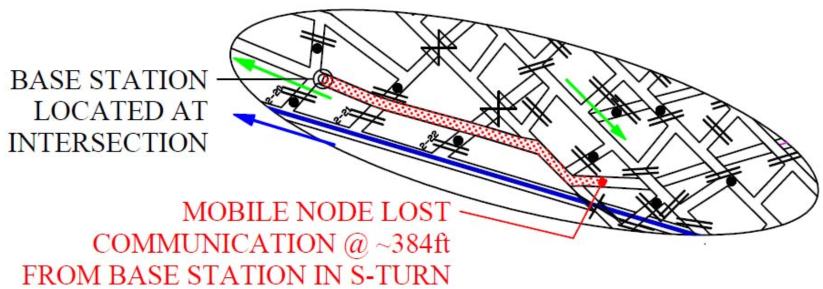

Figure 87 – S Curve Test Site at the McElroy Mine

It appears that the system tested by Concurrent Technologies Corporation was a development kit sold by Time Domain and that there was no product tailored specifically for underground communication. In addition, no information about the system was available on the Concurrent Technologies Corporation Web site. However, Time Domain's Web site (www.timedomain.com) includes documentation about the product called PulsON P220, and development kits are available for purchase. Time Domain confirms that its product can exceed by 10 to 20 times the technical specifications for communication distances because of the wave guiding effect of the galleries in underground mines.

Aether Wire & Location (www.aetherwire.com) offers a location product that uses UWB radio tags. The company claims that the system can read and communicate through a mesh network over a distance of 30 m (98') with accuracy of 1 centimetre. Because the system does not establish communication, it will be described in the **Equipment and Personnel Tracking Systems** section.

Multispectral Solutions (www.multispectral.com) offers a UWB radio tag location product called **Sapphire DART** that it claims can read up to 5,000 tags per second over a distance of 200 m (650') outside with accuracy of 30 cm (12''). The detection distance drops to 46 m (150') inside. Because the system does not establish communication, it will be described in the **Equipment and Personnel Tracking Systems** section.

L3-Communications (www.L-3com.com) offers **TRU-TRACKER**, a UWB radio tag system based on technology developed by Multispectral Solutions (www.multispectral.com). TRU-TRACKER works the opposite way from conventional RFID tags and reader systems. Personnel carry radio tag readers, and UWB tags are installed in whatever parts of the mine the company might want to locate personnel. The tag reader regularly transmits to the communications system confirmation of the tags it has encountered. The manufacturer claims that the system allows underground location with accuracy of 50' (15 m). However, the system does not communicate with the surface by UWB. A complete description of the system is given in the **Equipment and Personnel Tracking Systems** section.

Equipment and Personnel Tracking Systems

Description

Most tracking and location systems use radio tags (RFID) that are detected by RF readers. Passive RFIDs do not have a very wide range. Each RFID has a unique address and identifies the person or vehicle carrying it. A passive tag reader sends a modulated RF field to power the radio tag. The tag responds to the reader using the RF power it received to run its electronic circuit and transmit its identification. In a mine environment, most RFIDs are active (battery operated), because they offer greater detection distance. This type of system does not necessarily have to query tags, because the tags can transmit at regular intervals. The readers are placed in strategic places in order to identify and locate passing personnel and vehicles. In most of the cases, the information is sent to a tracking and location software on the surface.

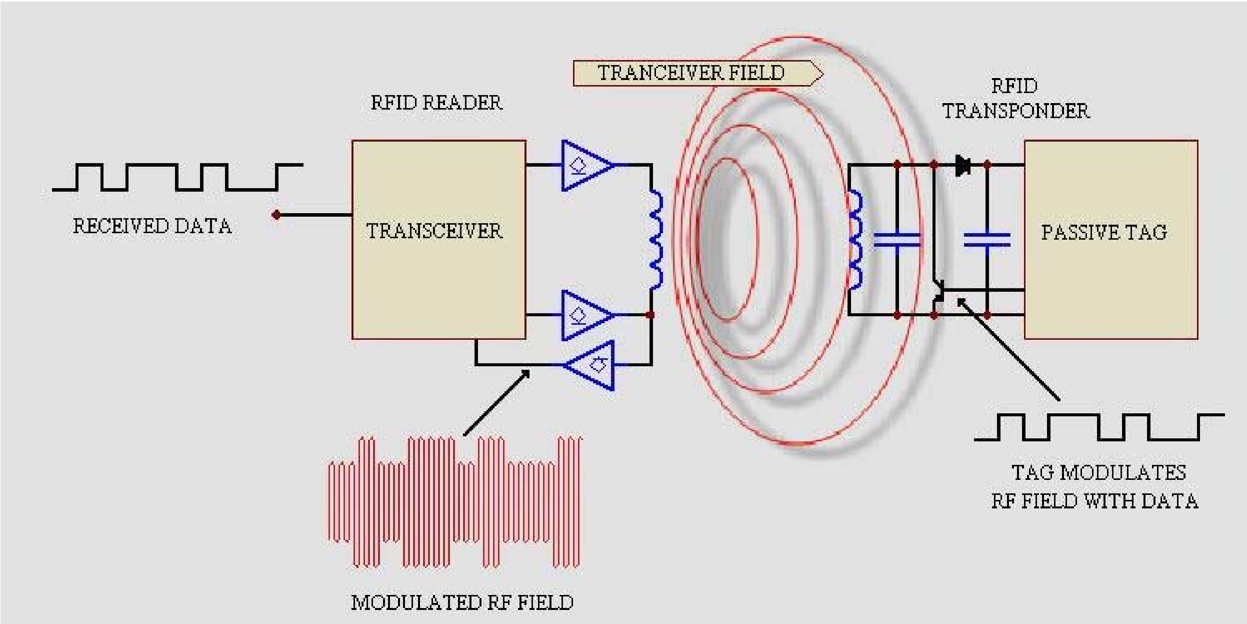

Figure 88 – Principle of Passive RFID Radio Tags

Advantages

- Long range of active RFID readers.
- Personnel tracking ensures more safety in the event of an accident.
- Some systems can identify danger zones in the mine.
- Vehicle tracking can be used to control traffic and ramp access.
- Vehicle and equipment tracking increases productivity by making it possible to locate vehicles and equipment more quickly at the start of each shift.
- Personnel and vehicle tracking makes it possible to control ventilation based on actual needs and thus save energy.

Limitations

- Limited range of some passive RFID readers.
- Some active RFID tags have limited battery life, especially if they are constantly being queried.
- Location technologies using UWB tags not widely available commercially.
- Many readers needed if the objective is to obtain great accuracy or monitor all levels of a mine.

SMART TAG from **Varis Mine Technology Ltd.** (www.varismine.com) is a 915 MHz active RFID tracking and location system manufactured by Identec Solutions (www.identecsolutions.com). The range of the UHF tags is approximately 100 m (328') and the battery lifespan is approximately six years at 600 readings a day. The tag readers can be connected directly to the mine's Ethernet network, and surface software is used to configure the readers and track personnel, vehicles and equipment. A reader can read up to 2,000 radio tags simultaneously or 50 tags travelling at a speed of 50 km/h (31 mph). A reader can use up to four different antennas at a time to monitor four zones or identify the direction of travel of a radio tag. The manufacturer's Web site has a great deal of information about the system, even training manuals. No independent test results were found on the Internet.

Figure 89 – Personal Radio Tag and Reader from Varis Mine Technology Ltd.

Becker Mining Systems (www.becker-mining.com) also offers a 433.92 MHz active RFID tracking and location system called BECKERTAG. The range of the UHF tags is approximately 200 m (656'), and the battery lifespan is one to five years depending on the query rate. The tag readers are capable of measuring the strength of the signal (RSSI) from the tags in order to improve location accuracy. The readers have an RS-485 port and can be connected directly to any existing communications network. A software tracks personnel, vehicles and equipment. The manufacturer's Web site has little information about the system. No independent test results were found on the Internet.

Figure 90 – Personal Radio Tag, Vehicle Tag and Reader from Becker

Mine Site Technologies (www.minesite.com.au) offers two tracking and location solutions. The first solution, **TRACKER**, is a UHF active RFID tracking and location system. Tags can be installed inside the batteries of miner's cap lamps and have a range of 50 m (164') to 60 m (197'). The lifespan of the NiMH battery is nine to ten months. The tag readers (Beacon) have an RS-485 port and can be connected to any existing communications network. They have to be deployed wherever the company might want to locate personnel or equipment. A reader can read up to 10 tags travelling at a speed of 40 km/h (25 mph). Surface software tracks personnel, vehicles and equipment. The manufacturer's Web site has a great deal of information about the system.

Figure 91 – TRACKER Radio Tag and Reader from Mine Site Technologies

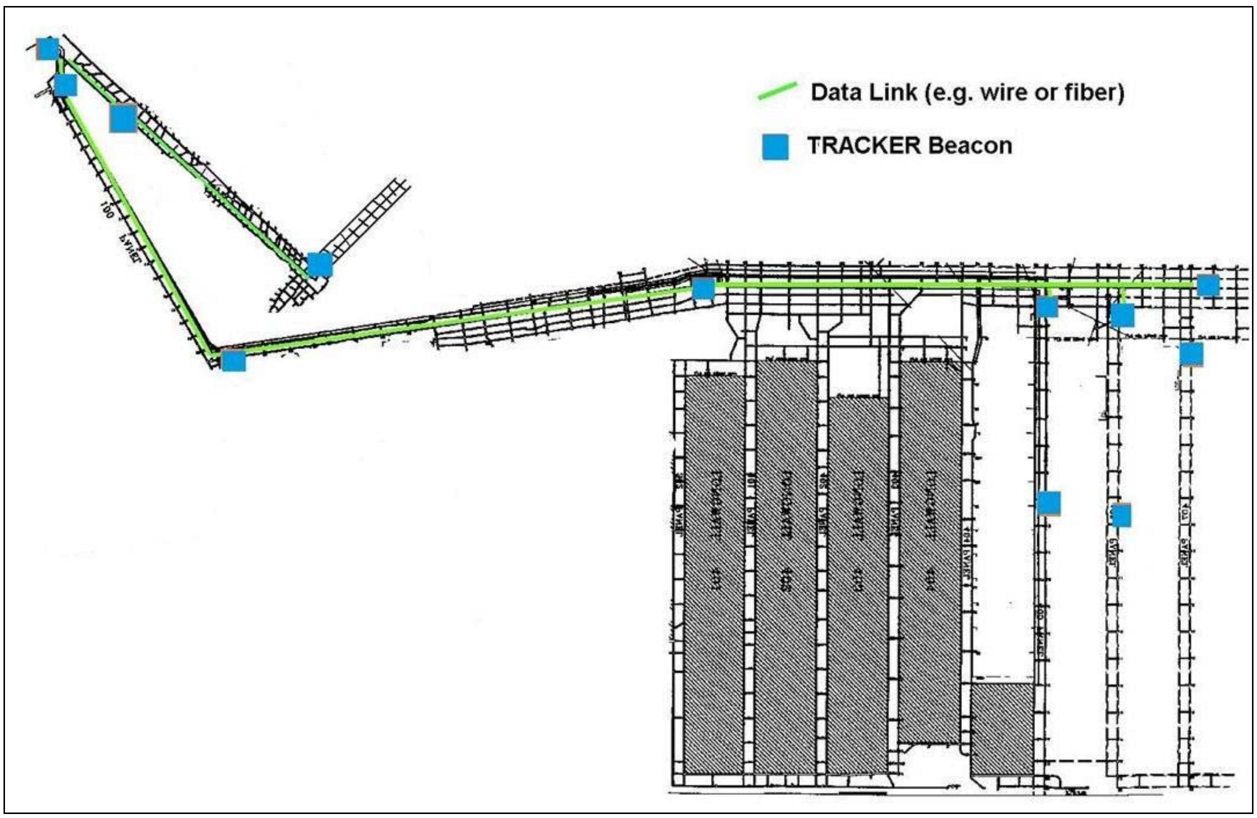

Figure 92 – Typical Installation of the TRACKER System from Mine Site Technologies

The second location solution from **Mine Site Technologies** uses Wi-Fi tags from Aeroscout (www.aeroscout.com) and Wi-Fi access points as tag readers. Aeroscout's Wi-Fi tags can be switched off and the transmission rate reduced in order to extend the life of the battery. A version of these tags can be integrated into the battery of a miner's cap lamp. The range of the tags is not known. The access points are powered and connected by optical fibre using a specialty cable that has connectors at both ends and contains both the electrical wires and the optical fibre. The connector appears to be fairly difficult to assemble, and the company offers predetermined lengths of cable with connectors on both ends. Specialized software tracks personnel, vehicles and equipment. The manufacturer's Web site has a great deal of information about the system.

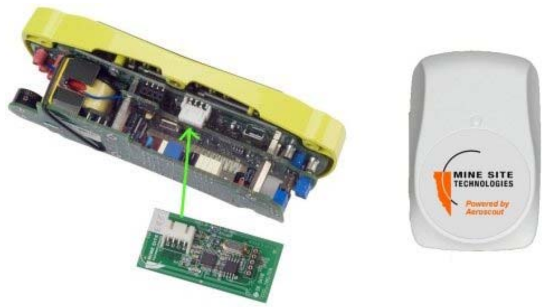

Figure 93 – Miner's Cap Lamp Battery Tag and Personal Tag from Mine Site Technologies

Figure 94 – Wi-Fi Access Point from Mine Site Technologies

NL Technologies (www.nltinc.com) offers two tracking and location solutions. The first solution, **Northern Light Digital RFID Tracking**, is a 433 MHz UHF active RFID tracking and location system. The second solution, **Northern Light Digital WiFi Tracking**, uses Wi-Fi tags from Aeroscout (www.aeroscout.com) and Wi-Fi access points as tag readers. The tags can be integrated into the battery of a miner's cap lamp. Surface software tracks personnel, vehicles and equipment. Very little information about these two products is available on NLT's Web site.

Text messaging, VoIP telephone and Wi-Fi location tests conducted in Peabody Energy's 20 Mile Coal Mine and Mine #2 and Trinity Coal's Logan Fork Mine in the United States showed Wi-Fi tag detection and wireless VoIP telephone distances of 2400' (731 m) to 2580' (786 m) in front of a directional antenna (Helical). The communication distance behind the directional antenna was 350' (107 m), while the distance on the sides was 250' (76 m).

