RECENT TRENDS IN COMMUNICATION SYSTEMS FOR UNDERGROUND MINES

***Dr Singam Jayanthu and **Singam Jayadarshana**
*Professor, Mining Engg Department,
National institute of Technology , Rourkela-563 117
**B Tech Student, Electronics and Comunicaton Engg Dept,
Sikkim Manipal institute of Technology – Sikkim, 737 136

ABSTRACT

This paper presents an overview of various communication systems for underground mines including voice and data commmunication. Development of Wired , semi wireless and wireless communications syetms are discussed. Application of various communications systems in underground mines of USA, australia, canada, South Africa, Europian countries etc including indeginous experimetnal trials were illustrated. In this paper a brief review is given on the advanced communication systems adopted in various mines with a bird's eye view on the basic researches made in 1970-2000. Recent devices such as SIAMnet, TeleMag, PED, and VDV leaky feeder systems are discussed which provide voice, video and Mobile Data Communication at very high speed data with wireless applications. Impetus is given for urgent application of recent technologies on wireless communication in view of various disasters due to lack of communication in mines. Emphasis is made on the future applications of Electronics and Communications Technologies (ECT) for not only realtime monitoring of men and machinary but also communication to the concerned persons such as machine operator/first line supervisor for taking necessay action at right time.

INTRODUCTION

Communication is the activity related to the transmission of signals (data) for the sake of information exchange. In underground mines communication is the crying need both from safety and productivity point of view. Keeping pace with the business market and lifestyle of the miners, which demand for more reliable communication methods, more and more researches have been made for improving the technology from the beginning of 20th century.Underground communication methods are lagging behind the surface level communication which is now crowned with 4G technology. The less improved communication inside U/G mine is not only due to lack of interest in this area but also for the unfavorable and hazardous environment.

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 as a huge amount of data can be sent at a very high data rate through cables or optical fibres in which noise can be easily eliminated without using any special techniques. But the real facts say wired communication is worthless at the time of need(i.e at the time of exposure to fire, roof fall, power or battery failure, and at the time explosion).Which encourages wireless communication in U/G mines.

COMMUNICATION SYSTEMS FOR UNDERGROUND MINING CONDTIONS

Various types of communications systems useful for undergorund mines are shown in Fig 1. Conventional systems or the wired system is comprised of magneto phones,paging phones,voice powered phones etc. Magneto phones are are the oldest

crank ringer phones of 20th century operated by DC batteries and AC signals. Paging phones are partly line wired phone for voice communication with no tracking capability. 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. Where as wireless network system deals with WiFi(IEEE 802.11), bluetooth(IEEE 802.15) and WiMax technologies. UWB (ultra wide band) system is the another radio system for short range communication with very low power at a very high data rate(very high band width). 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(i.e. use of capacitor as coupling device in the case of trolley carrier phones). The well known Leaky Feeder system is comprised of leaky feeder cable and amplifier boosters for two way voice,data and video communication utilising the leakage field of the cable.A hybrid RFID system is used for tracking of miners through out the mine by the help of Radio Frequency chip or tags worn by miners or installed in any large mining machines. Seismic system is another kind of portable system using seismic monitoring sensor on the surface to detect sound generated by trapped miners.

