Wireless Communication Systems For Underground Mines – A Critical Appraisal

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***Abstract*— This paper presents an overview of wireless communication systems for underground mines including voice and data communication. Development of Wired , semi-wireless and wireless communication syetms has also been discussed. Application of various wireless communication syetms in underground mines of USA, Australia, Canada, South Africa and some European countries including indigenous experimetnal trials have been illustrated. In this paper a brief review has been done regarding the advanced communication systems adopted in various mines with a bird's eye view of the basic research done in 1970-2000. Recent devices such as SIAMnet, TeleMag, PED, and VDV leaky feeder systems have been discussed which provide voice, video and Mobile Data Communication at very high speed data rate with other wireless applications. The importance of urgent application of recent technologies on wireless communication has been highlighted, in view of various disasters due to lack of communication in mines.**

Keywords*—wireless communication, RFID, multi-hop protocol, Voice over sensor network, PED, SIAMnet, TeleMag

I. INTRODUCTION

Communication is the activity related to the transmission of signals (data) for the sake of information exchange. In underground (U/G) mines communication is a crying need both from safety and productivity point of view [1,2].The need to keep pace with the market and lifestyle of the miners, demands more reliable communication methods, and hence more and more research has been done for improving the technology from the beginning of 20th century.Underground communication methods are lagging behind the surface level communication which has seen huge advancements, the lates being the 4G technology. The less improved communication inside U/G mine is not only due to general lack of interest in this area but also for the unfavorable and hazardous environment inside the same.

Communication is mainly comprised of transmission of data from the sender to receiver which may be in groups or from a miner to another miner, in which transmission deals with the amount and speed of the data through the transmitting medium. This seems very simple above ground, as a huge amount of data can be sent at a very high data rate through cables or optical fibres, which can be be conveniently installed, in which noise can be easily eliminated without using any special techniques. However, wired communication in fails in situations where connectivity is imperative e.g fire outbreak, roof fall, power or battery failure, explosions etc. This is the reason, wireless communication has a key role in underground mines.

II. TYPES OF COMMUNICATION SYSTEMS FOR UNDERGROUND MINE

Conventional systems or the wired system is comprised of magneto phones, paging phones, voice powered phones etc. Magneto phones are the oldest crank ringer phones of 20th century operated by DC batteries and AC signals [3]. Paging phones are partly line wired phone for voice communication with no tracking capability [4]. When high voltage trolley line is used as signal path only for voice communication then it is called as the trolley carrier phones system. Hoist rope system is nearly same as trolley carrier phones except that the hoist radio signal is inductively coupled to hoist rope through use of capacitor as coupling device with the trolley carrier phones.

TTE or Through The Earth system is a well known system providing alarming, tracking and messaging with the help of loop antennas on surface of mine which transmit low frequency signal to receivers, integrated into cap lamps[5].

Whereas, wireless network system deals with WiFi (IEEE 802.11), bluetooth (IEEE 802.15) and WiMax technologies. Ultra Wide Band system is the another radio system for short range communication with very low power at a very high data rate[6-10].

RFID System is comprised of radio frequency identifier tags, RFID readers, routers and a host station. RFID tags are very small chips which store a specified amount of data in its circuitry. RFID tags are of two types, active and passive; in underground mine active tags should be used as the signal range is nearly 100 metre for active tags whereas for passive tag's the range is practically 6-8 metres. In each level of the underground mine routers are placed for a specified region and these routers act as intermediate for host station and RFID tags. Routers give the information about the tags which are in its coverage-region and the RFID Reader reads the tag information and sends it to the host station. By this way miners position can be located and monitored by tracking and monitoring software. Attendance of miners can also be taken by this method and in the event of an undesirable situation the miners can be saved from the trapped zone [11, 12].

ZigBee is new wireless technology guided by IEEE 802.15.4 Personal Area Network standard. It is primarily designed for the wide ranging controlling applications and to replace the existing non-standard technologies. It currently operates in 868MHz band at a data rate of 20Kbps in Europe, 914MHz band at 40kbps in USA, and the 2.4GHz ISM bands Worldwide at a maximum data-rate of 250kbps. The sensor nodes in the underground section will send the collected data to the wireless network and then to the host or database for further analysis.

For through the earth communication radio wave attenuation creates the main problem. Attenuation is dependent on frequency of radio wave, earth conductivity, transmission power, antenna type and noise over the surface and in the underground [13-15]. To decrease the attenuation, low or very low frequency radio waves should be used. According to MSHA rules more power can't be transmitted through the earth due to the risky conditions and noxious gases present in the mine environment. In such conditions Helical ferrite antennas are very much helpful for a long range duplex voice communication and text messaging at very low power transmission. These low cost antennas are also small in size which can be mounted or wound around the pipes or pillars present in the underground mine. It also enables the communication in case of roof fall.