Figure 95 – Test Sites at Trinity Coal's Logan Fork Mine

Minecom (www.minecom.com) offers two tracking and location solutions. The first solution is an active RFID tracking and location system with an unknown frequency. The second solution uses UHF passive tags (860-930 MHz). The tags can be installed inside a miner's cap lamp battery. There is no mention of software for tracking personnel, vehicles and equipment from the surface. The tag readers have one RS-232 port and two RS-485 ports. Active tag readers have a range of up to 250 m (820'), while passive tag readers have a range of only 30 m (98'). Very little information about these two products is available on Minecom's Web site.

Figure 96 – Personal Radio Tag and Passive Reader from Minecom

Figure 97 – Active Vehicle Radio Tag and Reader from Minecom

Safety Trak from **Jannatec** (www.jannatec.com) only tracks personnel working alone underground. It has no location feature. Radios integrated into Jannatec's **Johnny Light** or any radio equipped with MDC 1200 can be tracked by surface software. Every time a radio is used, a code is sent to the system used to monitor personnel working alone in order to reset a meter that calculates the time since the employee last reported. The mine has to have a VHF Leaky Feeder radio communications system in order for Safety Trak to work.

MineAx Bird-Dog from **Tunnel Radio of America** (http://new.tunnelradio.com) is an active UHF tag (300 or 900 MHz) and tag reader system. The tags have a range of 100' (30.5 m) to 450' (137 m). The tag readers communicate with one another through a wireless network at 150 MHz or 500 MHz and thus serve as repeaters. The wireless network is separate from the existing communications system, and each repeater is able to communicate over a distance of up to 3000' (914 m). The disadvantage of this system is that it requires the installation of reader/repeaters all over the mine in order to ensure a wireless communication link and route the data. Information is relayed to the surface by means of an interface between the Leaky Feeder cable and the wireless tag reader/repeater network.

Figure 98 – Bird-Dog Active Radio Tags from Tunnel Radio of America

GG Automation (www.ggautomation.com) offers a location system based on Wi-Fi technology. The Wi-Fi tags from **Ekahau** (www.ekahau.com) have a number of advantages because they directly measure the strength of the radio signal (RSSI) and relay that information back to the wireless access points. The benefit is that any access point can be used, not just certain models that measure the RSSI. In addition, some Wi-Fi tags from Ekahau have buttons that can be used to report in or call for help and even an LCD screen to receive short text messages. The Wi-Fi access points are linked by the non-radiating coaxial cable network (DOCSIS) offered by GG Automation.

Figure 99 – Wi-Fi Radio Tags from Ekahau

Marco North America (www.marco-na.com) offers the **VisorTrac** system that comprises an active UHF tag system (900 MHz) called Portable Radio Identification Module (PRIM) and tag readers called Radio Identification Node Controllers (RINC). Vehicles can also be equipped with a type of tag called a Vehicle Identification System On Radio (VISOR) that can be used to locate PRIMs. PRIMs have a button that can be used to call for help in an emergency. The range of a PRIM is between 5 m (16.4') and 100 m (328'). The estimated lifespan of the batteries in a PRIM is two years. The tag reader (RINC) is linked by a network that uses Ethernet, RS-485 or Leaky Feeder cable. Connection to an optical fibre network is available as an option.

Figure 100 – PRIM, VISOR and RINC from Marco North America

Tests conducted at the International Coal Group's Imperial Mine in January 2007 showed UHF tag detection distances of up to 700' (213 m) where the roof height was 72'' (1.83 m). The coverage distance dropped to 260' (79 m) where the roof height was only 38'' (0.96 m).

Other tests at Peabody Energy's 20 Mile Coal Mine and the Bridger Mine showed UHF tag detection distances of up to 900' (274 m) where the roof height was between 84'' (2.13 m) and 124'' (3.15 m). Clearly, there is a direct relationship between roof height and communication distance.

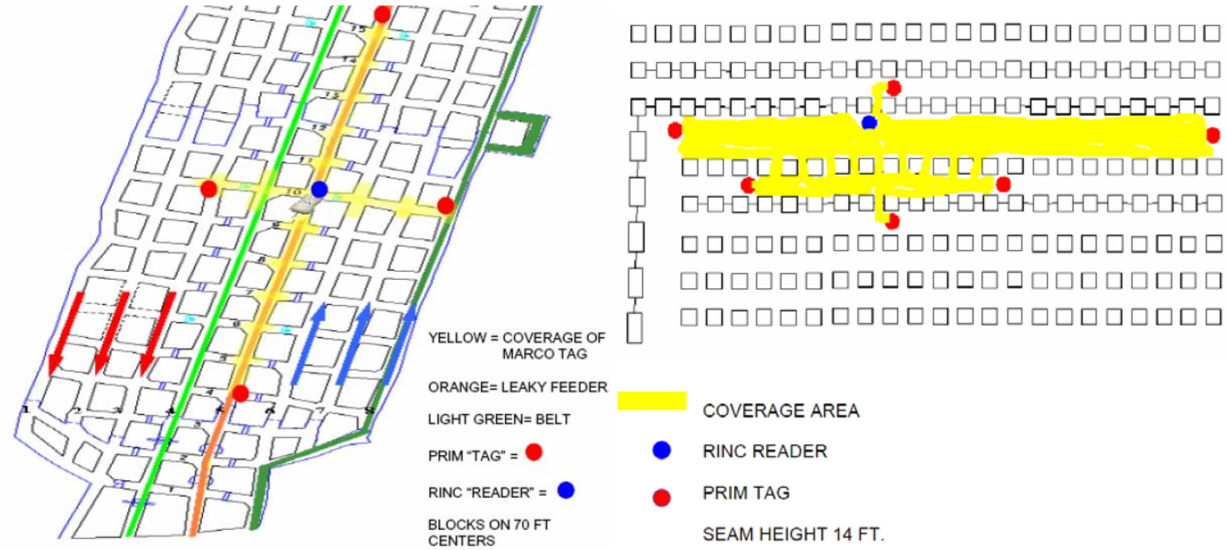

Figure 101 – Test Sites at the Imperial Mine and Peabody's 20 Mile Mine

Matrix Design Group (www.matrixdginc.com) offers **METS** (Miner & Equipment Tracking System). METS is an active UHF tag (433.92 MHz) and tag reader system. The tag readers are connected to one another by a non-radiating coaxial cable in a mesh network. The purpose of the wired mesh network is to provide multiple information routing options in the event of a power failure or if a tag reader or the network fails. The cable between the nodes or tag readers in the mesh network means that the nodes or readers can be spaced between 500' (152 m) and 3000' (914 m) apart because they do not require line of sight to send information back and forth.

Tests conducted at Mettiki Coal's Mettiki Mountainview Mine in West Virginia showed relatively disappointing line-of-sight detection distances of 225' (68.6 m) where the roof height was 108'' (2.74 m). One test even showed no reading of 8 tags worn by passengers in a vehicle travelling at a speed of 19 km/h.

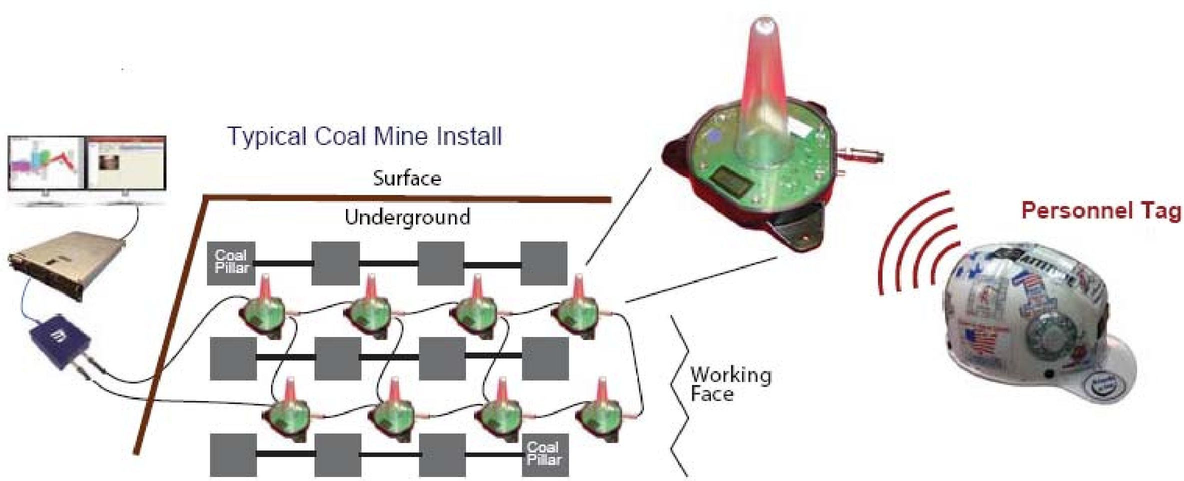

Figure 102 – METS System from Matrix Design Group

Venture Design Services (http://ventureminetracer.com) offers **MineTracer**, a system that uses active tags and low-power (10 mW) ZigBee access points. There are two models of ZigBee tag. One is for location only and has an SOS button. The other also has an LCD display for receiving text messages.

The access points are connected to one another by an electrical cable and a wireless link to form a mesh network. Their low power allows them to run on batteries for 48 to 96 hours in the event of a power failure. The access points have an external indicator lamp that changes colour depending on the status of the location system. A green light means that the system is in normal operating mode. A flashing yellow light means that someone has sent an SOS. Once officials at the surface start the response process, the yellow light stops flashing and remains on. The red light is used only for emergency evacuation of the mine.

Figure 103 – MineTracer System from Venture Design Services

A maximum of 75 wireless access points can by connected to a subnet controller. The subnet controller sends information to the surface through a serial link over a twisted-pair wire. The system seems to need a large number of access points and several subnet controllers to ensure a reliable mesh network. The manufacturer actually recommends that there be an access point every 150' (45.7 m). The loss of one access point cuts the rest of the wireless network off from the subnet controller. The company points out that the system is able to carry wireless voice communications, but only between two nodes (150').

Figure 104 – Typical Installation of the MineTracer System from Venture Design Services

Tests conducted at the Skyline Coal Mine in Utah, the Mountain Laurel Coal Mine in West Virginia and the Big Branch Coal Mine in West Virginia in the United States showed line-of-sight tag detection distances of approximately 300’ (91 m) to 700’ (213 m). The roof height in the test areas was between 84” (2.13 m) and 96” (2.44 m). The detection distances were two thirds smaller where there was no line of sight. MSHA recommends a maximum of 270’ (82 m) between a wireless access point and a tag and 370’ (112.8 m) between two access points if the system is to be reliable. One test even showed almost no reading of 4 tags worn by passengers in a vehicle travelling at a speed of 19 km/h between 0’ and 70’ (21.3 m) away from an access point.

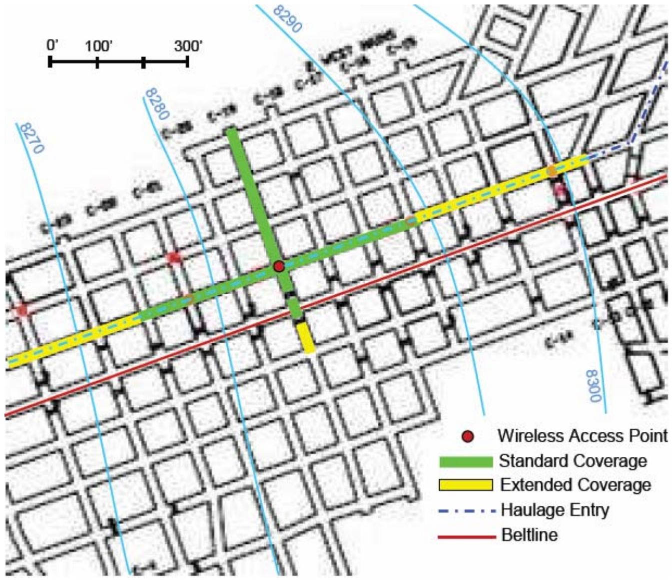

Figure 105 – Test Site at the Skyline Mine

Pyott Boone (www.pyottboone.com) offers the **Tracking Boss**, an active UHF tag (924 MHz) and tag reader system. The lifespan of the AA batteries in the tags is 18 to 24 months. The tag readers can be connected to one another and to the surface in three different ways: RS-232 cable, optical fibre or radio over the existing Leaky Feeder cable (VHF/UHF). The advantage of the radio wave option is that it uses the existing communications network and, more importantly, that it eliminates the need to cut the Leaky Feeder cable in order to insert the tag readers. The tag readers can run on battery power for up to 96 hours. A great deal of information is available on the manufacturer’s Web site.

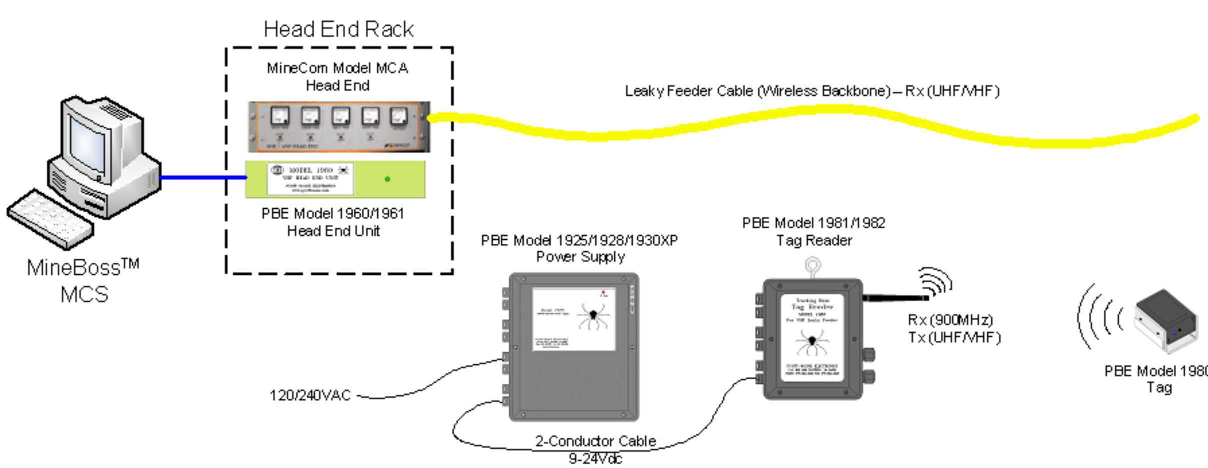

Figure 106 – Tracking Boss from Pyott Boone on Leaky Feader Cable

Tests conducted at Alex Energy's Jerry Fork Eagle Coal Mine in West Virginia showed detection distances of up to 500' (152 m). The roof height in the test areas was 70'' (1.78 m). Even with several obstacles between them, the readers were able to detect tags up to 150' (45.7 m) away.

