LOCATION AND MONITORING FOR PERSONAL SAFETY (LAMPS)

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SUMMARY

Underground communications systems have the potential to reduce the consequence and extent of emergency mine incidents. The Location And Monitoring for Personal Safety (LAMPS) project was conceived in response to recent events at Moura and will provide a capability to report the location and health of underground staff. The LAMPS project is part funded by the Australian Coal Association Research Program (ACARP) and is supported by the Australian Mineral Industries Research Association (AMIRA).

INTRODUCTION

Requirements for Underground Emergency Communications

A Wardens Inquiry was conducted into an accident at Moura No 2 Mine, which occurred in August 1994 [1]. Five Task Groups were formed to deal with the recommendations in the Wardens report. In the escape and rescue model proposed by Task Group 4 [2], there are three rescue phases: self-rescue, aided rescue and mine recovery. An emergency mine communications system is required to support these phases. In the support of **self rescue**, underground staff need to be made aware of safe exit paths for self escape. In the **aided rescue phase**, the emergency management team need to know where people are trapped in a mine by a physical impediment or injury. Finally, in the **mine recovery phase**, data about prevailing conditions is desired in order to minimise the exposure of risk to workers while attempting to stabilise the situation in a mine.

In addition to supporting the escape and rescue phases, an emergency communication network must survive the hazardous mine environment. The impact of mine hazards such as rock falls, floods, fires and explosions can cause catastrophic failures in localised areas. An emergency system is required to maintain service in spite of component failures. The key areas for communications network survivability are redundancy and autonomy. Any of the conventional communications technologies can be implemented to provide improved **redundancy**. Two or more backbones rather than one could be employed to service each region. It is desirable that the redundant backbones originate via disparate routes so that there is some resilience to localised mine problems. For example, boreholes may be available for alternate routes. It is important that failures in one part of the mine do not disrupt communications elsewhere. The internet is an example of system having **autonomy**. Each component of this network is independent of others yet remains connected to them via multiple redundant paths. On the local scale however, the internet is seen to be prone to disruption, because there is a reliance on information backbones. This is not admissible for an emergency communication system. The requirement for autonomy also applies to infrastructure. For example, the domestic telephone service remains in operation during short-term suburban power distribution failures. Clearly the same requirement exists for emergency mine communications. Indeed in [2] it is concluded that: "If the mine power fails the communications should remain active for up to a week. The system should be able to survive a section being taken out so systems with a single high capacity backbone are vulnerable."

A Brief Review of Conventional Underground Communications Technologies

The technologies employed underground variously include: fixed wire, power line, trailing cable, leaky feeder, spread spectrum, cellular and cordless.

Where **fixed wire** systems rely on PABX telephones, the capacity is limited by the number of available connections. While communicating over the existing **power line** infrastructure seems promising for cost reasons, there are many practical difficulties. There is variable fading, attenuation and in-band noise due to electrical loading and the network topology is governed entirely by the layouts of the individual phases [3]. Fixed wire systems need to be resilient to the physical mining environment. To this end a **trailing cable** can be used in which communications wires are located alongside power lines within a heavy duty sheath [4]. The use of **leaky feeder** cabling is a common option in metalliferous mines, and, with the availability of intrinsically safe (IS) versions, is likely to be widely adopted within underground coal mines. A difficulty that occurs underground is interference due to multipath propagation. This may be barely noticeable for personal communications because there is a great deal of redundancy in speech and it is easy to walk to nearby interference free locations. Multipath problems can become more significant for applications that rely on high data rates and has led to the use of spread spectrum. For example in [5] a tele-operation system, in which communications from a digital backbone network to mobile users is accomplished via **spread spectrum** links. The domestic **cellular** phone system has been adapted by a research team at Curtin University of Technology and migrated to an underground prototype as described in [6]. This system possesses handover capabilities to accommodate users roving from one cell to another. **Cordless** phone systems are finding application within department stores, building sites and in underground metalliferous mines The leaky feeder, cellular and cordless handsets rely on near line-of-sight communications. This contrasts with **PED** systems developed locally [7] and rely on through the earth propagation. The PED systems typically use high power transmitters and large loop antennas to communicate from the surface down to depths of 1 km. The PED receivers have IS approval and are either integrated with the cap-lamp battery or are vehicle-mounted. The data rate is about 10 baud, consequently PED applications are limited to paging/messaging. *CSIRO Telecommunication and Industrial Physics* are developing a reverse PED system which employs a base station to communicate with roving miners at a radius of 400m and transmit through 400m of rock up to the surface. **Optical fibres** can support high data rates and are used in fixed underground situations. The high cost of fibre optic cable precludes it from routine mine applications except in circumstances where high bandwidth is a requirement.

