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Underground Mine Rescue Equipment and Technology: A Communications System Plan

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1. Introduction

Sarnoff Corporation (Sarnoff) is a privately held, for-profit diversified technology services organization whose specific mission is to create innovation by bringing new products and services to market. While conventional research and development is in large part of what we do, Sarnoff goes beyond the limitations of the traditional R&D model in working to create value and solve complex technological problems for our commercial and government customers. Our track record of innovation, breadth of Intellectual Property and technology, flexible business approach and unique multidisciplinary expertise allow us to offer our customers a partnership solution that fully meets their needs.

Described below are several Sarnoff technologies with specific application to underground mine rescue and communication. For each of these technologies, Sarnoff has either existing products, demonstrated capabilities, or significant experience and intellectual property in the field.

2. A Self-Configuring Communications Network for Underground Mine Rescuers

E.1. Communications: What types of communication systems can be utilized in an emergency to enhance mine rescue?

2.1. Overview

Sarnoff has developed a system for Communications in Subterranean and Urban Environments (**CSUE**) that can function as an ideal voice and data communications system for underground mine rescue personnel. This system is built upon a hardware platform of small (~1 pound), self-contained communication **relays** that can be placed on the mine floor during emergency maneuvers, and handheld voice-and-data communication **terminals** (essentially two-way radios) carried by each rescuer. Sarnoff-developed protocols enable these relays and handheld terminals to form an easily deployed, robust, self-forming communication network supporting simultaneous reliable and secure two-way voice and data communications at rates up to 11 megabit/second.

Key to the success of the Sarnoff CSUE system is a data communications protocol that provides highly reliable operation in demanding RF environments where node mobility and the continuous entering and exiting of network nodes are standard operating conditions. Sarnoff's Deployable and Adaptive Mobile Ad Hoc Networks (**DAMAN**) protocol was specifically engineered and has repeatedly been proven to be the premier network solution in these demanding communications environments. DAMAN enables the formation of self-organizing, self-routing, and self-maintaining communication networks supporting continuous data communication between many highly mobile users, ideal for underground rescue operations.

Sarnoff has been developing and implementing Mobile Ad Hoc Network (MANET) protocols and technology since the mid 1990's. Sarnoff has expertise not only with the underlying ad hoc routing protocols used to form mobile networks, but also with the computer and communications systems used to implement these networks, and with the complex applications that use them.

DAMAN, the communications technology that is the backbone of the CSUE system, is a multi-hop mobile ad hoc routing protocol designed from first principles to operate in situations where mobility is the rule rather than the exception. Originally developed under DARPA funding to support small unit operations in tactical military networks, the DAMAN protocol has been refined and optimized to provide a robust general-purpose networking technology suitable for use in a variety of demanding applications. The DAMAN protocol has been successfully used to create dynamic, mobile multi-hop network infrastructures in numerous commercial and military/government environments in support of many communication-critical applications.

2.2. System Description

The Sarnoff CSUE system is based upon both IEEE 802.11 and DAMAN network protocols. It consists principally of intelligent **terminals** carried by each rescuer, and deployable **relays** that are placed at key mine corridor intersections. The terminals provide a voice-and-data interface for the rescuers. The relays, with extended line-of-sight range in all directions, form the network grid. The inherent DAMAN protocol in both terminals and relays provides superior network performance in dynamic high-load environments where other protocols break down. Figure 1 is a block diagram of a simple DAMAN CSUE network as it would be used for underground mine rescue.