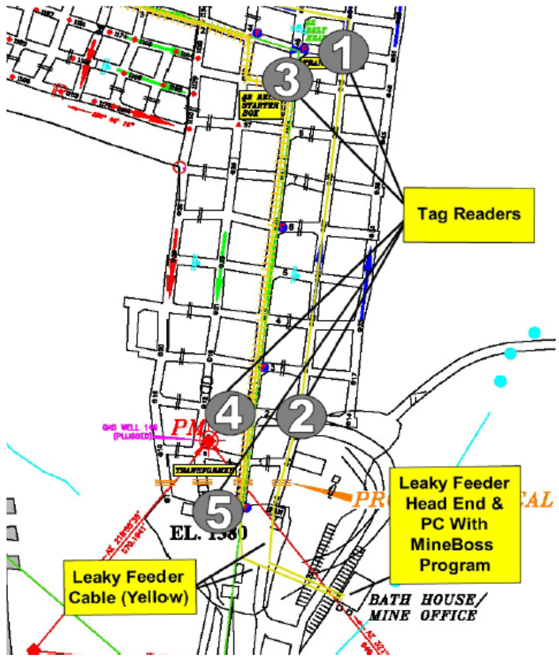

Figure 107 – Test Site for Tracking Boss from Pyott Boone

Newtrax Technologies (www.newtraxtech.com) offers a low-power wireless mesh network with operating frequencies of 902 MHz to 928 MHz. Each node in the network can run on two D cell batteries for more than two years. The "personnel tracking and location" part is covered by integrating a Newtrax module into the batteries of the miner's cap lamps from Jannatec Radio Technologies (www.jannatec.com). Vehicle and equipment radio tags, which are also nodes in the mesh network, have inputs/outputs that can be used to monitor and control specific input/output parameters. Vehicle and equipment nodes can therefore act as repeaters if they block the signal between two nodes of the fixed network.

Each node is able to communicate with another node through a mesh network without having to go through the central server or the gateway. The gateway can route to the central server by Ethernet, Wi-Fi, cellular, dial-up, Leaky Feeder cable or ground satellite link. Nodes are able to receive text messages.

To extend battery life, each node is programmed to receive and send data from and to other nodes at regular intervals (hop) of 0.5 to 2 seconds and then switch to standby mode. That delay is added to each hop until the data reaches the gateway or the destination. The result is a meshed network with a transmission speed between 1 kbps and 38.4 kbps, making it impossible to transmit voice or video. Interface with the Leaky Feeder cable is through a radio modem with a data rate between 1200 bps and 9600 bps.

The communication distance between nodes is 100 m (328') to 300 m (984') underground. Newtrax recommends that each node be able to see the next one and the one after in order to ensure a reliable network. This would put the actual node-to-node spacing at 50 m (164') to 150 m (492'). A great deal of information is available on the manufacturer's Web site.

Figure 108 – Vehicle Radio Tag, Node and Gateway from Newtrax Technologies

Figure 109 – Personnel Tracking by Newtrax Module in Jannatec Battery

L3-Communications (www.L-3com.com) offers **TRU-TRACKER**, a UWB tag system based on technology developed by **Multispectral Solutions** (www.multispectral.com). TRU-TRACKER works the opposite way from conventional RFID tag and reader systems. Personnel carry tag readers, and UWB tags are installed in whatever parts of the mine the company might want to locate personnel. The tag reader regularly transmits to the communications system confirmation of the tags it has encountered. The system can operate on Leaky Feeder cable or the **Accolade** communications system developed by L3-Communications. The tags, which run on AA batteries, will have a lifespan of approximately eight to 10 years. The tag readers, located inside the miner's lamp batteries, are recharged at the end of each shift.

According to the program manager at L3-Communications, the system can locate a person underground with 50' (15 m) accuracy. However, the UWB technology developed by **Multispectral Solutions** normally allows pinpointing to less than a foot (30 cm).

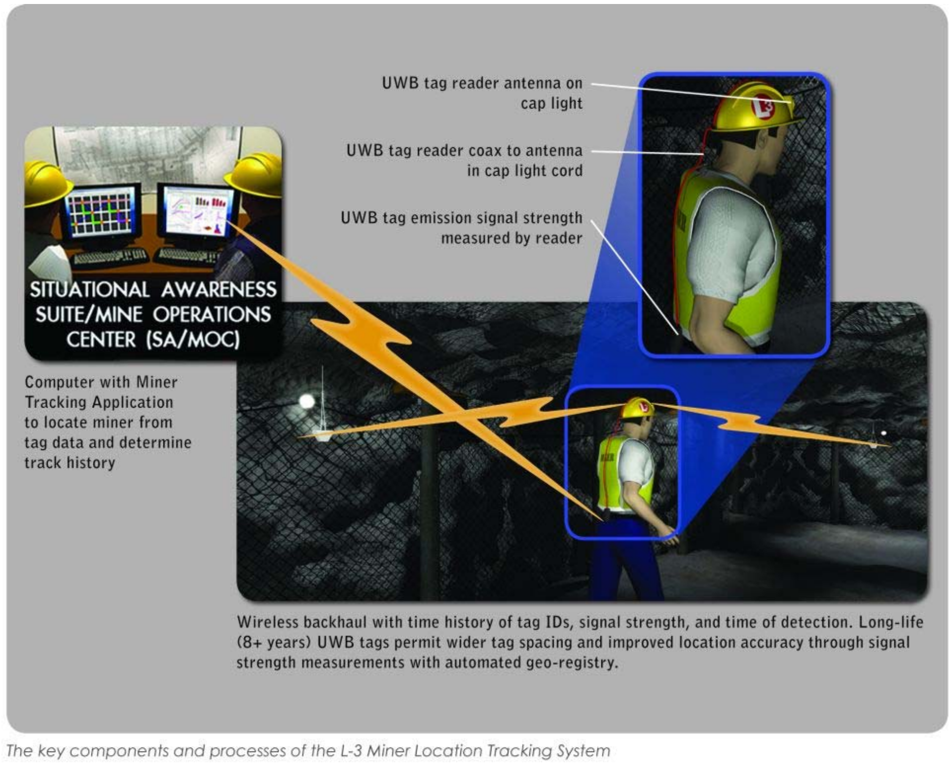

Figure 110 – Personnel Tracking System from L3-Communications

Multispectral Solutions (www.multispectral.com) offers a UWB tag location product called **Sapphire**. The system can read up to 5,000 tags per second over a distance of 200 m (656') outdoors with accuracy of 30 cm (12''). The detection distance drops to 45 m (150') indoors. The 3-volt watch battery in a tag can last up to 7.5 years emitting once a second. The system operates at frequencies ranging from 5.925 GHz to 7.250 GHz.

Figure 111 – Sapphire System and UWB Tag from Multispectral Solutions

The pulses emitted by the UWB tags last from a few hundred picoseconds ($1x10^{-12}$) to a few nanoseconds ($1x10^{-9}$). The combination of very low emission power and short emission times accounts for the very low consumption of electricity and the long life of Multispectral Solutions' UWB tags. The speed of light is approximately 300,000 km/s, or about 30 cm per nanosecond. That is the reason why the UWB tags have a location accuracy of 30 cm and better protection against multipaths. Multispectral Solutions does not offer an integrated solution for the mining industry, but L3-Communications (www.L-3com.com) has developed a prototype system based on that technology for the mining industry (see previous page).

Concurrent Technologies Corporation (www.ctc.com) has tested a radio communications and location system called **Time Domain UWB** (www.timedomain.com). The system is described in the **Ultra Wide Band (UWB) Communications** section. Bear in mind that software connected to one of the transceivers was able to measure the distance from the other transceiver with accuracy of 10' (3 m) over 1000' (304 m) and 21' (6.4 m) between 1000' (305 m) and 2000' (610 m). In addition, no information about the system is available on the Concurrent Technologies Corporation Web site. However, Time Domain's Web site (www.timedomain.com) includes documentation about the product called PulsON P220, and development kits are available for purchase.

Aether Wire & Location (www.aetherwire.com) offers a UWB tag location product. The company claims the system can read and communicate in mesh network mode over a distance of 30 m (98') with accuracy of 1 cm. According to the manufacturer, the mesh network can have more than one million nodes and cover a distance of more than 1 km by going through multiple nodes. Each node uses only 1 mW in emit mode and 10 μW in standby mode. Very little information is available on the manufacturer's Web site. Aether Wire & Location does not offer an integrated solution for the mining industry and appears to be still at the research and development stage.

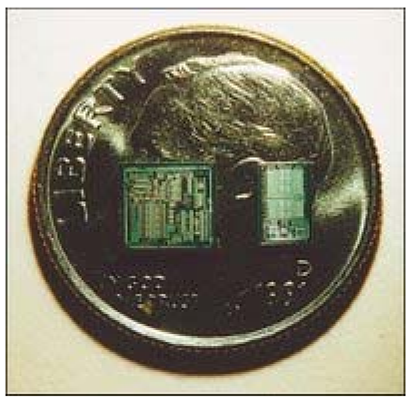

Figure 112 – Integrated UWB Tag Circuit from Aether Wire & Location

Active Control Technology (www.activecontrol.com) offers a mesh network called **ActiveMine** based on **MeshDynamics** (www.meshdynamics.com) technology. The system is described in detail in the **Mesh Networks** section.

The system offers real-time personnel tracking with accuracy of tens of feet using Ekahau tags. Ekahau tags measure the strength of the radio signal (RSSI) in order to increase location accuracy. A full suite of software is used to track and locate any underground Wi-Fi equipment. The system is set up in such a way that nodes cut off from the rest of the mesh network can ensure radio communication in the cut-off area without a headend. Personnel tracking cannot operate in that mode, which is called Starfish. Very little information is available on Active Control Technology's Web site.

Tests were conducted at International Coal Group's Viper Mine in Illinois in May 2007. Ekahau tags (T201) made it possible to attain line-of-sight location over a distance of up to 1750' (533 m) from a wireless node. The average roof height was 6' (1.83 m). Other tests without line of sight showed detection distances of 70' (21 m) to 420' (128 m) for a group of four tags in a vehicle travelling at 15 mph (24 km/h).

Summary

Table 10 – Summary – Tracking and Location Systems

Company	Description	Advantages	Limitations
Active Control Technology Inc.	ActiveMine. Wi-Fi tags from Ekahau. Tracking of all Wi-Fi devices. Mesh network and Wi-Fi based on MESHDYNAMICS technology.	Ekahau tags measure RF signal strength (RSSI) for greater location accuracy. Range of Wi-Fi tags up to 533 m. Some Ekahau tags have buttons and LCD screen to interact with user.	Very little information on Active Control Technology's Web site.
Aether Wire & Location	UWB tags capable of establishing mesh network with 30 m between tags. Network can gave 1 million nodes and cover 1 km.	Location accuracy 1 cm. Tag uses only 1 mW in emit mode and 10 µW in standby mode for longer battery life.	No integrated solution for the mining industry. Prototype appears to still be at the R&D stage.
Becker Mining Systems	BECKERTAG. UHF active tag at 433.92 MHz. Compatible with BECKER CAS anti-collision system. Tags for vehicles, equipment and miner's cap lamp.	Tag reader measures strength of radio signal (RSSI) in order to give a more accurate estimate of distance between tags and reader. Battery of radio tag last 1 to 5 years. Range 200 m. Tag reader with RS-485 port.	Tag reading takes between 100 ms and 200 ms (5 to 10 readings per second).
Concurrent Technologies Corporation & Time Domain	Time Domain UWB. UWB communications system (3.1 GHz to 7.3 GHz) with location software.	Accuracy of 3 m over 304 m and 6.4 m over 610 m. Very low emission power of 500 µW (-3 dBm).	No integrated solution for the mining industry.
GG Automation Inc.	Personnel and vehicle tracking using Wi-Fi tags from Ekahau and Wi-Fi access point on a DOCSIS network with non-radiating cable.	Ekahau tags measure strength of RF signal (RSSI) for greater location accuracy. No need for specialized access points that measure the RSSI signal. Some Ekahau tags have buttons and LCD screen to interact with user.	Very little information on GG Automation's Web site.
Jannatec Radio Technologies	Safety Trak. Uses MDC 1200 signal from integrated radios into Johnny Light miner's cap lamps.	Simple system. Can be used with any radio that has MDC 1200 technology.	No location function. Only for tracking personnel working alone.
L-3 Communication	TRU-TRACKER. Tracking and locating with UWB tags and mesh network. System compatible with Leaky Feeder cable and optical fibre. Radio tags are mounted on walls, and tag readers are carried by personnel and act as nodes in the mesh network.	Lifespan of AA batteries in radio tags from 8 to 10 years. Radio tags installed only where there might be a need for location. Location accuracy about 15 m.	UWB technology normally ensures accuracy of 30 cm, but L-3 Communications offers only 15 m using signal strength. System still at prototype stage.
Marco North America	VisorTrac. UHF tags at 900 MHz. Portable tag (PRIM) and vehicle tag (VISOR). Range of tags from 5 m to 100 m.	Interfaces with optical fibre, RS-485 network and Leaky Feeder cable. Lifespan of batteries in PRIM module is two years. Tag detection distance up to 274 m.	Range of tags decreases where the roof is low:79 m with 0.96 m roof.
Matrix Design Group	METS 1.0 & 2.1. UHF tags at 433 MHz and mesh network with non-radiating coaxial cable.	Spacing of tag readers between 152 m and 914 m using coaxial cable.	Line-of-sight range of radio tags 69 m. No reading in some tests where vehicle was traveling at 19 km/h.
Mine Site Technologies	Tracker. Tracking with active UHF tags. Range of tags between 50 m to 60 m.	Reader can read up to 10 tags traveling at 40 km/h. Tag reader with RS-485 port.	Range of radio tags limited to 50 m to 60 m. Lifespan or battery 9 to 10 months
Mine Site Technologies	Impact Wi-Fi RFID Tracking. Personnel and vehicle tracking with Wi-Fi tags. Tag readers are Wi-Fi access points.	Wi-Fi readers connected to wired Ethernet network or optical fibre. Aeroscout tags can be switched on and off on request using an exciter. Access points determine the strength and time of arrival of the signal from Wi-Fi tags in order to locate them.	Needs access points designed to measure signal strength (RSSI) or time of arrival (TDOA) from Wi-Fi tags. ImPact Wi-Fi network cables have to be purchased in predetermined lengths with connectors at both ends.