A New Approach for Emergency Underground Communications

While a mixture of conventional technologies can be readily integrated to suit routine underground mine requirements, clearly the same is not true for the emergency communications. Conventional communication technologies lack survivability. This weakness exists because conventional communication approaches are hierarchical, that is, there is a reliance on communication backbones which are susceptible to disruption during mine emergencies. For example, the occurrence of cable breaks result in a loss of communications downstream. Further, coaxial cable systems are sensitive to load impedance and a small number of accidental disconnections tend to cause severe performance degradations elsewhere.

The above-mentioned search and rescue model has prompted the development of a new approach, namely Location And Monitoring for Personal Safety (LAMPS). Rather than adopting a hierarchical structure, the communications traffic is distributed along a large number of redundant pathways. Thus when disruptions occur, the remainder of the network continues to provide communications. A LAMPS network is shown in Figure 1. Eight network beacons are depicted in the figure. These autonomous beacons provide communications along multiple, redundant, line-of-sight paths within underground tunnels. The figure also depicts a personnel transponder (which is worn by underground staff), reporting vital signs data to nearby beacons. A control and monitoring subsystem at the surface (not shown) sources the communications traffic from multiple paths and displays the staff location information. In emergencies, the control and monitoring subsystem serves to communicate escape route information for indication by the individual beacons.

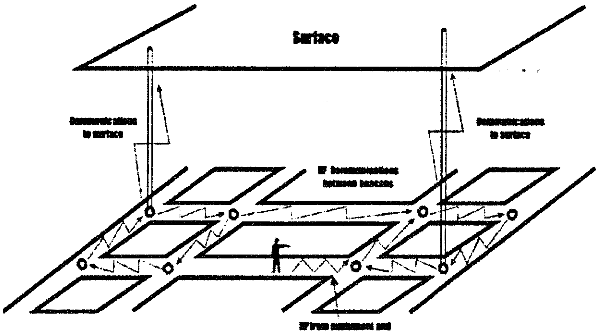


Figure 1 – Depiction of a LAMPS network

LAMPS

Performance Predictions

It is a good practice to ascertain the performance benefit of any new solutions prior to undertaking development. A simulation study has been carried out to investigate the communications survivability exhibited by a RF network such as LAMPS versus that of conventional leaky feeder technology. A performance comparison of one continuous cable, two branched cables and LAMPS within two panels at Moura No. 2 Underground Mine is presented in [8]. Briefly, the panels are partitioned into cells, and the probability of cells having communication available, P(N_a), is calculated as a function of the number of failed cells, N_f. The results are shown in Figures 2 and 3.

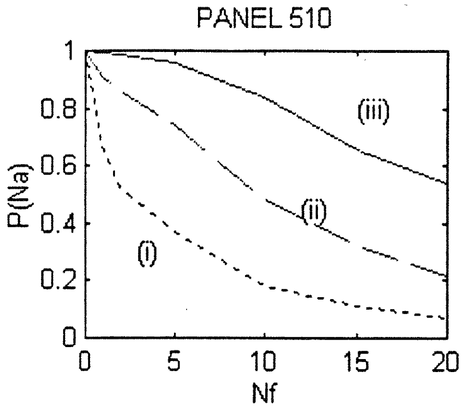


Fig. 2. Probability of cell availability for Panel 510
(i) Single cable, (ii) Two branched cables, (iii) LAMPS.