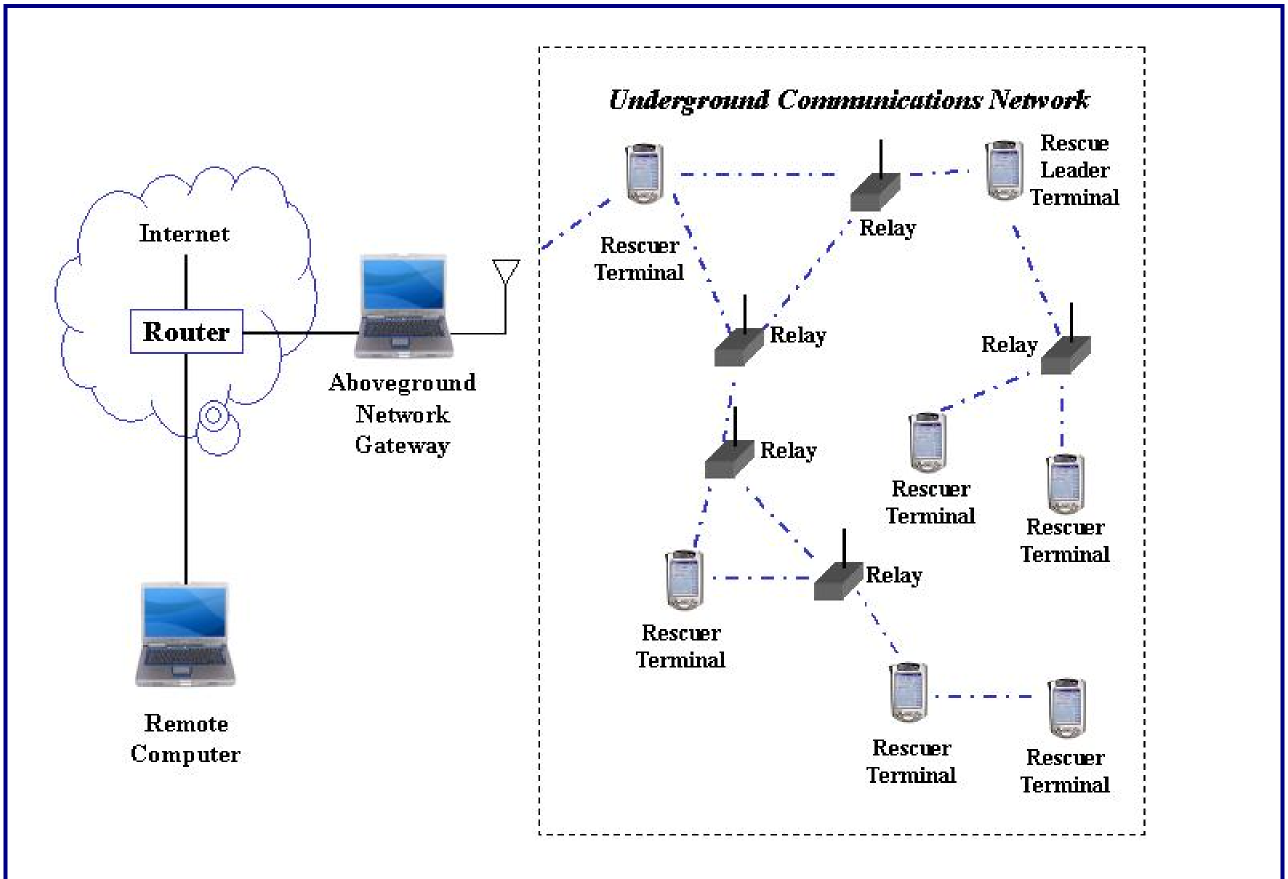

Figure 1. A simple DAMAN CSUE network for underground mine rescue.

2.2.1. The CSUE Relay

Figure 2. The CSUE Relay.

The CSUE Relay (Figure 2) is built around a commercial single board computer with an Intel XScale PXA 255 400 MHz CPU. The unit uses a 30mW 802.11b radio modified to use an externally mounted 3db omni-directional rubber-duck antenna. The Relay also contains a Relay Node Interface (RNI) board to interface the computer board to its environment. The RNI board controls startup, shutdown, battery voltage monitoring and battery charging functionality. The Relay also contains an integral battery pack and an onboard battery charger, supplying 7 hours of continuous operation in its present form. LED indicators and momentary switches on the top of the unit provide a simple user interface. The switches provide startup and shutdown control while the LED functions are software programmable. The Relay enclosure is ruggedized and environmentally sealed for safe, reliable operation. The Relay antenna is an omni-directional folding swivel antenna; a recess in the enclosure provides stowage space for the antenna that snaps securely in place.