Table 10 – Summary – Tracking and Location Systems (continued)

Company	Description	Advantages	Limitations
MineCom	Passive UHF tags at frequencies between 860 and 930 MHz.	RS-232 and RS-485 ports on tag reader. Tags can be integrated into miner's cap lamp.	Range of passive tag readers limited to 30 m.
MineCom	Active radio tag for tracking.	RS-232 and RS-485 ports on tag reader. Tags can be integrated into miner's cap lamp. Range of active tags on vehicles up to 250 m.	Lifespan of personal tag batteries 12 months.
Multispectral Solutions	Sapphire. UWB tags (5.925 GHz to 7.250 GHz).	Battery lifespan of 7.5 years. Location accuracy of 30 cm over 200 m outside. Detection distance 45 m inside. Can read 5,000 tags per second.	No integrated solution for the mining industry.
Newtrax Technologies	UHF tags (nodes) and mesh network (902-928 MHz) with very low power draw capable of running for two years on two D-cell batteries.	Node operational for two years (10 years optional). Does not require electrical power supply cable. Compatible with all communication systems (VHF/UHF Leaky Feeder cable, RS-485, Ethernet, Wi-Fi). Communication distance between 100 m and 300 m. Newtrax location module integrated into Jannatec's miner's cap lamp.	Data transmission fairly slow because each node has to be awakened in order to transmit to another node (1 kbps to 38.4 kbps). Latency 0.5 to 2 seconds per jump. Communication on Leaky Feeder cable between 1200 bps to 9600 bps.
Northern Light Technologies	Northern Light Digital RFID Tracking. Personnel and equipment tracking using active UHF tags at 433 MHz. Integrates into their Northern Light Digital Wi-Fi communications Network (optical fibre and CAT-5 cable).	Tags can be integrated into miner's cap lamp.	Very little information on NL Technologies' Web site.
Northern Light Technologies	Northern Light Digital WiFi Tracking. Personnel and equipment Tracking using Wi-Fi tags from Aeroscout. Integrates into their Northern Light Digital Wi-Fi communications network (optical Fibre and CAT-5) cable.	Wi-Fi tags can be integrated into miner's cap lamp. Optical fibre loop can be created for redundancy. Wi-Fi tag detection distance between 731 m and 786 m with directional antenna. Distance of 107 m behind antenna and 76 m on sides.	Very little information on NL Technologies' Web site.
Pyott Boone	Tracking Boss. Active UHF tags at 924 MHz powered by AA batteries with a lifespan of 18-24 months. Tag reader can run on VHF (155-174 MHz) or UHF (450-490 MHz) Leaky Feeder cable.	Readers compatible with several carriage media (RS-232, optical fibre). Reader with VHF or UHF interface does not require Leaky Feeder cable to be cut. Tag reader has 96 hours of back-up power. Range of radio tags between 46 m and 152 m.	RS-232 and RS-485 a bit slow.
Tunnel Radio of America	MineAx Bird-Dog. Active tags at 300 MHz or 900 MHz. Reader/repeaters linked by RF links at 150 MHz or 500 MHz.	Range of tags between 30 m and 137 m. Range between readers/repeaters is 914 m.	Uses an independent network of readers/repeaters to send information to the Leaky Feeder. Does not use existing infrastructures.
Varis Smart Underground Communications	SMART TAG. Active UHF tags at 915 MHz (Identec) that can be read from up to 100 m.	Radio tag will last 6 year on battery with 600 readings a day. Identec reader can be connected to four antennas to identify up to four zones or the direction in which a tag is moving. Reading range 100 m. Reader capable of reading 50 tags while traveling at 50 km/h.	Battery-powered tag has a limited lifespan if always queried by a reader. Location accuracy depends on number of readers.
Venture Design Services & Helicomm	MineTracer. Tracking and location using UHF tags and low-power Zig-Bee mesh network at 2.4 GHz. Subnet controller queries up to 75 nodes and transmits data to surface using RS-485 signal over twisted-pair wire.	Nodes have indicator light to alert personnel. Nodes can run on back-up power for 48 hours (96 hours optional). Distance between tags and access points up to 213 m. Location accuracy 23 m.	Requires access points every 46 m to ensure a sturdy network. If a node fails, the rest of the network is cut off from the surface. Network slow: 12 kbps and refresh every 20 to 30 seconds. RS-485 (DX-Bus) network to surface. No reading in some tests when reader traveling at a speed of 19 km/h.

Anti-Collision Systems

Description

Anti-collision systems are designed to prevent collisions between vehicles and between vehicles and personnel. Some anti-collision systems work by emitting a radio wave into the environment. Receivers establish the strength of the signal and determine how far away the source is. Other systems use the propagation time of the signal (sonar or RF) to measure distance relative to other vehicles or personnel.

In open-pit mines, most systems use a combination of cameras and radio tags (RFID). That type of system is quite effective and well known for surface applications and will not be discussed in this report.

Finally, a slower method uses mine vehicle tracking and location information to warn users of a potential collision. That type of system entails greater risk because of the time needed to take readings, process information at the surface and relay information back underground.

Advantages

- Increased worker safety.
- Productivity increased by lowering vehicle breakdown rate.

Limitations

- If not properly configured or designed, can generate false alarms and reduce productivity.
- Systems that use a magnetic field are generally more expensive.
- May result in personnel being less vigilant and relying solely on a technological solution (does not take the place of good work practices).

The **TramGuard 100** system from **Gamma Services International** (www.gsimining.com) and **Geosteering Mining Services LLC** (http://geosteeringminingservices.com) uses the principle of a generator-produced low-frequency magnetic field surrounding underground mining equipment. Personnel have to wear a receiver known as a Personal Alarm Device (PAD) that measures the strength of the magnetic field. The system works over a fairly short distance of about 12’ (3.66 m). It was designed specifically for continuous coal mining machines, which travel quite slowly, allowing time for the anti-collision system to react and stop the machine. The short range means that the detection system may not be able to react fast enough for vehicles travelling at a higher speed. Some information about the product is available on the manufacturer’s Web site.

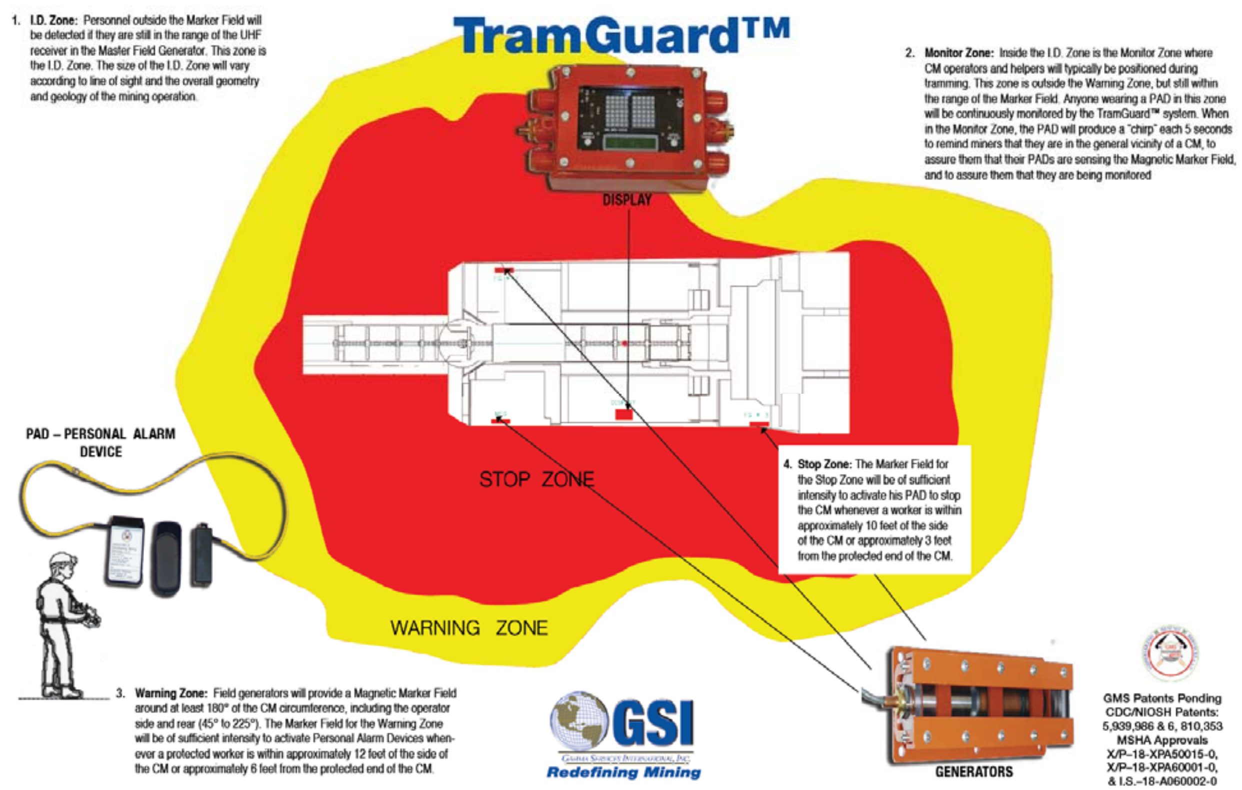

Figure 113 – TramGuard System from Gamma Services International

The **Buddy** system from **Nautilus International** (www.nautilus-intl.com) is also based on the principle of a generator-produced low-frequency magnetic field surrounding underground mining equipment. Personnel can wear a receiver in the form of a battery pack unit in their miner's cap lamp that measures the strength of the magnetic field. The receiver can also be integrated into the remote controls of a loader. The system works over a fairly short distance of about 15' (4.57 m). Unlike TramGuard, several versions of this system have been designed. There is a version for continuous coal mining machines, a version for loaders and a version for trucks. Very detailed information about these products is available on the manufacturer's Web site.

Figure 114 – Buddy System from Nautilus International

The **Jannatec Advanced Warning System (JAWS)** system from **Jannatec Radio Technologies** (www.jannatec.com) uses radio transceivers carried by personnel or mounted on vehicles. The radio transceivers detect the presence of other transceivers and issue a warning of a potential collision. The strength of the radio signal is used to determine distance in relation to another transceiver. The system can also use RFID tags. The anti-collision system is separate from the mine communications infrastructure. The system differentiates between different types of vehicles, personnel and even danger zones identified with a transceiver. There is little information about the product on the manufacturer's Web site.

Figure 115 – JAWS System from Jannatec

Becker NCS (www.becker-ncs.com) offers the **CAS (Collision Avoidance System)**, a system based on the detection of RFID tags at 433.92 MHz. The CAS receiver detects the presence of radio tags and tells the operator of the vehicle that personnel or other vehicles are in the vicinity. The system is designed to be able to exclude the operator and other radio tags as needed. Tag detection can be adjusted from 5 m (16.4') to 100 m (328'). Some information about this product is available on the manufacturer's Web site.

Figure 116 – CAS System from Becker NCS

MineCom (www.minecom.com) offers the **DACS600** (Dynamic Anti Collision System), a system based on the detection of RFID tags at 403 MHz. The CAS receiver detects the presence of radio tags and tells the operator of the vehicle that personnel or other vehicles are in the vicinity. Very little information about this product is available on the manufacturer's Web site.

Figure 117 – DACS 600 System from MineCom

Summary

Table 11 – Summary – Anti-Collision Systems

Company	Description	Advantages	Limitations
Becker NCS	Collision Avoidance System. Compatible with BeckerTag tracking and location system. Frequency 433.92 MHz.	Detection 5 m to 100 m. Takes into account occupants of vehicles equipped with the system.	Detects presence of radio tags, but not distance.
Gamma Services Inc. Geosteering Mining Services LLC	TramGuard. Uses low-frequency magnetic field around equipment. PAD measures strength of field and sounds alarm if too close.	System approved for coal mines.	Fairly short range of 3.66 m. System costly and bulky. Designed for fairly slow continuous mining machines.
Jannatec Radio technologies	J.A.W.S. Detection system based on strength of radio signal. Differentiates between personnel and several types of vehicles, equipment and danger zones.	Independent from existing communication systems and easy to install. Takes vehicle occupants into account. Wide range.	
MineCom	Dynamic Anti-Collision System. Frequency 403 MHz.		Very little information on the manufacturer's site.
Nautilus International	Buddy. Uses low-frequency magnetic field around equipment. BPU measures strength of field and sounds alarm if too close. System can be integrated into loaders' remote controls.	Anti-collision adapted for more than one type of equipment. Smaller generator.	Fairly short range of 4.57 m. Expensive.

Remote Controls and Remote Operation

Description

Most vehicle and equipment remote control systems use VHF, UHF and even Wi-Fi radio waves to send and receive commands. Some technologies use unique frequencies between remote controls and receivers on vehicles to ensure user safety. Others work on the same frequency but with unique ID codes that prevent a remote control from operating the wrong equipment.

Other systems control equipment by sending messages through the earth using very low frequency (ULF or VLF) magnetic waves. These systems are almost always unidirectional.

Finally, remote operation systems are used where there is a large distance between the equipment and the operator. They often use a cable network down to the equipment; if the equipment is mobile, the remaining communication is by radio. Remote operation requires the transmission of video and audio data and bidirectional commands at a very high flow rate with minimum latency. Cable communication systems appear to be best suited to this task.

Advantages

- Some systems use the mine's existing communication systems (Leaky Feeder, Wi-Fi) and thus permit long communication distances.
- Remote controls at UHF frequencies appear to be a better choice for communication distance where there is no line of sight.
- Remote blasting system (ULF/VLF or VHF/UHF) well designed and does not require a blasting line.
- Remote blasting systems (ULF/VLF or VHF/UHF) can save setup time for each blast.

Limitations

- Very low frequency control systems (ULF/VLF) often have no confirmation that all of the equipment has actually received the command.
- Leaky Feeder remote blasting system (VHF/UHF) requires continuous deployment and maintenance of the Leaky Feeder cable to the working face.
- Remote operation requires a communications system with a very high flow rate and minimum data transmission latency.

Smart Blast from **Varis Smart Underground Communications** (www.varismine.com) is a remote blasting system that uses Leaky Feeder communications systems. It is manufactured by Rothenbuhler Engineering (www.rothenbuhlereng.com) and is available in VHF and UHF versions. The advantage of this type of system is that it uses the communications system already in place in most mines. It is considered to be reliable and safe, as the blasting sequence is digitally encoded and communication is bidirectional. The remote unit performs a communication test with the control unit at the time of underground installation. However, the system requires the Leaky Feeder cable to be continuously extended and kept in very good condition almost all the way to the blasting site (max 300' or 91 m). A great deal of information about this product is available on the manufacturer's Web site.