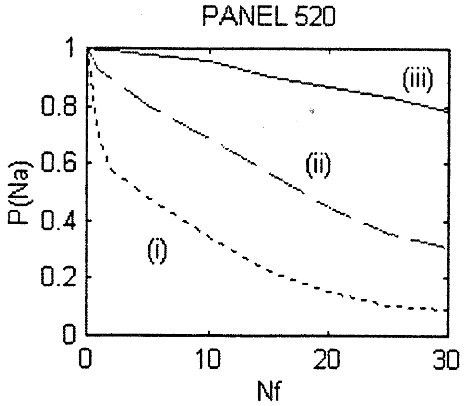


Fig. 3. Probability of cell availability for Panel 520
(i) Single cable, (ii) Two branched cables, (iii) LAMPS.

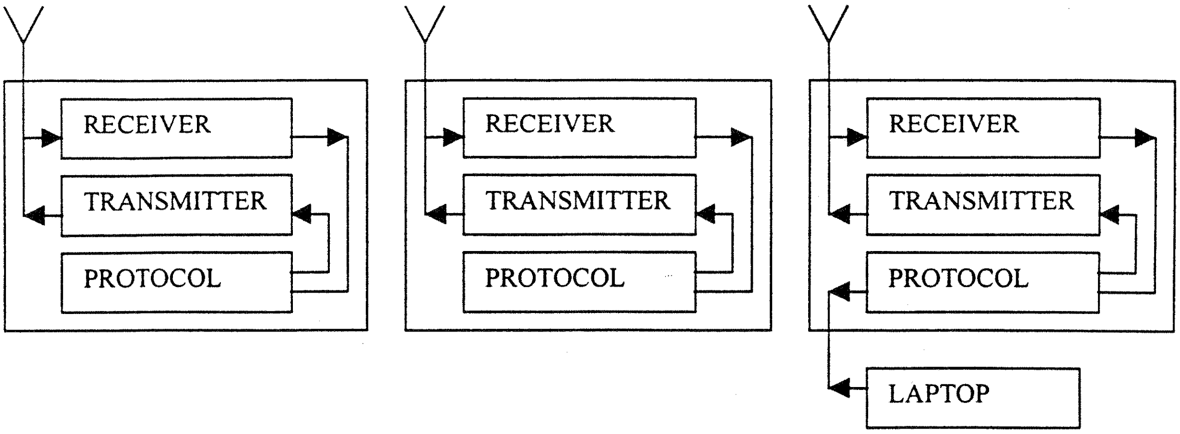
Figures 2 and 3 demonstrate the advantage of a LAMPS network. It turns out for LAMPS that N_a decreases approximately linearly for small N_f because there is no backbone. For larger N_a, an increased performance degradation is observed due to an increased likelihood of enclosed cells. It can be seen that performance degrades at a higher rate for panel 510 because it is narrower and it follows that there are less redundant pathways. In the case of panel 520 for example, it is seen for 10% of cell failures, the LAMPS network can on average provide about 80% communications availability. This contrasts with about 10% and 30% availability for the single and branched cable arrangements respectively. A longwall topology has similarly been studied in [9]. These simulation studies are indicative only, any cell availability calculations depend on the topography at hand and on the modelling assumptions. The simulations do emphasise the importance of providing redundant communications paths. In particular it is observed that: the performance of a single cable layout can degrade quite rapidly with increasing cell failure; a branched cable layout can yield an improvement; and, a LAMPS network can provide by far the greatest improvement.

LAMPS provides a survivability advantage because it makes use of multiple redundant communication paths. When a beacon receives a new data packet from a personnel transponder, it is time-stamped and automatically relayed via all other beacons in the network. A simulation study has also been carried out to investigate the error performance of a LAMPS network and the results are presented in [10]. The error performance analysis of [10] indicates that a data rate of around 100 kHz is required, which is consistent with the system under development.

Subsystems

LAMPS comprises three types of subsystems as depicted in Figure 4. The personnel transponders transmit at approximately two minute intervals, to a network of beacons. The prototype control and monitoring system consists of a laptop computer, at the surface, that is connected via serial links, to a number of network beacons. It can be seen from the figure that there are three blocks common to the subsystems. The receiver, transmitter and protocol hardware are identical throughout. It is configuration of the protocol block that is specialised for each subsystem.

