EVALUATION OF COMMUNICATION SYSTEMS FOR DEEP LEVEL MINING MONITORING APPLICATIONS

P.J.J. van Wyk[1*], G.A. Oosthuizen[2] and P.J.T Conradie[3]
[1]Department of Industrial Engineering
University of Stellenbosch, South Africa
15311910@sun.ac.za

[2]Department of Industrial Engineering
University of Stellenbosch, South Africa
tiaan@sun.ac.za

[3]Department of Industrial Engineering
University of Stellenbosch, South Africa
pconradie@sun.ac.za

ABSTRACT

Deep level mining companies face many problems affecting their development and profitability. One of these problems affecting growth is the lack of effective, yet economically viable, communication systems. This is especially necessary in rapidly expanding and changing environment mines. Resource companies need constantly growing revenues to remain competitive in the current mining industry. This paper identifies the constraints associated with applying communication systems in deep level mines, both the constraints affecting the physical machinery as well as constraints affecting the labourers installing, operating and maintaining the system. The existing communication systems are identified and then critically evaluated. The evaluation is done by identifying the advantages and disadvantages of each system, and by comparing the costs associated. The constraints play a prominent role in the evaluation phase as certain technologies immediately are discarded as possible selections when they clash with conflicting constraints. The results of the evaluation process are used to determine possible solutions with respect to communication problems faced in mining applications. Recommendations are made on the most efficient and cost effective technologies according to the results. These recommendations are used by mining companies to improve their current communication systems.

[*]Corresponding author

1. INTRODUCTION

Rockfalls occur in environments of all the mining commodities in South Africa. Rockfall fatalities occur predominantly in gold, coal and platinum mining environments as provided in the 2004-2005 Mine Health and Safety Council annual report [1]. The development of a measuring and monitoring methodology that could quantify the rockfall risk and allow for pro-active alleviation of such a hazard/risk is done by the CSIR [2]. The project specified that the methodology should provide for the recognition of the precursory indications of rockfalls; interpret the predominant and critical mechanisms involved in rockfalls; and develop algorithms to combine the critical parameters in order to activate an alarm. It is also well known in the mining industry that fragmentation has a pivotal role on downstream production outcome, cost and quality of the metal or mineral recovery [2]. In the gold mining industry monitoring of the fragmentation can play a significant role in improvement of the gold extraction from an ore body. After arrival of the rock on the surface, it is treated in the crushers and mills, where properly distributed fragmentation can help to optimize treatment process and reduce cost. The crushing time, consumption of steel balls, water and energy highly depends on the fragmentation of the delivered rock. An open standard architecture called AziSA for communication of sensor data, and a reference implementation using that standard [3] has been developed. AziSA is an architecture for measurement and control networks that can be used to collect, store and facilitate the analysis of data from challenging underground environments.

Figure 1 illustrates the main functions included in this architecture.

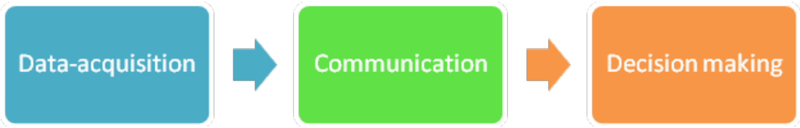

Figure 1: Systems included in the AziSA architecture for monitoring deep level mining operations

This architecture was created because the existing identified protocols could not offer an organized and open architecture for low power, low-cost, wireless systems [4]. It allows for dense sensor arrays in the workplace, wireless communication to the closest power line, and TCP/IP communication to a central server [2]. The current communication standard of choice is WiFi with its open architecture, high bandwidth and freely available hardware [5]. The ZigBee [6] standard has the potential to be a repeater system for longer distance transmission as part of the AziSA network, and is being considered as an alternative standard. Technological advances in mining are not always widely embraced with a large proportion of the this industry, as they are reluctant to make use of new and innovative communication solutions (even though many of these methods have been tested and proven)[7]. Many mines still make use of old, outdated communication technologies. A number of communication technologies that are popular in the mining industry are listed in Table 1.