2.2.2. The CSUE Terminal

The CSUE Terminal (Figure 3) is a voice-and-data terminal designed to function as the rescuer's squad radio, and is based on an iPAQ h5500 series handheld computer. It is equipped with a COTS IEEE 802.11b WLAN card, modified to use an external antenna to create a stronger, more uniform RF radiation pattern. The antenna is semi-permanent and can be removed if necessary.

The iPAQ-based CSUE Terminal provides:

- Active support by the open source software community. Linux Operating System and application development is well supported for this platform.
- Advanced performance. The h5500 series iPAQ is based upon the 400MHz Intel Xscale, newer, faster, more power-efficient processor architecture than previous iPAQ handhelds.
- External Headset Jack. The iPAQ h5500 contains an onboard microphone-and-headphone jack for easy interfacing to a wide variety of COTS audio transducers.

Figure 3. The CSUE Terminal.

The CSUE Terminal can be operated in either voice-operated (VOX) or push-to-talk (PTT) mode, and can be equipped with either a throat microphone (useful for gasmask-equipped rescuers) or a conventional boom-mounted microphone.

2.3. System Operation

Typical system operation involves the rescue team placing one Relay at the mine entrance, and placing other Relays as needed thereafter to establish a minimal number of line-of-sight point-to-point links between the rescuers and aboveground support. When a rescuer is leaving the network coverage area, he receives an audio indication from his Terminal that instructs him to deploy another Relay at his current location. In this manner a network is established providing maximum effective coverage using the fewest number of Relays. The grid nature of the room-and-pillar underground coal mine lends itself quite readily to the deployment of the CSUE system, with long lines-of site typical in one or both dimensions.

Rescuers maintain constant voice contact with other rescuers and with the aboveground support personal as they work their way through the mine. As the DAMAN CSUE system is designed to support all types of digital data, it can also function as a general-purpose data network. For example, network-enabled image sensors and emergency medical equipment can be operated from the surface to deep within the mine.

3. Expansion of the Emergency CSUE Communication Network To Provide the Basis for an Operational Mine Communications System

E.4. Communications: What new communication devices or technology may be well suited for day-to-day operations and also assist miners in the event of an emergency?

The CSUE system described in section 2 can readily be expanded to enable its communication Relays to interface to a wide variety of sensors and secondary communications devices. With proper development, a modified CSUE system could form the backbone of an underground mine sensor and communication network for operational as well as emergency use. This system would have many advantages over currently approved underground mine communications systems:

- The CSUE network could be configured as a redundant mesh providing communications from surface to underground even in the event of Relay failure or loss of Relay connectivity (e.g., due to roof collapse).
- Battery backed-up communication Relays would keep the underground network functional for hours or even days (depending upon specific requirements) following removal of power.
- Should emergency circumstances fully isolate a section of the network from the surface, a single Relay could be lowered through a small borehole to a location with line-of-sight access to any Relay in the isolated sub-network, thus allowing re-establishment of communications from the isolated sub-network to the surface.
- Failed and non-responding Relays detected following a fire, collapse, explosion, etc, could rapidly provide information as to the location of the emergency.
- The CSUE network could be programmed to provide location information to the surface for terminal-carrying miners. Data would indicate approximate distance from a miner to the nearest Relay in near real time. Thus, present miner location could be read, and “last known location” information would be available in the event of a network-isolating underground event.

4. Tooth Microphone

E.7. Communications: How can communications be improved when a rescuer is wearing a breathing apparatus and talking through a diaphragm in the mask?