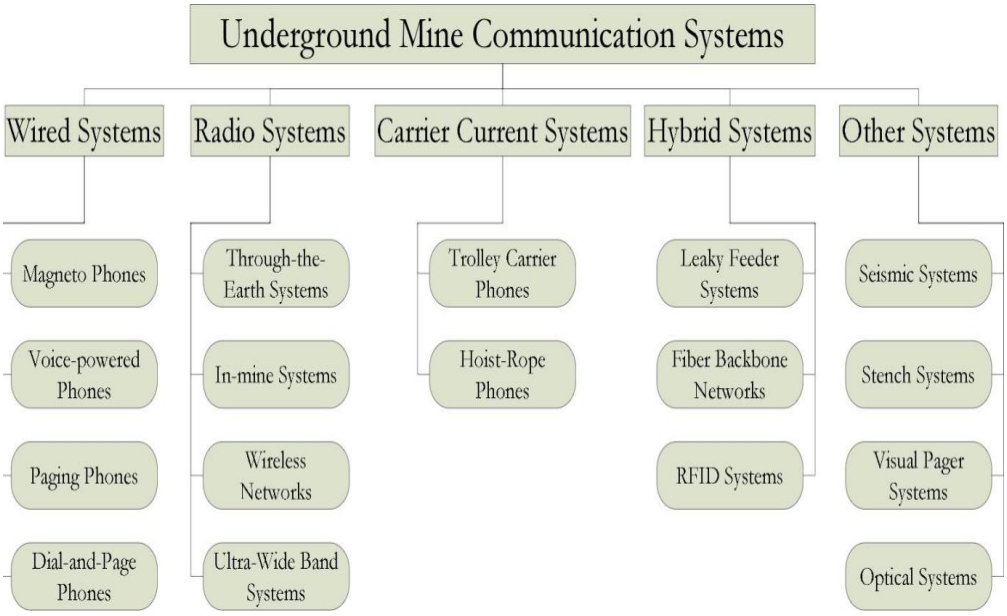

Fig 1: communications systems useful for undergorund mines

DEVELOPMENT OF COMMUNCATION SYSTEMS

Critical appraisal of developments in wired, semi-wired and wireless communications systems for underground mines is discussed below:

Wired communication systems

- Dial and paging phones are the developed wired communication system compared to the magneto type system. Now-a-days use of fibre optics cable ensures data reliability improving the quality, quantity and speed of the data.

Semi- Wireless and wireless communication systems

- In 1922, when the US Bureau of Mines performed experiments to detect radio signals from their experimental mine in Bruceton, Pennsylvania, since then various researches have been made in the area of communication in underground mines (USBM, 1922).
- In 1956 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.
- From 1970 to 1980 communication technology for U/G mines was more emergent. In this decade, radio waves in the tunnels of coal mines was also studied theoretically mainly focusing towards the rate of loss of signal strength along a tunnel and around a corner. Implementation of UHF (ultra high frequency) radio communication and closed circuit television (CCTv) system was done in the Black River Mine near Butler, Kentucky. Use of passive reflector to increase the quality and distance travelled by radio wave was also successfully implemented in this mine. Techniques were made 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) researches were made 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 (Bensema, 1974, Emslie, 1975, Terry, 1977, Robert L. Lagace, 1980).

Table 1: Development of Communication systems 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
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.Ferrer coll,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
Debalina Ghosh,Homg Sik Moon ,Tapan K. Sarkar,2008	TTE using helical antenna
Luckheed Martin,2011	Cost effective TTE wireless system, Magnelink Magnetic Communication System (MCS)

- 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) (Stolarczyk,1991).