Technology	Description
VHF (Very High Frequency) Leaky Feeders	Coaxial cable modified to allow signals inside the centre wire to emit through the cable housing and effectively "leak" to the outside. Frequency range30MHz – 300MHz
UHF (Ultra High Frequency) Leaky Feeders	Same as UHF but with frequency rang 300MHz – 3000MHz. Less noise disturbance and propagates better around corners
Optic Fibre and Ethernet Networks	Fibre optic cables with extensions of standard unshielded twisted pair (UTP) cables (usually Cat 5e). It uses TCP/IP (Transmission Control Protocol/ Internet Protocol for data transfer as well as VoIP (Voice-over-Internet-Protocol)
Wi-Fi (Wireless Fidelity)	Wireless communication that uses the 802.11 IEEE standards
Telephone and Paging Systems	Implemented in older mines

Table 1: Popular communication technologies in the mining industry [7],[8],[9],[10]

There are many different types of technologies that have been implemented in mines as shown in Table 1. These Ethernet networks (both Optic Fibre and UTP varieties) as well as Leaky Feeders are the most commonly used communication methods in modern mines. Apart from measuring and monitoring, these technologies also track personnel and assets underground, communicate and optimize schedules through tracking [11].

2. RESEARCH APPROACH

It is important to understand the people and environment for which the innovative communication technology is designed. To attain this, the approach to this study is illustrated in Figure 2.

Figure 2: The research approach to design communication technologies for deep level mining applications

The first phase of this study was to understand the mining environment better by contacting specialists in the field, conducting a thorough literature study and completing surveys. In the second phase various communication technologies were explored for these applications. More than 20 systems were explored, before it was prioritized to 12 technologies. Finally, various communication technologies could be evaluated by comparing strength and weaknesses.

3. MINING ENVIRONMENT CHALLENGES AND APPLICATIONS

There are several challenges associated with applying a technology in deep level mines. Possibly one of the most important constraints is the underground environment itself. The temperature can be up to and above 60°C [12], relative humidity can exceed 90% and corrosive water and dust can also be present[13]. Toxic and explosive gasses are often found, making open sparks very undesirable. The implication of these environmental constraints is the added cost of specially insulating and shielding every component [13]. Cables are also most often damaged by seismic activity (i.e. rock falls) and normal mining activity. Should a cable be damaged, disabling communication, the loss of productivity will be directly translated into a loss of profit [14]. Mines are a dynamic environment in the sense that they are always changing and often expanding, and with the rock mass preventing radio signal propagation it becomes even more difficult to devise a permanent communication solution and adding to cost (as new cable must be added as the mine grows). Radio signals can also be affected by particular characteristics of a mine such as the type of ore, which may have electromagnetic properties interfering with the signals, as well as the style of mining, where the differing structures especially affects TTE (through-the-earth) communication [13]. Another important constraint is the maximum permissible level of power with which a device may operate [13]. Further criteria for communication systems in deep level mining include conforming to the AziSA standards as set forth by the CSIR [11] to be cost effective, maintenance free and quick and easy to deploy. This system includes the use of a network of sensors for monitoring purposes. By analyzing these requirements it can be seen that the most important requirement for sensors is to be wireless (and thus also reduce the damage caused by seismic activity) and secondly have very low energy consumption (batteries must last the effective lifetime of the sensor, eliminating maintenance). The network itself must, like the sensors, also require low maintenance [11]. To improve the overall safety of the mine workers, workers must be kept away from the stoping area. A large number of fatalities occur in the stoping area and is thus a problem area which must be targeted in this investigation. [15]. The technologies identified and evaluated will be used in two main areas of the mine: in stope and from stope to shaft. A schematic layout of the stope to shaft and stoping area is shown in Figure 3.

3.1 In-stope

Initial investigation showed that in-stope communication would have to be wireless. The environment is simply too hostile to consider wired sensors. Investigation into short-range low power wireless networks revealed two major players: the TinyOS system from UC Berkeley and Zigbee, which is an open standard. It was decided that Zigbee would be the protocol of choice for in-stope communication [2]. Each sensor may act as a network router and network paths are dynamically determined and are automatically re-arranged should any sensor fail. At the nearest electrical power, an aggregator is placed that also functions as a bridging device between the in-stope Zigbee and the power line communication (or any other Internet Protocol communication) to the shaft area.