Multi-hop Protocol technology is developed to provide long range wireless communication inside the mine (through the air) by using portable relay nodes. These nodes carry the data in packet form and this is a half-duplex communication method. By implementing this method instructions can be given to the rescue robots with a certainty of guaranteed data transmission [16].

Voice over Sensor Network in underground mine works for the data communication between the sensors and the host station [17]. But now a days wireless sensor network is developed to use the wireless network for real time voice streaming in a TDMA based bidirectional communication. Audio signals are compressed and then modulated in the carrier radio wave as the wireless network works for low frequency bandwidth.

III. DEVELOPMENT OF COMMUNCATION SYSTEMS

Since the US Bureau of Mines performed experiments to detect radio signals from their experimental mine in Bruceton, Pennsylvania, a lot of research has been done in the area of communication in underground mines [18].

Use of leaky feeder technique was first introduced using simple open-braided coaxial or a twin-lead cable connected to one or more standard VHF base stations [19].

From 1970 to 1980 communication technology for U/G mines emerged. In this decade, radio waves in the tunnels of coal mines were also studied theoretically, mainly focusing towards the rate of loss of signal strength along a tunnel and around a corner.

Implementation of ultra-high-frequency (UHF) radio communication and closed circuit television (CCTV) system was done in the Black River Mine near Butler, Kentucky [20]. Use of passive reflector to increase the quality and distance travelled by radio wave was also successfully implemented in this mine.

Techniques were developed to measure the electromagnetic noise in and above the mine due to mine machineries used in Itman No-3 mine and McEloroy mine, West Virginia. Leaky feeder radio system using signal booster for powerful amplification was improved in many underground mine.

Utilising the EM waves in the frequency range of 630 to 3030 Hz (in the voice frequency range) research was done for detection of trapped miner inside a coal mine with the help of regression analyses and probability calculations.

In 1980, U.S. Department of the Interior, Bureau of mines, conducted a data analysis in eleven coal mines for the radio wave propagation at 50 KHz to 5000 KHz frequency [21-23].

In 1980-90 low and medium frequency radio system was developed by Dr. Stolarczyk, which provides both TTE and inside the underground communication utilising two robust signal transmission mode which were Seam Transmission mode (medium frequency-300 to 23000Khz) and Conductor Transmission Line mode (low frequency-30 to 300Khz) [24].

From the mid of 1990's a new *deployable and adaptive Mobile Ad Hoc Network* (**DAMAN**) protocol by Sarnoff corporation, Washington, has been enabling the formation of self-organizing, self-routing and self-maintaining communication networks. This supports continuous data communication between many highly mobile users, ideal for underground rescue operations [25].

TABLE I
DEVELOPEMENT OF COMMUNICATION SYSTEM IN UNDERGROUND
MINES- INTERNATIONAL SCENARIO

Investigator	Particulars
USBM, 1922	Initial experimental trials on radio communication for U/G mines
Anon,1956	Introduction of leaky feeder technology
Bensema,M. Kanda, J.W. Adams,1974	EM(electromagnetic) noise studies
Emslie,A.G.,1975	Propagation of UHF radio waves in coal mine tunnels

Robert L., Martin L.,Lagace,1975	Propagation of radio waves in coal mines
Terry S. Corry,1977	Propagation of EM signals in U/G mines
Robert L. Lagace, James M. D obbie, Thomas E. Doerfler,1980	Detection of trapped miner EM signal above coal mines
Martin, D.J.R.,1981	Cost effective leaky feeder radio system
Walter E.,Ronald H. Church,Pittman,1981	TTE electromagnetic trapped miner Location system
J. Durkin,1984	EM detection of trapped miners [26]
J. Durkin,1984	Apparent earth conductivity over coal mines for TTE communication
Stolarczyk,1991	Emergency and operational low and medium frequency band radio communication for U/G mines
P. Angskog,J.Ferrercoll,J. Chilo	EM properties in iron mine production tunnels
Ph. Mariage,M. Lienard, P. Degauque,1994	Propagation of light frequency in road tunnels
Bandyopadhyay L.K., Kumar S., Mishra P.K.,2003	Wireless communication for U/G coal mine
Ian F. Akyildiz,Erich P. Stuntebeck,2006	Wireless sensor network in U/G Mine
Michael R. Yencheck,2007	TTE magnetic communication system
DebalinaGhosh,HomgSik Moon ,Tapan K. Sarkar,2008	TTE using helical antenna
Luckheed Martin,2011	Cost effective TTE wireless system, Magnelink Magnetic Communication System (MCS)

Tele Mag wireless system (United States) is a two way (duplex) system both for voice and data communication operating at a frequency range of 4 KHz which was first demonstrated in august of 2000 at NIOSH Lake Lynn Laboratory Mine. It is not portable [27].

A system composed of beacon contained in a miner's cap lamp and hand held location receiver for trapped miner's beacon was tested at Tirol mine up to a detection accuracy of 50 cm.