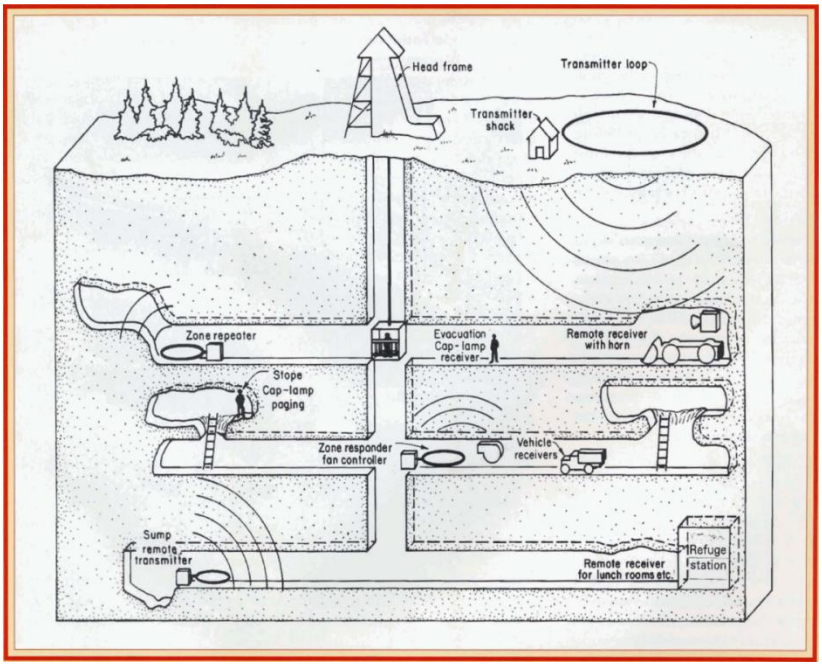

Fig 2: Conceptual representation of a TTE wireless mine communication and Warning system (Conti, 2008).

- 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.
- 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 was demonstrated in august of 2000 at NIOSH Lake Lynn Laboratory Mine. It is not portable (NIOSH, 2000).
- 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.

- Helical ferrite antenna for through-the-earth communication also has been implemented in some mines of United States for duplex wireless communication in disaster situations.
- In the Val d'Or mine, Canada, experiments gave fruitful results regarding mesh wireless local area network (WLAN) using WAP (Wireless Access Point) protocol (Moutairou,2006)
- 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 BreadCrumb units and configurations to meet specific portable mesh-networking needs. BreadCrumbs 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 instruction can be sent to the operator for quick actions.

Fig 3: SIAMnet device

SIAMnet provides Voice Communication, Mobile Data Communication, High Speed Data Communication, Wireless Applications and Video Communication (Cattron, 2011).

- 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 is 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 -2.

Table 2: 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

APPLICATION OF COMMUNICATION SYSTEMS- CASE STUDIES

In North America and in some European countries NLT serves the underground mines for the purpose of VoIP and data communication based on Ethernet network standard. Table-3 provides some data regarding the installation of various technologies by NLT **(**NLT, 2009-10).

Table 3: Application Of Communication Systems in underground mines- Case Studies

Mine	Year	Specification On The Installed System
ULAN	2010	460 reserve tracking messenger lamps and 45 IS nodes and client to track personnel within a few metres.
West Wallsend Colliery	2010	Full messenger and Tracking System
Blackfield	2010	Wi-Fi and 50 Messenger lamps

		and Wi-Fi tracking.
Carborough Downs	2009-10	Messaging and tracking

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:

- Leaky feeder based system- It was installed in Nandira Mine,Talcher Area,Mahanadi Coalfields Limited,sambalpur. The leaky feeder cable was laid on from control room available at pit top to different working location of the U/G Mine covering total distance of about 5 km (Bondyopadhyay,2010).
- 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(Bondopadhyay,2010).
- 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(Bondyopadhyay,2010).
- **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(Bondyopadhyay,2010).

SCOPE FOR FURTHER APPLICATIONS OF ECT

Recent trend in electronics and communication technologies may be applied for better utilisation of the mechanised mining systems such as wireless sensor networks to online monitoring of location of men or machinery, status of condition of machinery, stability of workings by various sensors through application of gateway, fixed or mobile mesh nodes (Fig 4 and 5). The future applications of Electronics and Communications Technologies (ECT) should focus not only on real time monitoring of men and machinary but also apropriate communication to the concerned persons such as machine operator/first line supervsor for taking necessay action at right time. Cap lamp battery can be effectively utilised as source of power for such systems with necessary modifications to suite underground mining conditions. Aggressive applicaton of innovative technologies in future should show to any administrator or manager, the complete online and realtime status of men and machinay on the plan/ tablet PC/ mobile for efficient utilisation of mechnised mining in undergrund mines.