Figure 118 – Smart Blast from Varis (UHF & VHF)

BlastPED from **Mine Site Technologies** (www.minesite.com.au) is a remote blasting system that uses Leaky Feeder communication systems or ultra low frequency (ULF) through-the-earth communication. The advantage of this type of system is that it uses the communications system already in place in most mines. The advantage of the version that uses ULF through-the-earth communication is that the Leaky Feeder cable does not have to be taken near the blasting site because the signal is everywhere underground. This means that less underground maintenance is required. However, the system does require a very large loop antenna on the surface. BlastPED is considered to be reliable and safe. Pumps, fans and other accessories can be operated remotely using the ControlPED system, which also uses ULF frequencies. A great deal of information about this product is available on the manufacturer's Web site.

Figure 119 – BlastPED and ControlPED from Mine Site Technologies (ULF)

Cattron-Theimeg (www.cattron.com) offers several models of remote controls for underground mining vehicles and also for surface applications. The frequencies used are in the UHF band (450-470 MHz) for remote control and 900 MHz for video signals. This is a good option for propagation in an underground mine environment. Cattron-Theimeg also offers a remote operation system that uses a proprietary TCP/IP system (CAT-800) that requires a cable network and then a wireless link if the equipment to be controlled is mobile. A great deal of information about this product is available on the manufacturer's Web site.

Figure 120 – Remote Controls (UHF) and Remote Operation from Cattron-Theimeg

Cattron-Theimeg/SIAMTEC (www.siamtec.com), offers several models of remote control for underground mining vehicles. The frequencies used are in the UHF band (800 MHz) for some models and the 2.4 GHz band for others, which is a good option for propagation in an underground mine environment. 2.4 GHz offers a line-of-sight communication distance of 600 m (1968') and 100 m (328') to 250 m (820') without line of sight. 800 MHz models are used for remote operation through the SIAMnet communications network. Some information about this product is available on the manufacturer's Web site.

Figure 121 – SIAMremote Remote Control and Receiver from SIAMTEC

Nautilus International (www.nautilus-intl.com) offers several models of remote controls for underground mining vehicles. The frequencies used are in the UHF band (406-520 MHz and 903-926 MHz), which is a good option for propagation in an underground mine environment. Some information about this product is available on the manufacturer's Web site.

Figure 122 – 140SSF Remote Control and Receiver from Nautilus

Hard-Line solutions (www.hard-line.com) offers a wide selection of remote control and remote operation systems. Most remote controls use UHF frequencies (902-928 MHz) and are therefore well suited to an underground mine environment. Where video is required, it is transmitted through a separate channel at 2.4 GHz. In some cases, remote operation is done through cable networks for distances under 300 m (984') and fibre optics for distances over 300 m and up to 4 km (2.48 miles). Some information about this product is available on the manufacturer's Web site.

Figure 123 – Remote Control and Remote Operation from Hard-Line Solutions

Meglab Électronique (www.meglab.ca) designs and manufactures some vehicle remote controls, but also devices for remote operation of stationary equipment (MicroData), such as pumps and fans. Meglab also offers a wireless control system for signals for the cage (MicroCage) to the hoist operator. Very little information about this product is available on the manufacturer's Web site.

Figure 124 – MicroData Remote Controls and Receivers from Meglab Électronique

Summary

Table 12 – Summary – Remote Controls and Remote Operation

Company	Description	Advantages	Limitations
Cattron Theimeg	Remote control system for underground mine vehicles at 450-470 MHz (UHF). Video carried on separate 900 MHz channel Remote operation system through proprietary TCP/IP network Cat-800.	UHF frequencies propagate very well in an underground environment without line of sight. Video at 900 MHz is a good choice.	
Cattron-Theimeg, Siamtec	SIAMremote II. Remote control system for underground mine vehicles at 800 MHz and 2.4 GHz. Remote operation using SIAMnet at 800 MHz.	Unique key code system for enhanced safety. UHF frequencies propagate very well in an underground environment without line of sight. Line-of-sight range 600 m at 2.4 GHz and 100 m to 250 m without line of sight.	Does not appear to be widespread.
Hard-Line Solutions	UHF remote control for vehicles at 902-928 MHz. Audio and video carried on separate channel at 2.4 GHz up to 183 m with line of sight.	UHF frequencies propagate very well in an underground environment.	Range of audio and video signals at 2.4 GHz limited where no line of sight.
Meglab Électronique	Remote control system for loader, cavo, backfill system and signals from cage through wireless links.	Wireless system for sending cage signals less costly to maintain than pull cords on each level.	Very little information on the Meglab Web site.
Mine Site Technologies	BlastPED. Uses VHF Leaky Feeder cable or through-the-earth ultra low frequency (ULF) at 400 Hz to 1000 Hz.	Digital encoding of data for enhanced security. Maintenance of conventional blasting lines eliminated. ULF signal present throughout mine (in theory).	BlastPED ULF: Unidirectional communication from surface to underground. Underground antennas have potential of breaking. Surface antennas up to 12 km in circumference. Potential shadow zones. BlastPED VHF: Leaky Feeder cable must be continuously extended to a maximum distance of 100 m from the blasting area and can be damaged.
Nautilus International	UHF remote control 406-520 MHz and 903-926 MHz.	UHF frequencies propagate very well in an underground environment.	
Varis Smart Underground Communications	Smart Blast. Uses a VHF or UHF Leaky Feeder cable	Digital encoding of data for enhanced security. Bidirectional communication. Confirmation of communication between remote unit and control unit before blasting (safety poll). Maintenance of conventional blasting lines eliminated. No need to install another communications system.	Leaky Feeder cable must be continuously extended to a maximum distance of 100 m from the blasting area and can be damaged.

Results of Survey on Underground Communications

A survey of 13 mining companies was conducted in the summer of 2008. The results of the survey are presented in the following pages.

The first question concerned the communication technologies currently used by mining companies. The respondents were asked (Yes or No) whether they used the technologies indicated. The most popular communication technologies are Leaky Feeder cable, optical fibre and cable network.

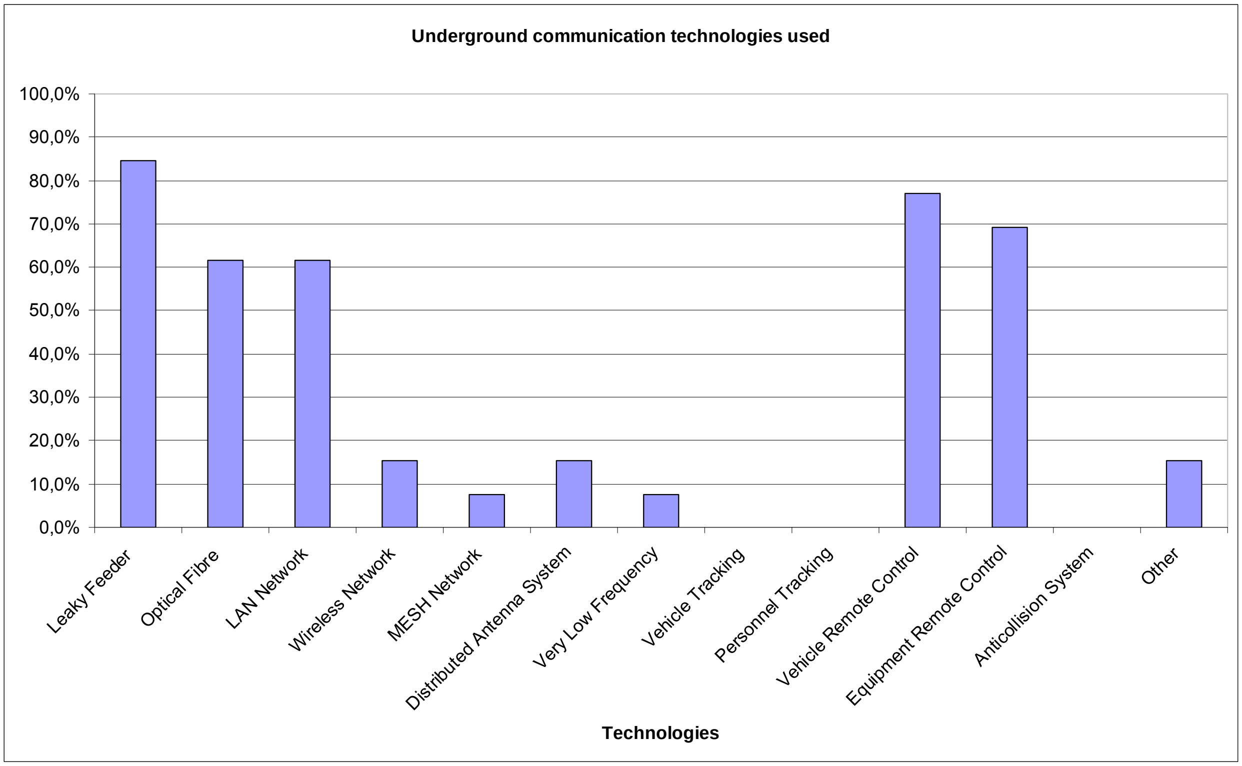

Figure 125 – Communication Technologies Used

The second question concerned the level of knowledge of underground communication technologies. The respondents were asked to rate their knowledge of each technology on the following scale:

1. Very little or no knowledge
2. Little knowledge
3. Good knowledge
4. Very good knowledge
5. Excellent knowledge

In the chart, each blue line indicates the range of the respondents' answers. The longer the blue line, the wider the range of knowledge. For example, knowledge of Leaky Feeder cable communication systems and remote control systems was rated between 3 and 5, or Good to Excellent. However, knowledge of mesh network, distributed antenna and tracking and location systems was rated between 1 and 5, or Very Little to Very Good.

The red square indicates the average rating. Comparison of the first two charts immediately shows that the most widely used technologies are the best-known technologies. Are they better known because they are the most widely used or vice versa?

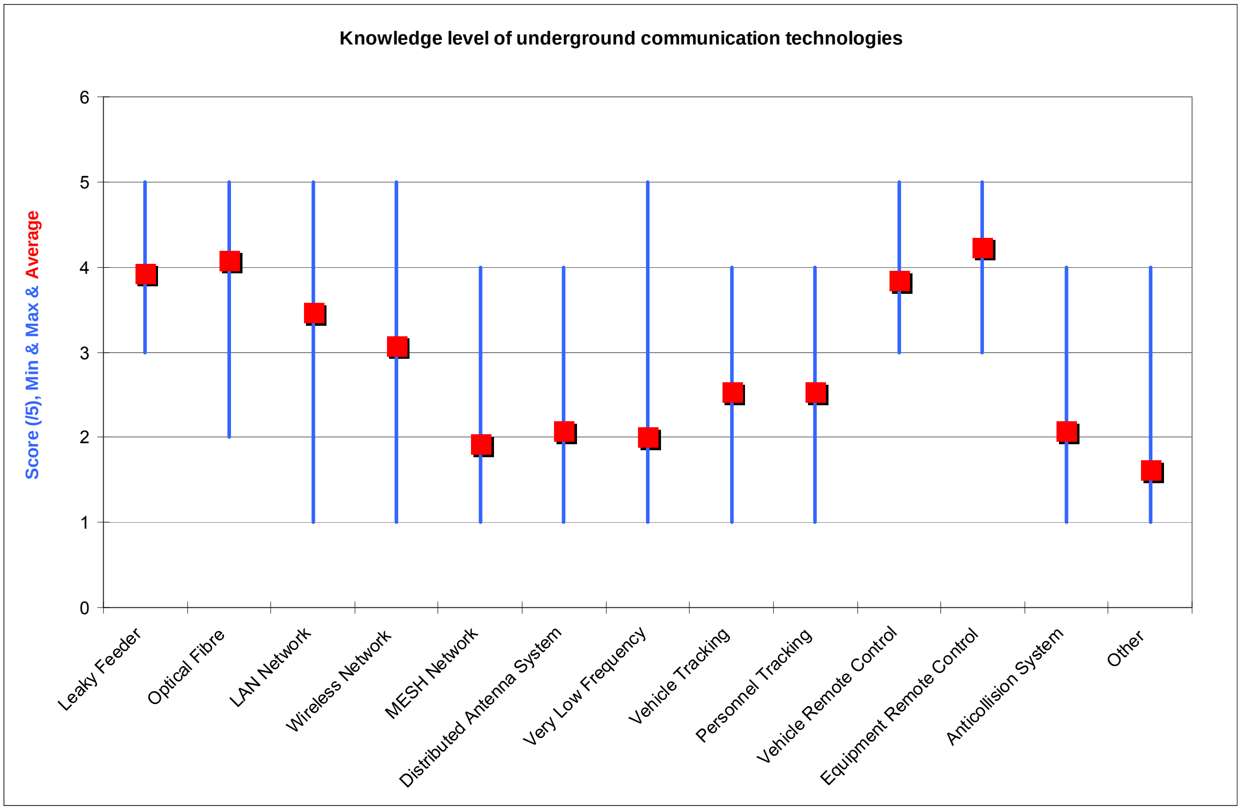

Figure 126 – Knowledge of Underground Communication Technologies

The third question concerned the way mining companies use their existing communication infrastructures. The respondents were asked to identify the communication infrastructures they use for each application listed. Once again, Leaky Feeder cable, optical fibre and Ethernet cable networks are the technologies most widely used for applications.