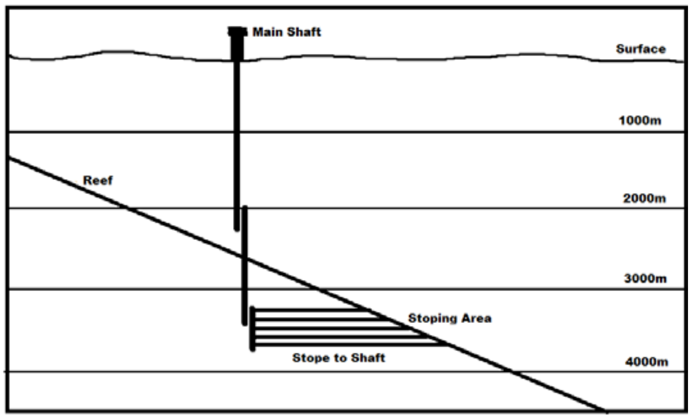

Figure 3: Typical Schematic Layout of a Shaft Mine

3.2 Stope to shaft

Extensive mining in a tabular ore body leads to long distances from stope to mining shaft. In many cases no fast communication (semi-broadband) cabling exists and it is envisaged that Power Line Communication (PLC) will be used. PLC essentially transforms the power grid into a network carrying broadband communication in the form of an IP (Internet Protocol) signal. Commercial equipment is to be used and an evaluation of such equipment in an underground environment is being undertaken [2].

4. COMPETITIVE COMMUNICATION SYSTEMS

An innovative framework was developed by the CSIR which defines a standard architecture and set of protocols which govern the use of communication technologies in a mining network. This framework is called AziSA (Zulu for 'to inform') and is an open standard based on other open standards (IEEE 1451, Zigbee and CORBA)[15]. AziSA is not technology specific and allows any device which meets the standard to be integrated into the supporting system. This system focuses on the use of wireless technologies, specifically wireless sensors [11]. A list of possible communication technologies which are available was compiled and is discussed below. The list consists of old and new technologies which can possibly be used in mining applications. They will also be evaluated to see if they conform to AziSA standards.

4.1 Ethernet Networks (Using Fibre Optic and UTP Cables)

Fibre Optic & Ethernet Communication was already touched earlier in this paper, but will be described in more detail. Ethernet networks need not be connected by Fibre Optic or UTP cables and can be connected by a wide range of cables [7]. Only for the purpose of this report these two fairly common mediums will be described as the desired carrier of the Ethernet network. Fibre Optic cables and UTP cables are often used in conjunction with each other. A popular setup [9] with this system would be to have a Fibre Optic backbone going down the main shaft of the mine with a switch connected to this backbone at each level. From these switches UTP or further Optic Fibre cables emanate deeper into every level. Fibre optic cables are sometimes used as a direct link without UTP cables splitting the signal. It is usually for higher bandwidth applications such as direct links to PLC's (programmable logic controllers)[8]. Ethernet operates according to the IEEE standard 802.3 using the CSMA/CD (Carrier Sense Multiple Access with Collision Detection) Access Method and Physical Layer Specification [16]. There are several prominent advantages and disadvantages associated with using an Optic Fibre and UTP Ethernet networks that are summarised in Table 2.

Advantages	Disadvantages
High data rates (UTP-1Gbps; Optic Fibre-10Gbps)	Cables can break easily
Power over Ethernet capability (no external power)	VoIP phones not very rugged
Allows VoIP (audio transmission)	Technology not yet very popular
Easy installation and high compatibility	
Optic fibre unaffected by noise and mining equipment	

Table 2: Advantages and Disadvantages of Ethernet (UTP & Fibre Optic)[7],[8],[9],[17]

Ether networks are extremely powerful communication mediums and they have very high transfer speeds with no noise, but the problem remains that it is not resistant to the rugged underground environment.

4.2 Power Line Communications (PLC)

Power Line Communications use the existing power lines in a building as transmission medium for an Ethernet network [18]. This technology is also known as Ethernet over Power Line communication. The devices designed for home use connect to the power line through wall sockets and further Ethernet cables (usually UTP) are connected to the device from there [18].The Netgear model [18] that was made to comply with the IEEE draft P1901 standard is illustrated in Figure 4.

Figure 4: PLC adaptor for home use from Netgear [18]

The advantages and disadvantages associated with using Power Line Communications are described in Table 3.