CONCLUSION

As the communication system is an indispensable part for underground mines, implementation of TTE and TTA technology should be developed with a cable system as the backbone in mining industry. Now-a-days, TTA (line of sight) wireless system for underground mine is in a very healthy condition 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. Research should be pursued on earth conductivity, radio antenna and the other factors influencing the data rate. Mechanised mining would be highly successful with appropriate communication system for online and real time health and status monitoring of the machines. Emphasis is made on the future applications of Electronics and Communications Technologies (ECT) for not only realtime monitoring of men and machinary but also communication to the concerned persons such as machine operator/first line supervsor for taking necessay action at right time.

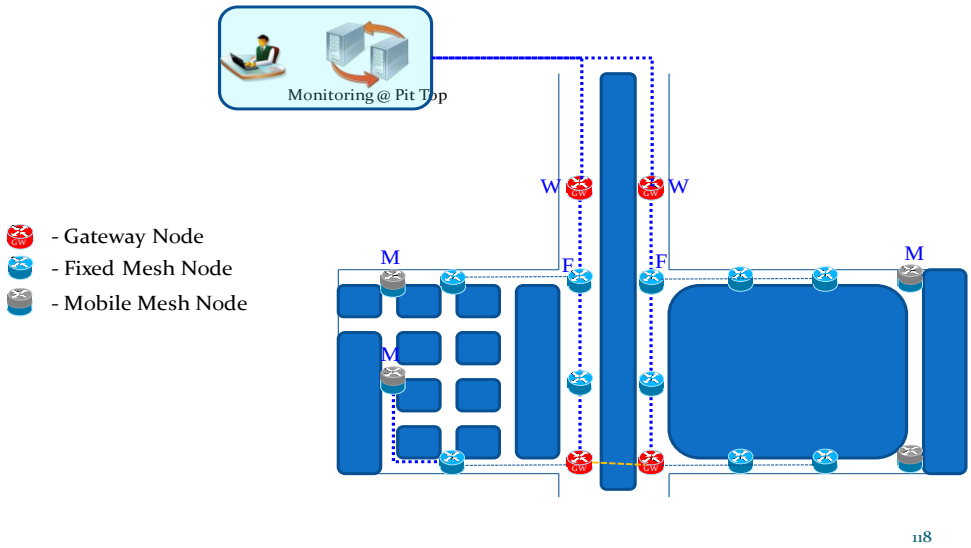

Fig 4: Scope for application of ECT for monitoring of environment, locationof miners etc. in underground mines

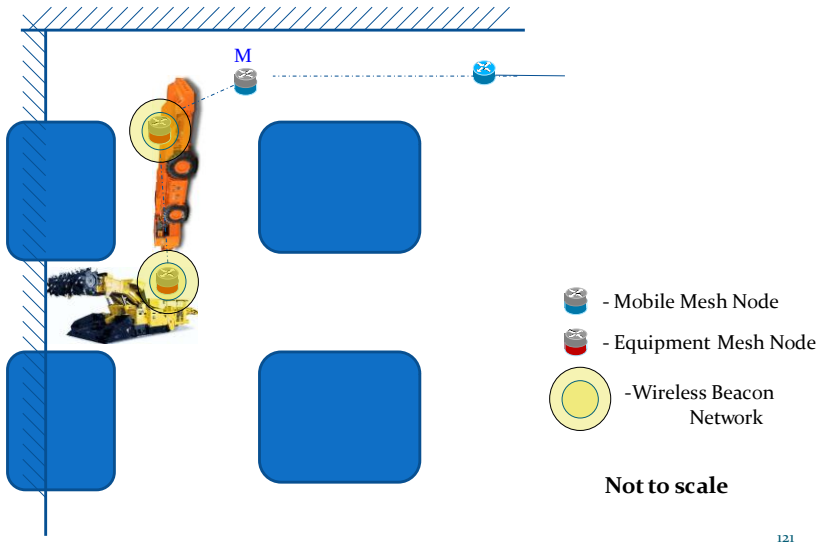

Fig 5: Scope for application of ECT for equipment monitoring in underground mines

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