The personal transponder possesses a receiver so that a failsafe capability can be implemented. In the event that any personnel transponders do not maintain communications with the network then two alarm conditions can be flagged. Firstly, those particular underground staff can be alerted that they are beyond the network coverage region. Secondly, the absence of communications with underground staff is also flagged by the control and monitoring system at the surface.



Personnel Transponder Subsystem Network Beacon Subsystem Control and Monitoring Subsystem

Figure 4 - LAMPS subsystem block diagram.

The personal transponders will be integrated within the cap-lamp assemblies and powered by existing cap-lamp batteries. The network beacons will be self-contained and powered by internal single-use batteries. The advantage of completely wireless beacons is that there is no need for any external power supply infrastructure and thus the mine installation and maintenance costs are minimised.

The required beacon communications range is determined by typical underground tunnel spacings and desired location accuracy. Some candidate transmitter and receiver blocks have been developed and tested successfully underground within level 18 of the Gympie Eldorado Gold Mine. A 20mW, 152 MHz transmitter and a single conversion superhetrodyne receiver, operating through quarter wavelength antennas, have provided an underground communications range of over 40m along the 3m x 3m drives. The choice of carrier frequency is influenced by the trade-off in underground propagation mechanisms. Since there is an abundance of structures in underground mines, which limit line-of-sight availability, it is desirable to take advantage of diffraction, or in other words, propagation around corners. The path loss in the diffraction region increases with frequency [11]. However when the frequency is sufficiently low, so that the wavelength is comparable to the dimensions of the tunnels, then the propagation loss of the direct path becomes significant. In underground mines, clearly there is a need to provide communication coverage around columns and other structures, so therefore it is necessary to trade-off direct path loss against diffraction loss. Increased communication ranges are expected by employing a higher radio frequency and conducting trials within 4m x 4m and 5m x 5m drives, which are typical of newer coal and metalliferous mines respectively.

Applications

The LAMPS project is divided into two phases. The first phase commenced in March 1998 and is jointly funded by ACARP and CSIRO Exploration and Mining. The phase one objectives are to develop functional prototypes and conduct trials in metalliferous mines. The phase two objectives are to produce IS versions, conduct tests in underground coal mines and transfer the technology to Industry.

The applications currently under development are the location, monitoring and escape route indication functions. The role of the personnel transponders is to transmit vital signs data together with the transponder identification number at approximately two-minute intervals. Every network beacon also possesses a unique identification number, which is recorded along with the physical location at the time of installation. The location of underground personnel is accomplished by reporting the network beacon that first intercepts a personnel transponder transmission. Thus the location precision is determined by the spacing of network beacons. During emergencies, the escape route information will be indicated by low power displays on the beacons.

Numerous other applications are compatible with the LAMPS system. The transponders could be mounted on equipment and report mine sensor or machine condition data. Since cabled communications systems are somewhat difficult to maintain at the face, applications exist for the wireless LAMPS transponders, for example the reporting of longwall chock and geophone data.

CONCLUSIONS

An emergency mine communications system is required to support three roles: self rescue, aided rescue and mine recovery. A further requirement is that the candidate systems are able to survive component failures and loss of mine power. These requirements are unlikely to be satisfied by current or developing commercial technologies.

The search and rescue model has prompted the development of a new approach to the emergency mine communications problem. The Location and Monitoring for Personal Safety (LAMPS) system provides capabilities for indicating escape routes, personnel location and mine sensor monitoring. Further, LAMPS does not rely on mine power during emergencies and the communications network is robust with respect to node failures.

The success of emergency mine communications depends on the capacity to make use of redundant communications paths. The results of simulation studies demonstrate that a LAMPS network exhibits significantly improved survivability compared with that of cabled systems.

Phase 1 of the LAMPS project has commenced and the wireless network beacons are under development. The advantage of completely wireless communications is that there is no need for any external power supply infrastructure and thus the mine installation and maintenance costs are minimised.

ACKNOWLEDGMENT

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