Advantages	Disadvantages
No extra cabling (Uses existing power lines)	Signals generated in power lines might interfere with other radio devices
High data rates (Up to 500Mbps)	Much interference and noise from high voltage machinery turned on and off.
Uses Ethernet that supports many devices	

Table 3: Advantages and Disadvantages of Power Line Communications [18],[19],[20]

This communication is very rugged and can support high transfer speeds which are ideal for use in the mining industry, but due to interference it has limited applications.

4.3 Wi-Fi (Wireless Standard)

Wi-Fi is a very popular wireless communication standard and is used for medium to high data rate, short to medium range communications. Wi-Fi can be integrated into any Ethernet network or can be used as a standalone node network [7]. At each section in a mine where wireless connectivity is required a wireless access point (Figure 5) would be connected to Ethernet cables or be connected to an adjacent node [7]. Wi-Fi technologies can also be integrated with other communication systems such as Distributed Antenna Systems [7] and thus need not be associated with Fibre Optic or UTP cables.

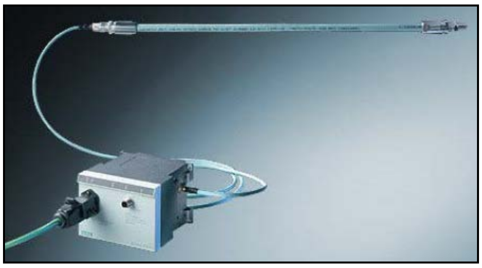

Figure 5: Wi-Fi access point from Siemens [7]

Wi-Fi operates according to the IEEE 802.11 b, IEEE 802.11 g or IEEE 802.11 n standards and usually operates in the 2.4 GHz range [7]. Wi-Fi is an open architecture [7], which means that any device which is Wi-Fi compliant can connect to a Wi-Fi network (given that the device provides the required pass codes).The advantages and disadvantages of using Wi-Fi in mines are listed in Table 4.

Advantages	Disadvantages
High data rates (54Mpbs)	Proximity to access point required (<32m indoors, <95m outdoors)
Supports Wi-Fi tags (accurate tracking)	
Supports VoIP (can transfer audio)	VoIP phones not very rugged
Compatible with many devices	

Table 4: Advantages and Disadvantages of Wi-Fi[7][8]

Wi-Fi is extremely applicable to the mining environment as it does not have any wires that might break or pick up noise. The limitation to this technology is that it does not work over long distances (especially underground) and the technology using Wi-Fi such as VoIP phones are very fragile in this rugged environment.

4.4 ZigBee (Wireless Standard)

The ZigBee shown in Figure 6 can be considered as an emerging wireless standard and is designed for short to medium ranged, low data rate communications [21]. The standard was specifically designed for sensors and other control devices with low energy usage. ZigBee was created to standardize and replace the large amount of proprietary communication methods which have the same functions as ZigBee [21]. ZigBee is based on and conforms to the IEEE 802.15.4 standard for Low-Rate Wireless Personal Area Networks (LR-WPANs) and typically operates in the 2.4GHz range [21].

Figure 6: ZigBee access point from Passport Networks [22]

The advantages and disadvantages of using ZigBee in the mining industry are summarised in Table 5.

Advantages	Disadvantages
Uses very little power	Low data rates (20-250kbps)
Low cost communication	Limited Range (between 10 & 75m)
Supports various topologies (such as mesh and star)	Limited availability (Emerging standard)
Low latency	

Table 5: Advantages and Disadvantages of Zigbee [21]

This technology is very cost effective as it is inexpensive to buy and it requires only a small amount of power for operation. It is also very adaptable and supports other devices, but due to the emerging standards and limited ranges, availability is a problem. The low data rates make it less desirable than other available technologies.

4.5 VHF Leaky Feeder System

The coaxial cables shown in Figure 7 act as antennas as well as the main data transfer lines and are installed wherever communication with workers or machines is required [10]. Repeaters must be used to strengthen signals when signal loss occurs along the length of the cable [23]. The Leaky Feeder system uses radio signals for data transfer in most cases [10], although it is possible to use the system for an Ethernet network, given that modem technology is used [7]. Leaky Feeders are a well established system used in many mines and have been in use for more than twenty years [7].