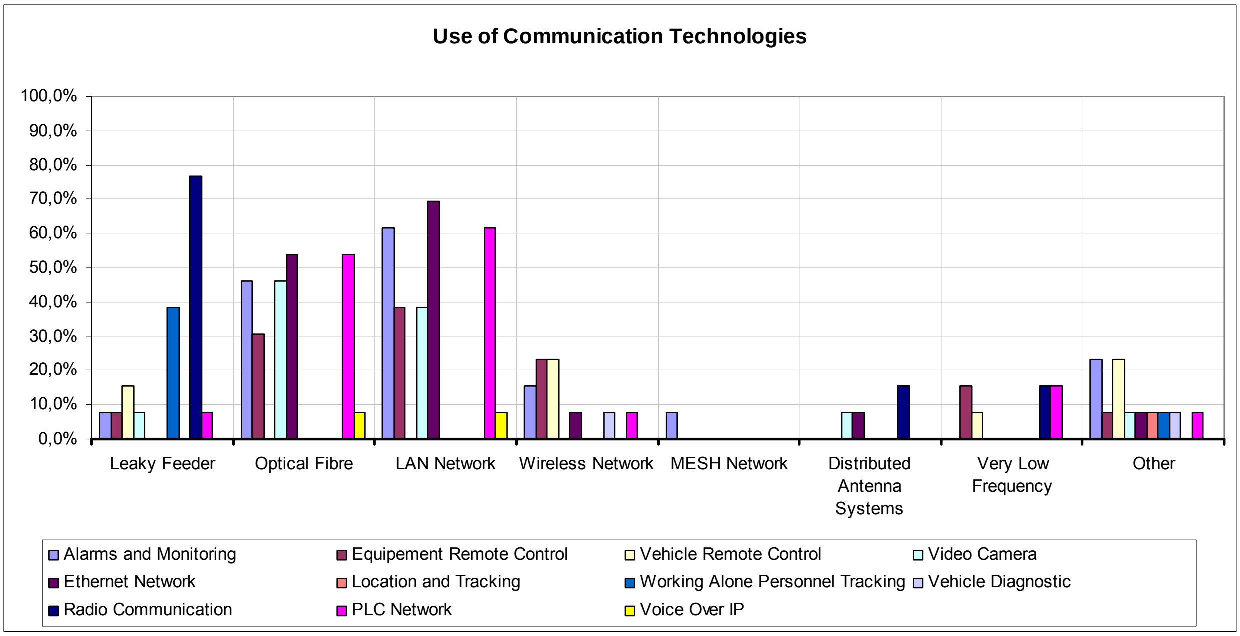

Figure 127 – Use of Communication Technologies

The fourth question concerned the respondents' perceptions of underground communication technologies. The respondents were asked to rate seven aspects of their perception of underground communication technologies:

- Reliability
- Purchase cost
- Ease of installation
- Maintenance costs
- Ease of maintenance and repair
- Ease of operation
- Capacity (data, voice, etc.)

The rating scale was:

1. Very bad
2. Bad
3. Average
4. Good
5. Very good

As in the second question, each blue line indicates the range of the respondents' answers. The longer the blue line, the wider the range of knowledge. The red square indicates the average rating. The grey column is the number of respondents who gave a rating.