Sarnoff has developed (under contract with the US Army Communications Electronics COMmand [CECOM]) a dental bone conduction voice communications system (the Sarnoff Tooth Microphone) that provides high voice intelligibility independent of the ambient noise level. The system consists of a small intra-oral transducer (IOT) that clips to the user's upper left molars, and a body- or head-mounted transceiver that receives a wireless signal from the IOT and outputs it to a traditional 2-way radio. The Sarnoff Tooth Microphone system provides outstanding speech intelligibility in demanding environments ill-suited to traditional air-path microphones, such as from within a gas mask, SCSR or SCUBA facemask.

The most obvious application of the Sarnoff Tooth Microphone is as a means to improve the rescuer's ability to communicate while wearing breathing apparatus. An IOT interfacing wirelessly with a transceiver-equipped breathing mask would implement an unobtrusive voice communications system for ready use with a voice-activated two-way radio.

A secondary application would integrate the Sarnoff Tooth Microphone with the Self-Contained Self Rescuer (SCSR) worn by the miner during emergencies and/or in the presence of smoke or hazardous gases. The IOT and a transceiver-equipped SCSR could be worn by the miners, driving their voice-activated two-way radios. This would allow for safe, intelligible and unobtrusive communications during emergency situations.

5. Super Low Frequency Beacon

E.1. Communications: What types of communication systems can be utilized in an emergency to enhance mine rescue?

In many recent mine disasters (Sago, W. Virginia; Grupo Mexico, San Juan de Sabinas, Mexico; Black Wolf Coal Quecreek Mine #1, Somerset, PA), miners were trapped underground but healthy and waiting for emergency workers to find and rescue them. A simple tool that could aid in locating such trapped miners is a Super Low Frequency (SLF) beacon. The SLF beacon would be used to indicate the underground location of the miners in the event of a communication system failure. Low-cost battery-operated beacons with hand-cranked auxiliary power could be stored in underground caches and rescue chambers for use during an isolation emergency. These beacons would consist of a small (desktop telephone size) main unit containing a battery, a hand crank and generator, and beacon-generating electronics interfaced to a large detachable loop antenna. The loop antenna would be a robust yet flexible jacketed cable 50 to 100 feet in length with physical characteristics similar to those of an outdoor extension cord. The cable itself would be made of multiple insulated small-gauge wires jacketed in a bundle, forming a multi-turn loop antenna. This loop would be permanently connected to the main beacon unit to ensure safe, simple and reliable operation. To use the SLF beacon, the miner would first spread out the antenna to achieve the largest loop area possible. A simple on-off switch on the main unit would then be toggled "on" to activate the beacon, and an LED would begin blinking at a low rate/low duty cycle to indicate an actively pulsing beacon. Extreme caution would be taken in the development of the system to render it fully explosion-proof.

The SLF beacon would produce harmonic rich pulses of super low frequency energy with a fundamental frequency between 20HZ and 200Hz at a rate of approximately 1 pulse per second. Rescuers would employ portable SLF receivers at the surface to monitor signal strength and thus determine the surface point closest to the beacon. The SLF receivers would feature a significantly smaller (~3 foot) diameter multi-turn loop antenna interfaced to an analog receiver front end, an analog-to-digital converter, and a Digital Signal Processor (DSP) based SLF demodulation/detector. Any number of rescuers equipped with such SLF receivers could thus cover the surface of the mine either on foot or from within ground vehicles to rapidly determine the location of the underground beacon.

6. Conclusion

Sarnoff has both existing products and demonstrated capabilities in the areas described in this paper. Significantly more detail can be made available regarding any of these items, and design solutions can be tailored to meet specific needs and requirements.

Sarnoff also has expertise in other key technologies that may have specific application to mine safety, specifically in the fields of vision processing, image sensor design/development, visualization, vital signs monitoring, optoelectronics, and ASIC development.