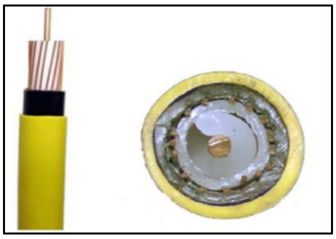

Figure 7: Typical Leaky Feeder Cable [7]

The VHF Leaky Feeder System is very comprehensive and there are various advantages and disadvantages to using it specifically in the mining industry. These advantages and disadvantages are listed in Table 6.

Advantages	Disadvantages
Tried and Tested System (dependable)	Line of sight with cable required
Compatible with commercial 2-way radios	Expensive technology
Central wire powers amplifiers	Cables can break
Cable acts as antenna	Data capacity limitations (unless used as modem)
Can accommodate Ethernet network	
Less signal loss than UHF	Many amplifiers needed
Longer distance between amplifiers than UHF	Backup power needed

Table 6: Advantages and Disadvantages of VHF Leaky Feeder [7],[24]

VHF Leaky Feeder Systems have been in use for a long time and have proven to work effectively. Its construction has various advantages and the technology is compatible with various devices. The main limitations is that the data capacity is not very big and the technology expensive to buy and maintain. Although the construction of the wire has advantages, it also introduces extra costs such as the amplifiers and compulsory power backup systems.

4.6 UHF Leaky Feeder System

UHF Leaky Feeders are in principle exactly the same as VHF Leaky Feeders, with the difference being the operating frequency range. UHF Leaky Feeders operate in the range of 300MHz to 3000MHz, which is deemed the Ultra High Frequency range [7].The advantages and disadvantages are listed in Table 7.

<table>
<tr><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>Tried and Tested System</td><td>Greater loss than VHF</td></tr>
<tr><td>Compatible with commercial 2-way radios</td><td>Many amplifiers needed</td></tr>
<tr><td>Cable acts as antenna</td><td>Cables can break</td></tr>
<tr><td>Can accommodate Ethernet network</td><td rowspan="2">Data capacity limitations (unless used as modem)</td></tr>
<tr><td>Better signal propagation than VHF</td></tr>
<tr><td>Not as affected by noise as VHF</td><td rowspan="2">More expensive than VHF</td></tr>
<tr><td>Central wire powers amplifiers</td></tr>
</table>

Table 7: Advantages and Disadvantages of UHF Leaky Feeder [7],[24]

As illustrated in Table 7 there are various advantages and disadvantages for UHF Leaky Feeder Systems that are exactly the same as that listed in Table 6 for VHF Leaky Feeder Systems. The difference between them is that UHF has better signal propagation than VHF and UHF is not so much affected by noise as VHF. The drawbacks of UHF to that of VHF are that UHF has a greater signal loss and is also more expensive to install than VHF.

4.7 Mesh Networks

Mesh Networks are networks that consist of nodes which are all linked to each other through various connection paths, forming a type of mesh or net [24]. These nodes may be wireless or connected by wires, but have no central control station and each node can be seen as a host [7]. This would imply that if one node should fail, no other node will be affected and only that specific connection channel would be lost. Adjacent nodes will simply find another route through the mesh network to communicate. Due to this unique feature mesh networks are very dependable [7].

Mesh Networks are not technology specific and their specific features vary greatly from one supplier's system to the next. Technologies used to connect nodes vary from Wi-Fi and UHF to coaxial, UTP and optic fibre cables [24].The advantages and disadvantages of this system is summarized in Table 8.

Advantages	Disadvantages
Quick and easy installation	Vulnerable to interrupts
High flexibility	
Robust system	Large numbers of nodes required
Nodes can be battery powered	
High data rates	Nodes must be preconfigured
Not affected by interference	

Table 8: Advantages and Disadvantages of Mesh Networks [7],[24]

The main advantage of this system is that it is very dependable and would still function in the event where certain nodes would fail. There is no central control point which eliminates the possibility of complete failure due to one small problem. It is also very robust and supports transfer rates that are not affected by interference. The quick installation and high flexibility also makes it very popular. The limitations for this system to work correctly are that the programming must be done correctly and there must be a very large number of nodes to ensure alternative paths can be created.