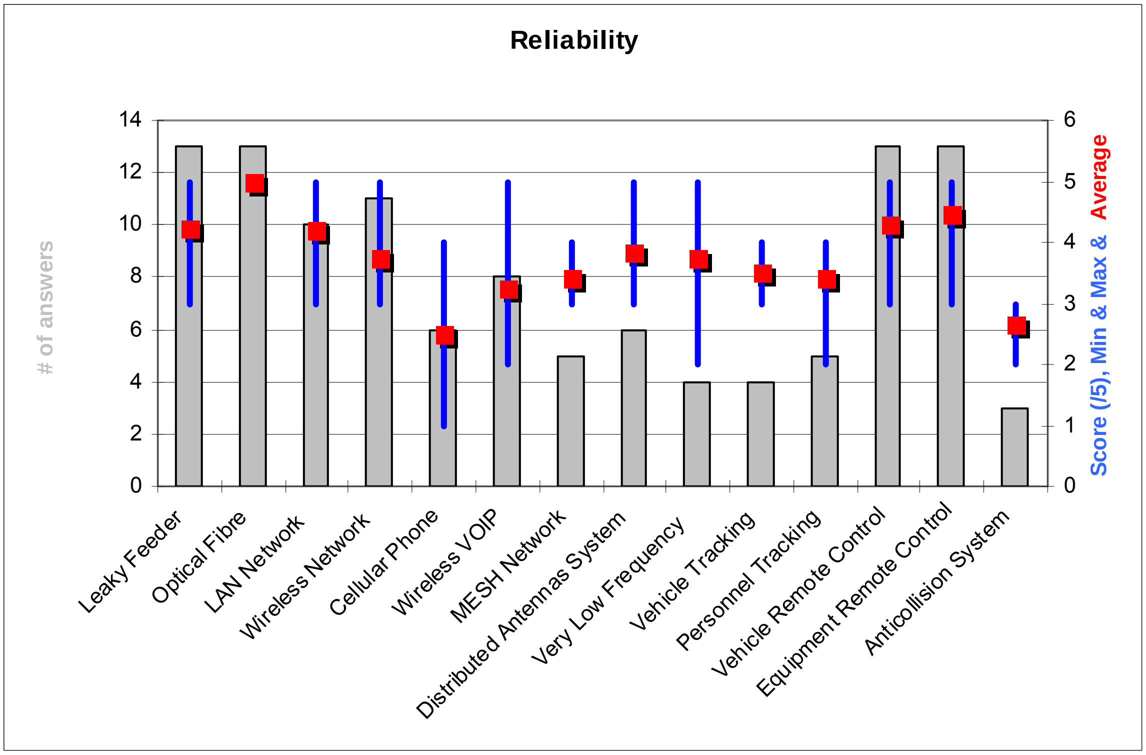

Figure 128 – Perception of Reliability

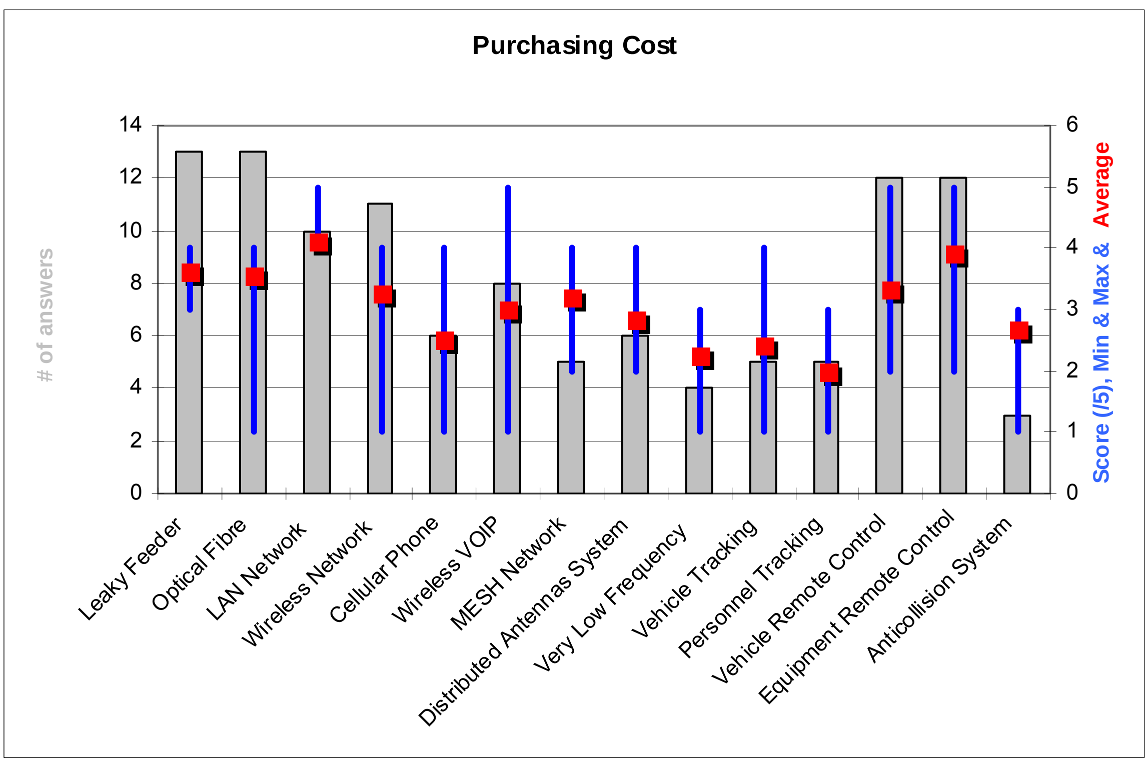

Figure 129 – Perception of Purchase Cost

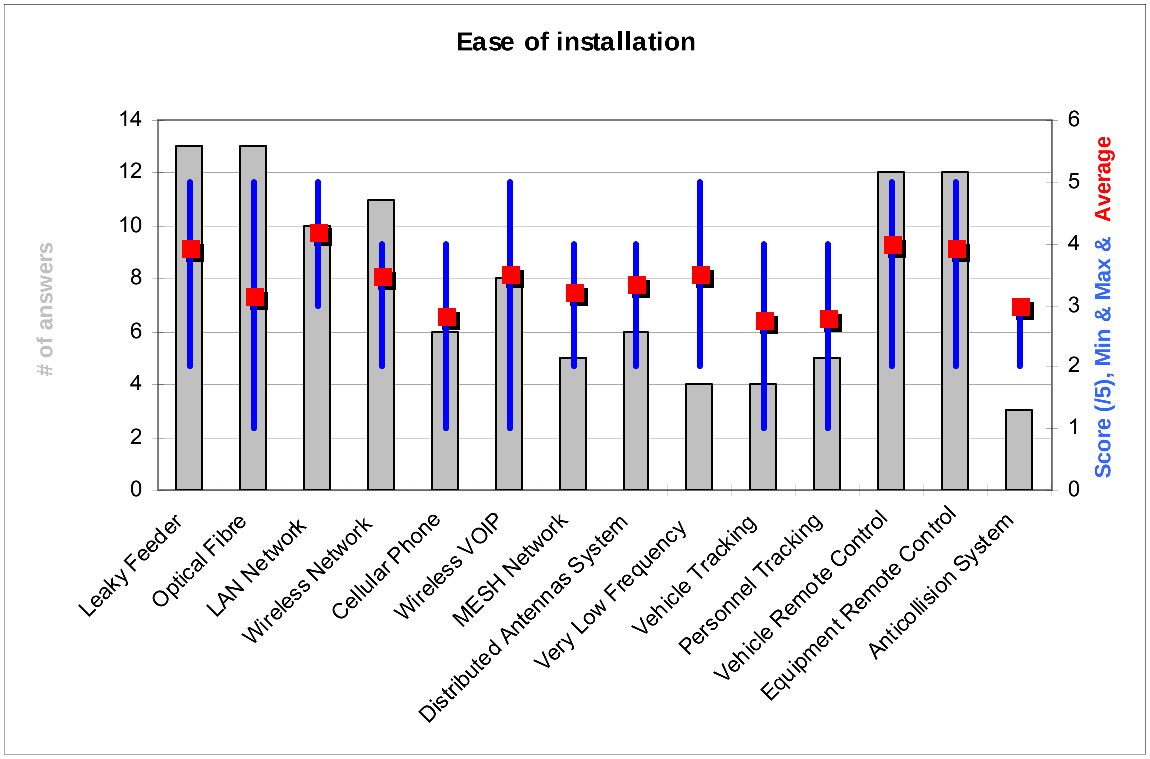

Figure 130 – Perception of Ease of Installation

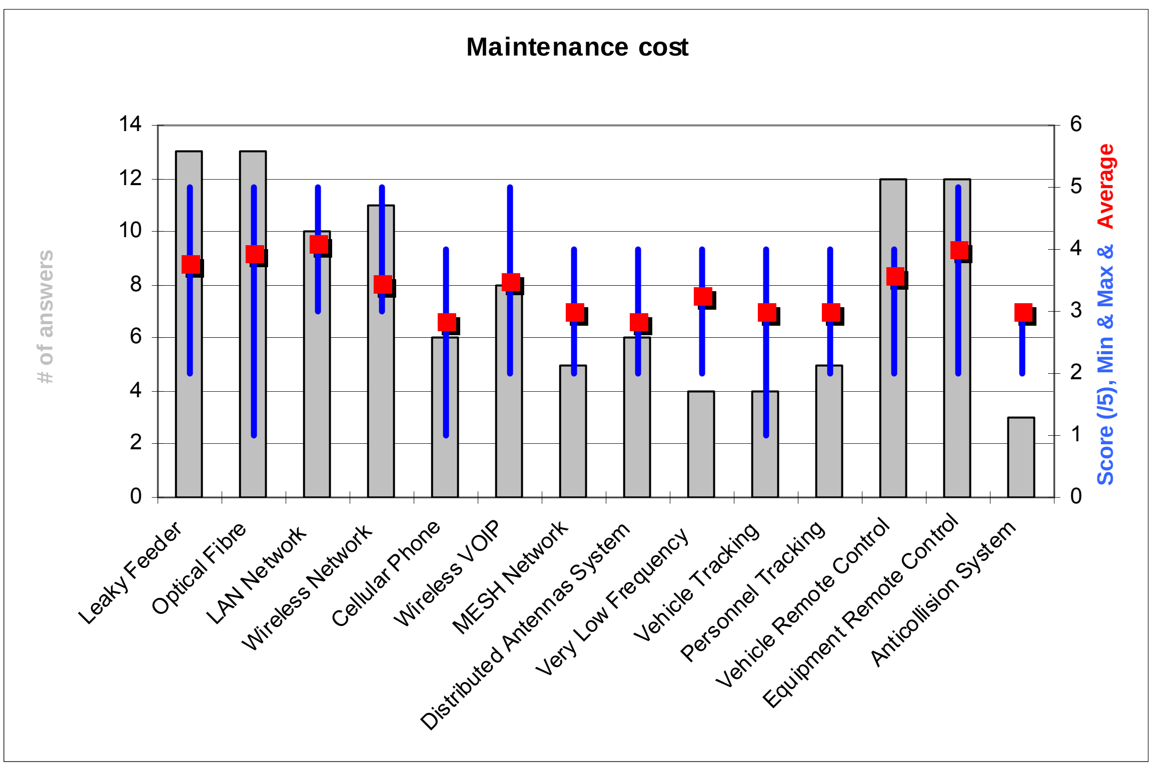

Figure 131 – Perception of Maintenance Costs

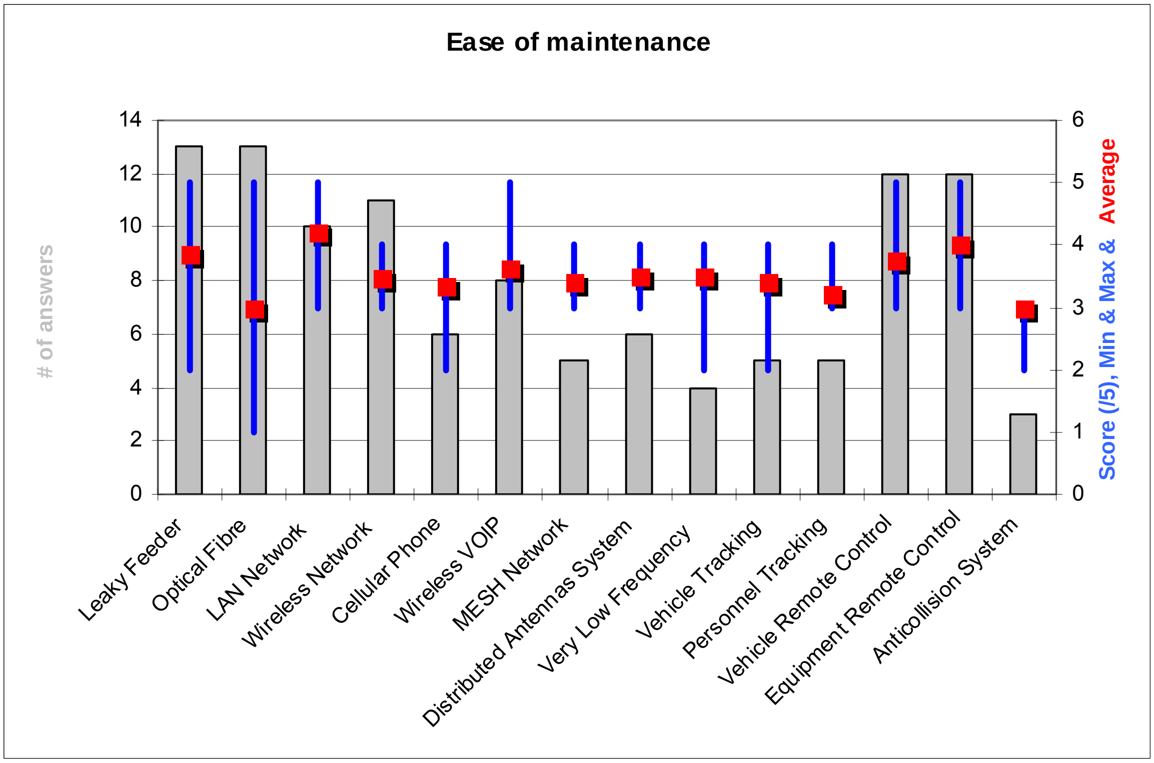

Figure 132 – Perception of Ease of Maintenance

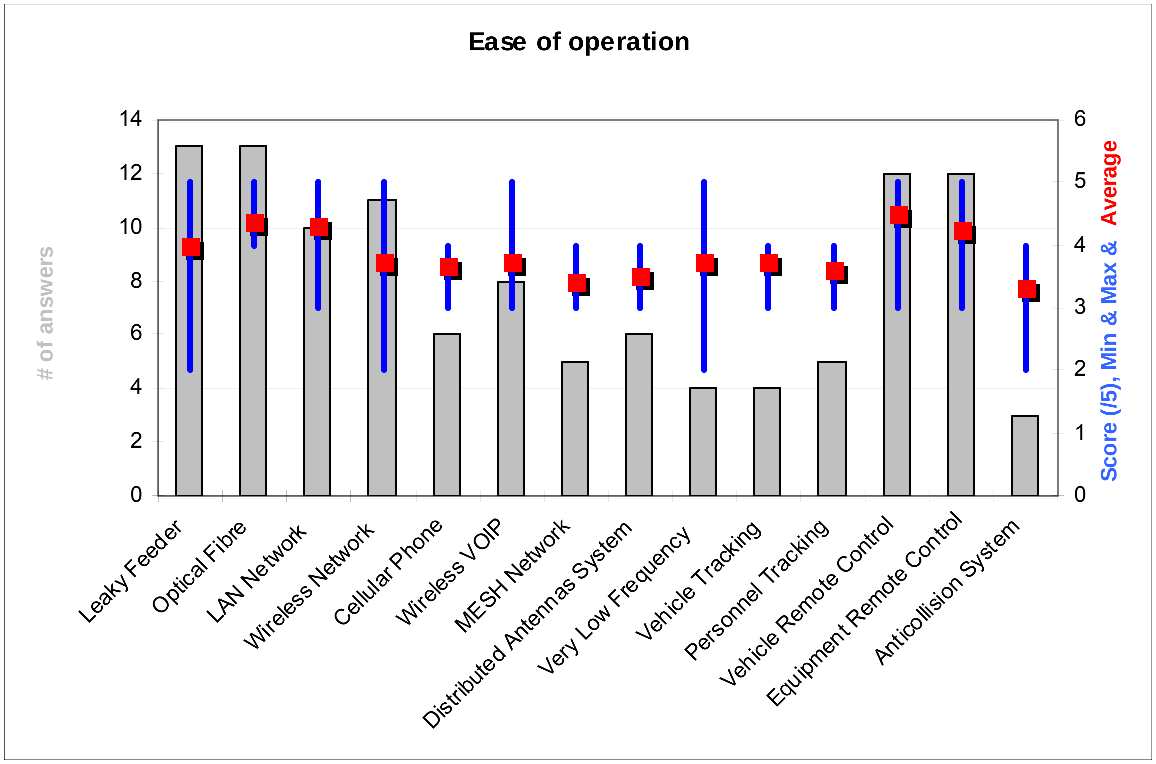

Figure 133 – Perception of Ease of Operation

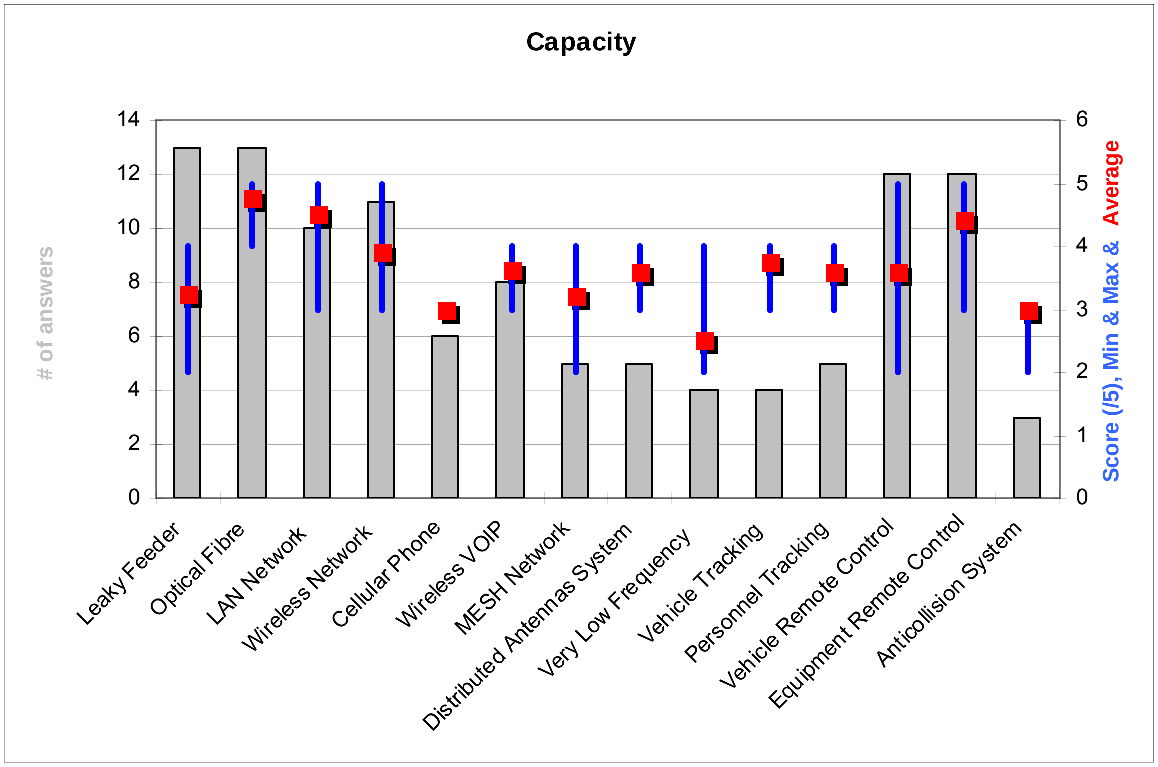

Figure 134 – Perception of Capacity

The last question in the survey asked the respondents if their underground communications needs were being met by manufacturers. The respondents could answer Yes or No. It appears that 8 out of 11 respondents are happy with the products currently on the market.

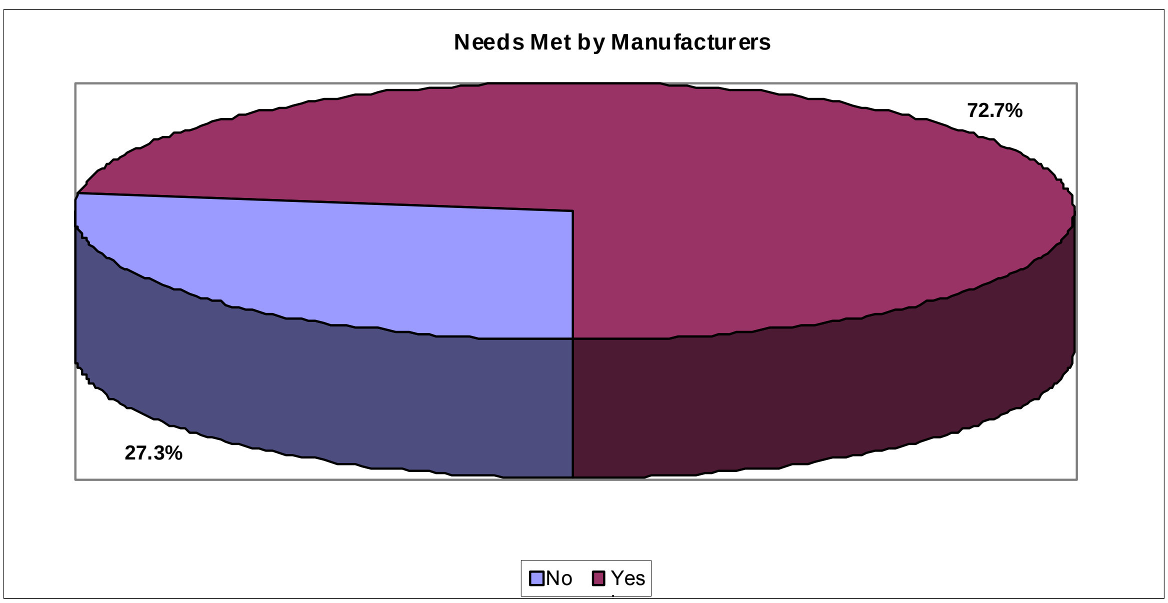

Figure 135 – Needs Met by Manufacturers

Conclusion

Analyses and test results of the various underground communication systems brought a number of interesting points to light. Compilation of selected data from the communications system tests based on frequency used, roof height in underground test area and distance covered yielded the following chart.

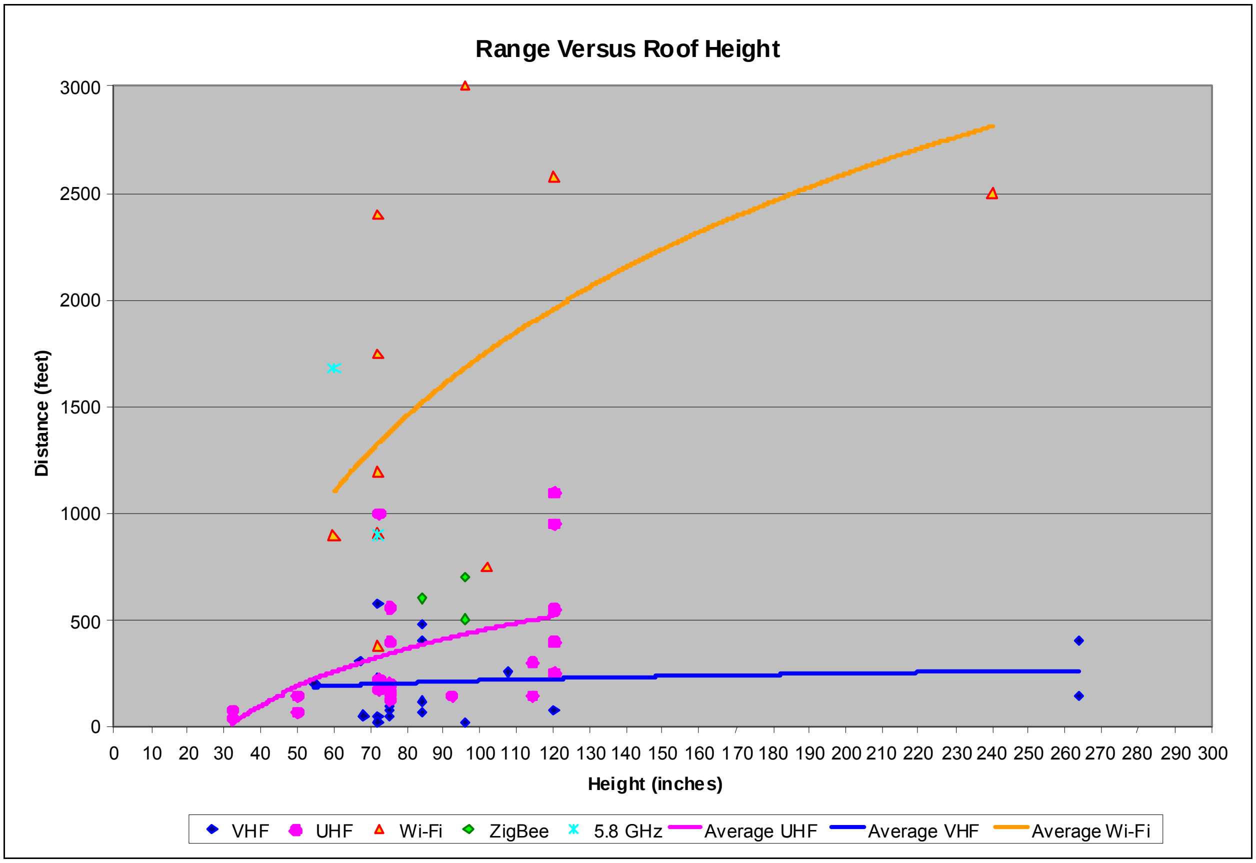

Figure 136 – Range as a Function of Roof Height and Line-of-Sight Frequency

The chart clearly shows that Wi-Fi signal frequencies at 2.4 GHz outperform the other lower frequencies. It must be remembered, however, that some communication distances at 2.4 GHz were obtained with directional antennas, whereas the tests using UHF and VHF radios were conducted with omnidirectional antennas. Note that the UHF frequencies outperform the VHF frequencies. It is important to bear in mind that the data used to produce the chart are for line-of-sight or near line-of-sight communications.