In the Val d'Or mine, Canada, experiments gave fruitful results regarding mesh wireless local area network (WLAN) using WAP (Wireless Access Point) protocol [28].
2006 Miner Act by MSHA: According to this, the installation of two-way wireless voice and tracking systems for all underground coal mines in US has been made compulsory.

Rajant and Mine Site Technologies (MST): Since 2007 it offers digitally based communication systems for mines. Rajant offers a variety of Bread Crumb units and configurations to meet specific portable mesh-networking needs. Bread Crumbs are MSHA approved, and classified as intrinsically safe (IS).

Kundana, Western Australian gold mine: In 2008 mine's management system installed VDV Leaky feeder technology (advanced very high frequency leaky feeder). In 2009 installation of the BlastPED as the mine's remote and centralised blasting system took place.

SIAMnet Communication System: This system uses cable modem and coaxial cable for voice and data communications in underground mines. It is a cost-effective alternative to fibre optic and leaky feeder technologies for voice and data communication in undergrounds mine. One coaxial cable supports up to 32 simultaneous voice transmissions, three 1.5 Mbps mobile data sub-networks each supporting up to 64 UG vehicles, and 12 DOCSIS 1.1 cable modem channels for total of 360 Mbps downstream and 120 Mbps upstream. Modem and 802.11 access point draw power through coaxial cable. By the help of this system hard wired or wireless VoIP telephones may be used underground as well as at the surface. Vehicles can be monitored wherever there is coverage in the area where the vehicle is situated. Engine condition can be checked and instructions can be sent to the operator for quick actions.

Fig. 1 SIAMnet device

SIAMnet provides Voice and Mobile Data Communication with High Speed Data rate along with Wireless Applications and Video Communication [29].

South African mining industry communication system: In most of the mines of South Africa advanced underground communications is made by Radiaflex cable. First installation of 1/2-inch RLK Radiaflex cable was successfully implemented in the South Deep gold mine by the beginning of 21st century. Originally it was designed to provide immediate and near-future 3G cellular confined coverage requirements. The Radiaflex cables in the mine are used for multi-level UHF-based voice, video and data communications.

*Mine Radio Systems Inc. (MRS)***:** In Europe from the year of 2007**,** MRS offers the following Integrated Safety and Communication Solutions.

- Leaky Feeder based communications
- Voice, Video and Data
- Personnel, Vehicle and Asset Monitoring and Control
- Collision Avoidance
- Ethernet over Leaky Feeder
- Trapped Miner search and location
- Equipment remote control and monitoring.

Personal Emergency Device System: The personal emergency device (PED) communication system is one way TTE (inside the mine) system operating at frequency range of 1Khz for digital text messaging first demonstrated in United States in 1990. The first successful evacuation of miners attributed to PED technology occurred during the Willow creek Mine fire in Helper, Utah, on November 25, 1998 (Helper, 1998). It is a portable device which utilises Ultra Low Frequency (ULF) range for mine wide text messaging. Some of the data regarding PED is given in Table -II.

TABLE II
DATA REGARDING PED TECHNOLOGY

Mine	**Year**	**Specification of The Mine**	**No. of Pagers Used**
Genwal (Utah)	1998	U/G-38000ft	50
Co-op(United States)	1999	U/G	40
Dugout(United States)	2000	U/G	75
Newstan (Austalia)	2000	U/G-35000ft	250
Myuna (Austalia)	2001	U/G-28000ft	200

IV. INDIAN SCENARIO

The communication in Indian Coal Mines is primarily based on CDS, signalling or telephone system. Telephones are located at strategic points in UG mines. The technologies developed in the indian mines in the 21st century are discussed below.

Trapped miner communication: Tests had been made in the under ground mines of Bharat Coking Coal Limited (BCCL) and Mahanadi Coal Fields (MCL) and the system was enabled to precisely locate the position of the transmitter placed under the debris,coal block, broken coal, coal dust and at different levels.

Induction- based hoist communication system: It was first experimented at Bagdiggi undeground mine of BCCL, resulting a clear and loud voice communication. The audio signal could be detected in the moving cages as well as at pit bottom and pit top.

*Line of sight communication (los)***:**Using UHF transceiver operating at frequency range of 410-500 Mhz was tested in the shaft of Chinakuri Mine of Eastern Coalfields Limited giving result to the clear communication between the pit-top and pit-bottom having depth of around 612m.

V. CONCLUSION

As the communication system is an indispensable part for underground mines, implementation of TTE and TTA technology should be done alongside the cable system as a backbone. Nowadays, TTA (line of sight) wireless system for underground mine is more popular as compared to TTE communication system. In case of, through the earth communication system, from surface to underground, more importance should be given to develop new technologies as the attenuation of radio wave causes the greatest problem for data transmission. Further research should be pursued on earth conductivity, radio antenna and the other factors influencing the data rate.

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