4.8 VLF/ULF Through-the-Earth (TTE) Communication

The VLF (Very Low Frequency) or the ULF (Ultra Low Frequency) system makes use of magnetic or electromagnetic waves which propagate through the earth. The system uses a very large antenna (sometimes 12km in circumference) situated on the surface of the mine to communicate with receivers inside the mine [7]. The system can only send or receive data in one direction and is thus unidirectional. This system is illustrated in Figure 8..

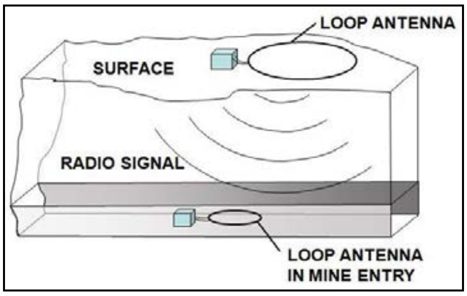

Figure 8: Illustration of TTE concept [24]

The VLF frequencies are typically between 3 to 30 KHz and the ULF between 300 Hz to 3 KHz [7].The advantages and disadvantages of using this system in mining applications are listed in Table 9.

Advantages	Disadvantages
Only receivers required underground – no cables	Very slow data rates (2400bps)
	Massive antenna required
Signal penetrates through the earth	Susceptible to interference
	Can interfere with other equipment
	Range can be limited (<300m)

Table 9: Advantages and Disadvantages of Through-the-Earth Communication [7]

This system is very effective for mining as its low frequency signals can penetrate through the earth. This is especially useful in the case of rockfalls where people are cut off from the surface. There are no cables and therefore communication cannot be cut off by damaged cables. The problem with this technology remains that it requires a very large antenna and has very slow transfer speeds. It is therefore not ideal for day to day data transfers, but would work very well in the case of n emergency.

4.9 Distributed Antenna (Coaxial) System

This system consists of a network of shielded coaxial cables used as data transfer medium. This system is used for standard radio signals and with antennas connected at each point where radio communication would be required [7]. The system can also be converted into an Ethernet network, if a modem is incorporated [7]. The advantages and disadvantages of this system are summarized in Table 10.

Advantages	Disadvantages
High data rates	Cables can break
Many devices compatible	High cost cables
Easy installation and maintenance	
Can support Ethernet	Proximity to antennas required
Can be hidden and shielded	

Table 10: Advantages and Disadvantages of Distributed Antenna Systems [7]

This system can be implemented effectively in a mine since it is simple, supports high transfer speeds and can support numerous devices. The limitation is that many antennas would be needed as it requires close proximity for operation.

4.10 Ultra Wide Band (UWB) Communications

UWB communication was developed for high speed wireless personal area networks. The technology works by transmitting billions of short pulses over a very wide range [25]. This minimizes interference, but the technology is limited to short range and was intended for home wireless use [25]. UWB frequencies can range between 3.1 GHz and 10.6 GHz [7].An UWB transceiver is illustrated in Figure 9.

Figure 9: UWB Transceiver [7]

UWB uses very little power, has a high data transfer capacity [25] and can even penetrate several metres into the earth [7].The advantages and disadvantages of using UWB Communications in mines are summarized in Table 11.

Advantages	Disadvantages
High data rates	Limited range (<40m)
Low power consumption	
Low cost	Directional antennas needed for long range
Good signal propagation underground	
Unaffected by interference	Not commonly available
Can accurately pinpoint sensors	

Table 11: Advantages and Disadvantages of Ultra Wide Band Communication [25],[7]

The main advantage of this technology in the mining industry is that it propagates signals very well underground. It also has a very high transfer rate and is unaffected by interference. The key problem is that it has very limited range. If it is out of range, transfer speeds drops exponentially. It needs many transceivers throughout a mine which would be expensive and in many cases not practical.

4.11 Medium Frequency (MF) Systems

Medium frequency systems are unique in that the signal can couple to metal structures, such as the infrastructure of a mine, and then use it as an antenna [7]. This means that apart from the transmitter and receiver no further infrastructure for the system would be required. AM radio operates in the same range of frequencies as MF systems which is between 300 and 3000 KHz [7].

The different advantages of MF Systems compared its disadvantages are listed in Table 12.