The following chart presents more of the data gathered during the tests, including data obtained where the tests were conducted with no line of sight, the communication quality was acceptable and the signal strength dropped to approximately 50%.

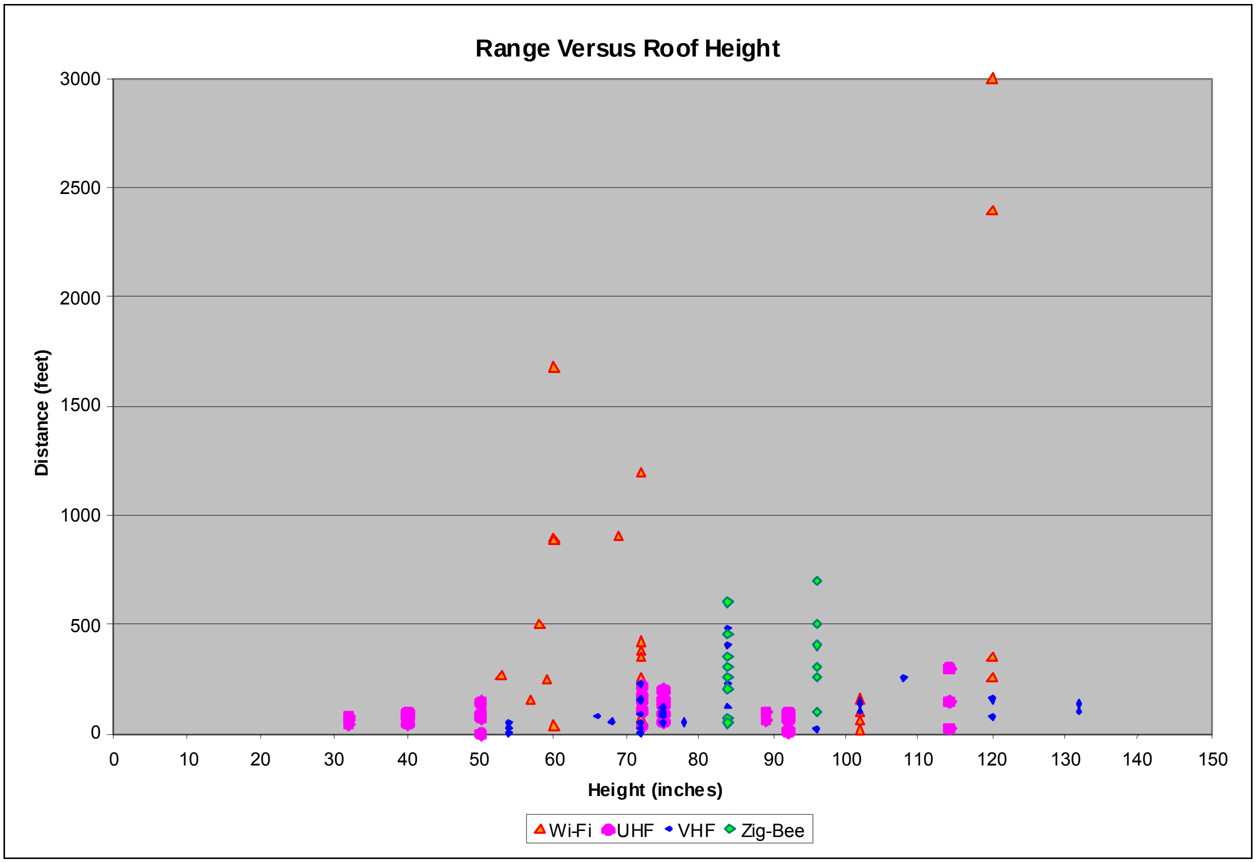

Figure 137 – Range as a Function of Roof Height and Frequency

This chart, too, shows that Wi-Fi signal frequencies at 2.4 GHz outperform the other lower frequencies. UHF frequencies rank second, followed by VHF frequencies. There is little data on the Zig-Bee signal (2.4 GHz), but it is clear that this low power signal has excellent potential. It would fall between Wi-Fi and UHF. One important consideration to bear in mind is that the radio power levels used are not specified for most of the tests.

The tests conducted at American coal mines suggest that VHF frequencies have more trouble turning around or passing through pillars, concrete walls and other obstacles, especially where the roof is low. UHF and Wi-Fi frequencies performed better in similar conditions. VHF Leaky Feeder communication systems appear not to perform as well as other communications systems, but they are still very reliable and widely used for radio voice communication.

Based on the information gathered, there does not seem to be one communications system that meets all the requirements of the United States' Miner Act of 2006. Most of the systems that use optical fibre, coaxial cable, Leaky Feeder cable or any other cable to carry communications will not function if they break unless there is a redundant system and an alternative route that allows communications to reach the surface.

Wireless mesh networks require a communications link between nodes. In surface applications, each node can be connected to many other nodes by radio link. In underground galleries, nodes are usually arranged in a linear configuration, and the signal could be impeded or cut off completely if any galleries were to collapse. Again, there has to be an alternate route so that the mesh network can get communications to other nodes and ultimately to the surface. That may not be possible in long dead-end galleries that are not connected to other levels or the surface. In addition, there has to be a separate back-up power system for each node in case the electrical power cable is cut.

Ultra low frequency communications are promising, because even with no underground infrastructures, they are able to communicate with miners equipped with receivers. Communication is usually unidirectional, however, and very often limited to some extent in terms of underground coverage distance. UWB technology, though meant for short-distance applications in the commercial sector, could be used as a communications system in isolated areas of underground mines where there is no communications infrastructure.

The information gathered in this study shows that considerable effort has been made in recent years to advance knowledge in the field of underground communications and make practical use of that knowledge. Still, a great deal of work remains to be done in order to meet the objective set by the United States in the Miner Act of 2006.

Acknowledgments

CANMET-MMSL would like to thank the West Virginia Office of Miners' Health, Safety and Training (www.wvminesafety.org) for allowing us to use and present some of their findings. This report would not be as comprehensive as it is without the research carried out by that organization, which is dedicated to the health and safety of miners in the state of West Virginia.

CANMET-MMSL would also like to thank the Québec Mining Association (Association minière du Québec www.amq-inc.com) for their assistance in distributing the survey on underground communication technologies to their members. We are also grateful to all the mining companies that completed the survey.

References

Manufacturers or Suppliers

www.activecontrol.com. Active Control Technology Inc. December 18, 2008.

www.advminingtech.com.au. Advanced Mining Technologies. December 18, 2008.

www.aeroscout.com. Aeroscout. December 18, 2008.

www.afltele.com. AFL Telecommunications. December 18, 2008.

www.americanmineresearch.com. American Mine Research, Inc. December 18, 2008.

www.becker-mining.com. Becker Mining Systems. December 18, 2008.

www.becker-ncs.com. Becker Newcomm Solutions. December 18, 2008.

www.cattron.com. Cattron (Siamtec). December 18, 2008.

www.cervisinc.com. Cervis Inc. December 18, 2008.

www.ctc.com. Concurrent Technologies Corporation (CTC). December 18, 2008.

www.conspec-controls.com. Conspec Controls Inc. December 18, 2008.

www.daveytronic.com. Davey Bickford. December 18, 2008.

www.deltaremote.com. Delta Remote Control Systems. December 18, 2008.

www.ekahau.com. Ekahau. December 18, 2008.

www.el-equip.com. ELEQUIP. December 18, 2008.

http://geosteeringminingservices.com. Geo Steering Mining Services, LLC. December 18, 2008.

www.ggautomation.com. GG Automation Inc. December 18, 2008.

http://gsimining.com. GSI: Gamma Service International, Inc. December 18, 2008.

http://hannahengineering.com. Hannah Engineering. December 18, 2008.

www.helicomm.com. Helicomm. December 18, 2008.

www.hard-line.com. HLS HARD-LINE Solutions Inc. December 18, 2008.

www.identecsolutions.com. Identec Solutions. January 16, 2009.

www.iwtwireless.com. Innovative Wireless Technologies. December 18, 2008.

www.insetsystems.com. InSeT Systems LLC. December 18, 2008.

www.ipackets.com. iPackets International, Inc. December 18, 2008.

www.ivolve.com. iVolve Information Technology. December 18, 2008.

http://jannatec.com. Jannatec Radio Technologies. December 18, 2008.

www.kuttatech.com. Kutta Technologies. December 18, 2008.

www.gses.l-3com.com. L-3 Communications Global Security & Engineering Solutions. December 18, 2008.

www.magnetoinductive.com. Magneto-Inductive Systems Limited. December 18, 2008.

www.ultra-uems.com/pdfs/MI_Rock_Phone%20_Report_Paris.pdf. MI Rock Phone Test Report – Underground demonstration to the Paris Police Prefecture. January 6, 2009.

www.marco-na.com. Marco North America. December 18, 2008.

www.matrixdginc.com. Matrix Design Group. December 18, 2008.

www.meglab.ca. Meglab Électronique. December 18, 2008.

www.meshdynamics.com. Meshdynamics. December 18, 2008.

www.mineradio.com. Mine Radio Systems. December 18, 2008.

www.minesite.com.au. Mine Site Technologies. December 18, 2008.

www.minecom.com. Minecom. December 18, 2008.

http://ventureminetracer.com. MineTracer. December 18, 2008.

www.multispectral.com. Multispectral Solutions, Inc. December 18, 2008.

www.nautilusautomation.com. Nautilus Automation. December 18, 2008.

www.nautilus-intl.com. Nautilus International. December 18, 2008.

www.newtraxtech.com. Newtrax Technologies. December 18, 2008.

www.nltinc.com. NL Technologies Inc. December 18, 2008.

www.omnexcontrols.com. OMNEX Controls Systems ULC. December 18, 2008.

www.polycom.com. Polycom. December 18, 2008.

www.pyottboone.com. Pyott-Boone Electronics. December 18, 2008.

www.rajant.com. RAJANT Corporation. December 18, 2008.

www.rothenbuhlereng.com. Rothenbuhler Engineering. December 18, 2008.

www.siamtec.com. SIAMTEC. December 18, 2008.

http://www.automation.siemens.com/net/html_76/produkte/050_scalance_w700.htm. Siemens Scalance Wireless Communication. January 13, 2009.

www.subterracom.com. SubTerra Wireless Communications. December 18, 2008.

www.timedomain.com. Time Domain Corporation. December 18, 2008.

www.transtekcorp.com. TRANSTEK. December 18, 2008.

http://new.tunnelradio.com. Tunnel Radio of America. December 18, 2008.

www.ultra-uems.com. Ultra Electronics Maritime Systems. December 18, 2008.

www.varismine.com. Varis Mine Technology Ltd. December 18, 2008.

www.vitalalert.com. Vital Alert. December 18, 2008.

www.wirelesssecureinsight.com. Wireless Secure Insight (WSI). December 18, 2008.

Government References

www.cdc.gov/niosh/mining/mineract/communicationsandtracking.htm. NIOSH Mining: Miner Act - Communications and Tracking | CDC/NIOSH. December 18, 2008.

www.msha.gov/MinerAct/MinerActSingleSource.asp. The Mine Improvement and New Emergency Response Act of 2006. January 6, 2009.

http://www.msha.gov/techsupp/commoandtracking.asp. Communications and Tracking for Underground Mines, January 14, 2009.

http://www.msha.gov/techsupp/pedlocating/consolmcelroyfullreport.pdf. Underground Communication and Tracking Systems Tests at CONSOL Energy Inc., McElroy Mine. January 14, 2009.

www.cdc.gov/NIOSH/. The National Institute for Occupational Safety and Health, January 14, 2009.

www.wvminesafety.org. West Virginia Office of Miners' Health, Safety and Training. December 18, 2008.

www.wvminesafety.org/Communications and tracking.htm. West Virginia Office of Miners' Health, Safety and Training, Emergency Communications & Tracking. December 18, 2008.

www.wvminesafety.org/comtraclibrary.htm. West Virginia Office of Miners' Health, Safety and Training, Emergency Communications & Tracking. Communication and Tracking Library. December 18, 2008.

www.wvminesafety.org/contrmanufdoc.htm. West Virginia Office of Miners' Health, Safety and Training, Manufacturers' Approval Documents. Manufacturers' Approval Documents. December 18, 2008.

Leaky Feeder Cables

www.afltele.com/products/fiber_optic_cable/coax_cable/leaky_coax/index.html. AFL Telecommunications Leaky Coaxial Cable. January 13, 2009.

http://awapps.commscope.com/catalog/product.aspx?id=322. Andrew Radiating Cable, January 13, 2009.

www.benelec.com.au/nk_cables/radiating_cables.htm. NK Radiating Cable, January 13, 2009.

www.draka.com/draka/DrakaCableteq/Cableteq_Mobile_Network/Languages/English/Navigation/Products/RFX_-_Coaxial_Antennas/index.html. Draka Coaxial Antenna, January 13, 2009.

www.rfsworld.com/index.php?p=226&l=1. Radio Frequency Systems Radiaflex Radiating Cable, January 13, 2009.

http://www.automation.siemens.com/net/html_76/produkte/050_rcoax_cable.htm. Siemens IWLAN RCoax Cable, January 13, 2009.

www.timesmicrowave.com/wireless/index.shtml. Time Microwave Systems Leaky Feeder Radiating Cable, January 13, 2009.

www.trilogycoax.com/products_wireless_radiating.shtml. Trilogy Communications Inc AirCell Radiating Cable, January 13, 2009.

General

http://en.wikipedia.org/wiki/Extremely_low_frequency. Wikipedia, Extremely Low Frequency, January 16, 2009.

http://en.wikipedia.org/wiki/MELP. Wikipedia, Mixed Excitation Linear Prediction, January 12, 2009.

http://en.wikipedia.org/wiki/Medium_frequency. Wikipedia, Medium frequency, January 16, 2009.

http://en.wikipedia.org/wiki/Ultra_high_frequency. Wikipedia, Ultra high frequency, January 16, 2009.

http://en.wikipedia.org/wiki/Ultra-wideband. Wikipedia, Ultra-wideband, January 16, 2009.

http://en.wikipedia.org/wiki/Very_high_frequency. Wikipedia, Very high frequency, January 16, 2009.

http://en.wikipedia.org/wiki/Very_low_frequency. Wikipedia, Very Low Frequency, January 16, 2009.