Advantages	Disadvantages
Uses mine structure as antenna	Large transmitters and receivers
Good range	Repeaters required
No cables required	Can couple to blast line and trigger detonation
Signal turns around corners	Weak propagation when structure is not insulated
Can transmit voice and data	

Table 12: Advantages and Disadvantages of Medium Frequency Systems [7]

Since mine equipment is mostly metal, there is more than enough structure to use as antennas. As a result of this, it will also have a good range throughout the underground tunnels in the mine. This system is very robust and can carry data and voice. Although it can make use of mining equipment, some form of insulation is required that is sometimes not possible to achieve. In mines where explosives are used, this technology would pose a major threat as the signal could couple to a blast line and trigger detonation. This technology is therefore very mine specific.

4.12 Cellular Communication Systems

Cellular communication works on the principle of frequency reuse, which means that the same frequency can be used for different communications on the same system. This is done by dividing areas into hexagonal cells, where each two adjacent cells operate on different frequencies.

A frequency is reused in a cell which is just out of range of a cell with the same frequency

[26]. The signal can be received anywhere within a cell and is not lost when travelling between cells. Commonly used standards of cellular communication are GSM (Global System for Mobile Communication) and 3G (Third Generation)[26] The advantages and disadvantages of Cellular Communication are listed in Table 13.

Advantages	Disadvantages
Can cover wide areas	Signal cannot penetrate earth
Can have many devices transmitting and receiving simultaneously	
Signals can bend around corners	Many transmitters required for proper coverage
High data rates (3G)	

Table 13: Advantages and Disadvantages of Cellular Communication [26],[27],[28]

Cellular communication systems are very effective since it can cover wide areas and can transmit and receive many signals simultaneously. It is also capable of transferring data at high speeds. The problem with this technology is that it is very effective above ground, but below it becomes extremely limited. Signals cannot penetrate the earth and therefore need many transmitters that are expensive and ineffective in mining applications.

5. EVALUATION OF COMMUNICATION SYSTEMS

After the technologies had been identified it was prioritized and evaluated according to the strength and weaknesses with the help of mining specialist and surveys. This was done by compiling tables for in-stope and stope to shaft communication. The tables all follow the same format: the horizontal axis lists all the constraints associated with the evaluation and the vertical axis lists all the communication systems. The evaluation was then done by ranking each technology according to the criteria on a scale of very bad to very good. The constraints used were determined by combining the criteria for mining applications mentioned earlier with the different aspects contributing to advantages and disadvantages of each technology.

5.1 Communication: In-stope

In Table 14 the different technologies have been listed where the most important fields have been highlighted to facilitate the process of comparisons in the in-stope areas.

	Range	Penetration of earth mass	Signal propagation	Power Consumption	Data transfer capacity	Cost	Reliability	Wireless	AziSA Compliant
Wi-Fi	Bad	Very Bad	Bad	Good	Very Good	Good	Very Good	Yes	Yes
ZigBee	Very Bad	Very Bad	Bad	Very Good	Bad	Very Good	Good	Yes	Yes
Ethernet (UTP, Fibre Optic)	Good	Neutral	Very Good	Good	Very Good	Good	Very Good	No	Yes
PLC	Good	Neutral	Good	Neutral	Bad	Good	Very Bad	No	Yes
VHF Leaky	Neutral	Neutral	Bad	Neutral	Neutral	Bad	Very Good	Partially	Yes
UHF Leaky	Neutral	Neutral	Neutral	Neutral	Neutral	Bad	Very Good	Partially	Yes
Mesh	Bad	Bad	Good	Good	Good	Neutral	Very Good	Yes	Yes
TTE	Good	Very Good	Good	Very Bad	Very Bad	Bad	Very Bad	Yes	No
Distr Ant	Neutral	Neutral	Bad	Neutral	Good	Bad	Very Good	Partially	Yes

	Range	Penetration of earth mass	Signal propagation	Power Consumption	Data transfer capacity	Cost	Reliability	Wireless	AziSA Compliant
MF	Neutral	Neutral	Good	Bad	Bad	Good	Bad	Yes	No
UWB	Good	Neutral	Neutral	Very Good	Neutral	Neutral	Neutral	Yes	Yes
Cellular	Bad	Bad	Bad	Neutral	Good	Bad	Neutral	Yes	No

Table 14: Evaluation of Communication Technologies In-Stope

The most important constraints to be considered during the evaluation of in stope communication technologies are power consumption, cost, wireless ability and AziSA compliance. From the table we can see a few technologies which may be suitable in the given framework: Wi-Fi, ZigBee, VHF/UHF Leaky Feeder (only the wireless elements), Mesh Networks (which is just a special form of wireless), Distributed Antenna Systems and Ultra Wide Band Communication.

5.2 Communication: Stope to Shaft

In Table 15 the different technologies have been listed where the most important fields have been highlighted to facilitate the process of comparisons in the Stope to Shaft areas.

	Range	Penetration of earth mass	Signal propagation	Integration with existing systems	Wide-spread Acceptance	Reliability	Maintenance	Cost	Data transfer capacity	AziSA Compliant
Wi-Fi	Bad	Very Bad	Bad	Bad	Bad	Very Good	Good	Good	Very Good	Yes
ZigBee	Very Bad	Very Bad	Bad	Bad	Bad	Good	Good	Very Good	Bad	Yes
Ethernet (UTP, Fibre Optic)	Neutral	Neutral	Very Good	Bad	Bad	Very Good	Good	Good	Very Good	Yes
PLC	Neutral	Neutral	Good	Good	Good	Very Bad	Bad	Good	Bad	Yes
VHF Leaky	Neutral	Neutral	Bad	Good	Good	Very Good	Neutral	Bad	Neutral	Yes
UHF Leaky	Neutral	Neutral	Neutral	Good	Good	Very Good	Neutral	Bad	Neutral	Yes
Mesh	Bad	Bad	Good	Neutral	Bad	Very Good	Good	Neutral	Good	Yes
TTE	Good	Very Good	Good	Neutral	Good	Very Bad	Very Bad	Bad	Very Bad	No
Distr Ant	Neutral	Neutral	Bad	Good	Good	Very Good	Neutral	Bad	Good	Yes
MF	Neutral	Neutral	Good	Good	Neutral	Bad	Neutral	Good	Bad	No
UWB	Good	Neutral	Neutral	Neutral	Neutral	Neutral	Good	Neutral	Neutral	Yes
Cellular	Bad	Bad	Bad	Bad	Bad	Neutral	Neutral	Bad	Good	No

Table 15: Evaluation of Communication Technologies from Stope to Shaft

The most important constraints to be considered during the evaluation of stope to shaft communication technologies are range, space utilization, signal propagation, maintenance, data transfer capacity and AziSA compliance. It can be seen from the table that there are a few communication technologies which may be suitable for data transfer from stope to shaft: Ethernet (UTP/Optic Fibre), Power Line Communications, VHF/UHF Leaky Feeder, Mesh Networks and Distributed Antenna Systems.

6. SOLUTIONS IDENTIFIED

The communication method of choice for in-stope operation would be a combination of ZigBee and Wi-Fi. ZigBee would be highly compatible with environmental sensors and link up with the AziSA framework. Wi-Fi would be used for higher bandwidth communications such as voice communication (VoIP phones). Both ZigBee and Wi-Fi are also directly compatible with Ethernet networks and require only an access point connected to the Ethernet network. The communication technology of choice from stope to shaft would be an Ethernet network, due to its compatibility with Wi-Fi and ZigBee. The physical cabling used would be a choice between UTP and Optic Fibre depending on the desired bandwidth requirements of the system. Optic Fibre would be a good choice for a backbone for the communication system, due to its high data transfer rate. Wireless access points could also be placed at strategic points along the line to ensure communication is possible all the way from the stope face to the vertical shaft. An alternative communication technology from stope to shaft would be a Mesh Network using Wi-Fi as carrier. This would not have the same bandwidth as a cabled Ethernet network but holds the advantage of not having cables that can break and cause a loss in communication.

7. CONCLUSION

Communication systems are identified and then evaluated for deep level mining applications. Mining specialist helped to complete the surveys and evaluations. The results of the evaluation process are used to determine possible solutions with respect to communication problems faced in mining applications. Recommendations are made on the most efficient and cost effective technologies according to the results. These recommendations are used by mining companies to improve their current communication systems.

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