

FINAL TECHNICAL PROGRESS REPORT

Project Title: Wireless Mine-Wide Telecommunications Technology

**Reporting Period: Start Date: 12/12/00
End Date: 1/11/04**

Principal Author: Zvi H. Meiksin

Date Issued: March 2004

DOE Award Number: DE FC26-01NT41065

Submitted by:

**TRANSTEK, INC.
35 Wilson Street, Suite 103
Pittsburgh, PA 15223-1719**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ABSTRACT

A comprehensive mine-wide, two-way wireless voice and data communication system for the underground mining industry was developed. The system achieves energy savings through increased productivity and greater energy efficiency in meeting safety requirements within mines. The mine-wide system is comprised of two interfaced subsystems: a through-the-earth communications system and an in-mine communications system. The mine-wide system permits two-way communication among underground personnel and between underground and surface personnel. The system was designed, built, and commercialized. Several systems are in operation in underground mines in the United States. The use of these systems has proven they result in considerable energy savings.

A system for tracking the location of vehicles and people within the mine was also developed, built and tested successfully. Transtek's systems are being used by the National Institute of Occupational Safety and Health (NIOSH) in their underground mine rescue team training program.

This project also resulted in a spin-off rescue team lifeline and communications system. Furthermore, the project points the way to further developments that can lead to a GPS-like system for underground mines allowing the use of autonomous machines in underground mining operations, greatly reducing the amount of energy used in these operations.

Some products developed under this program are transferable to applications in fields other than mining. The rescue team system is applicable to use by first responders to natural, accidental, or terrorist-caused building collapses. The in-mine communications system can be installed in high-rise buildings providing in-building communications to security and maintenance personnel as well as to first responders.

TABLE OF CONTENTS

Executive Summary	5
Research, Development, and Experimental	8
Results and Discussion	28
Conclusions	29
Appendix: Survey Summary.....	30

EXECUTIVE SUMMARY

The objective of this project was to reduce the amount of energy usage in the mining industry through increased operations productivity and safety. Increase in productivity and safety was to be achieved through the introduction of a comprehensive wireless mine-wide voice and data communications system to operate underground and between the mine and surface. Productivity and safety were to be increased further by developing a vehicle and people tracking system compatible with the communication system. Instant communication makes possible immediate reaction to changing circumstances preventing waste, and allowing people and vehicles to be where they are needed when they are needed, reducing energy waste from idling machinery.

The communication system was built by developing two subsystems: a through-the-earth wireless communications system, and an in-mine communications system. The two subsystems were interfaced resulting in the mine-wide communications system.

The system for tracking the location of vehicles and people within the mine was designed through the development of beacons and transponders. This tracking system, in turn, was interfaced with the in-mine system to allow the information from the tracking system to be transmitted to a control room, displaying the information on a monitor.

Two types of in-mine systems were studied and built. One system used dedicated cables to form the infrastructure that connects the wireless control modules and antennas. The second system makes use of existing power lines for the infrastructure, thus eliminating the need for dedicated cables. The power line based system required the development and design of additional components to bridge multiple, non-connected lines, typically installed in mines. Further, means were developed to prevent the power signals and the communications signal that share the same lines from interfering with each other. There is a clear tradeoff between the two in-mine communication approaches.

Transtek collaborated with its partners from government, academia, and mining communities. These partnerships assisted in design, field tests, and commercialization.

In-mine communication systems were commercialized and installed in mines in Pennsylvania and Wisconsin. Experience gained from the installation and use of the systems in these mines led to the development of several design improvements. The customers expressed full satisfaction with the installed systems, and reported substantial productivity increases directly related to the use of wireless instant communication resulting in substantial energy savings.

As a spin-off from this project, Transtek developed, designed, and built a portable, battery operated communication system for rescue teams. The system offers four modes of operation that meet rescue teams specifications. The system is used by The National Institute of Occupational Safety and Health (NIOSH) in training programs that they conduct for mining companies.

The results of this project highlighted several mining needs that point the way forward to additional research and development directions. Further development can lead to a GPS-like system for use in underground mines. Such a system will make the use of autonomous equipment in underground mining a reality resulting in increased safety, productivity and in large amounts of energy saving in mining operations.

Broad protection coverage of the technology was obtained with the issuance of a US Patent issued by the Trademark and Patent Office. An international patent is pending. The preparation for additional patent applications is in progress.

The technologies received recognition in national and international Journals that published articles describing Transtek's systems.

Some of the technologies developed for the mining industry are transferable to other fields, including Homeland Security/first responders in natural or man-made disasters as well as to security

and maintenance personnel in high-rise commercial and residential buildings.

RESEARCH, DEVELOPMENT, AND EXPERIMENTAL

Objective

The objective of Transtek's project was to reduce the amount of energy used in mining through the increase in employee productivity and safety. Mining operations consist of several tasks. The highest efficiency can only be achieved with full coordination among the persons carrying out these tasks while these people remain free to be mobile, and if the locations of vehicles and people are known by those who coordinate the activities. Ordinary use of two-way radios that meets these requirements above ground in open space does not function in underground mines because the obstacles inside the mines that prevent radio waves propagation over long distances. Radio waves can only propagate a few feet before they are absorbed, reflected or diffracted by rocks, walls, and other objects. Transtek achieved the object stated above through the development, design and installation of a comprehensive wireless communications and tracking system that works in underground mines.

Products

To meet the objective of this project, Transtek addressed the problem of instant wireless communication in underground mines to increase productivity and safety, and eliminate energy waste. Businesses have always recognized the value of reliable communication and have been willing to pay for commercial grade service. More recently, the maturity of wireless as an accepted medium has increased the demand for instant, reliable, portable communication. Underground mines, however, have proved resistant to wireless communication due to environmental conditions that limit the transmission of radio waves.

In free space, two-way radios can communicate over several miles. In mines, however, transmission is limited to a few tens or hundreds feet. Radio waves are absorbed, diffracted, or reflected from rocks, walls, and other objects in the mine. Before beginning this project, Transtek – with the help of the School of Business of the Carnegie Mellon University under the auspices of the Pennsylvania Ben Franklin Partnership – conducted an extensive survey of

coalmines to determine communication needs and present practices. A summary of respondents to the survey is given in Appendix A. The survey showed that many mines still use traditional hard-wired, wall-mounted telephones and a paging system. The time lapse between a page and a response is typically fifty minutes, resulting in inefficiency causing considerable energy waste.

The most effective product that has been offered for wireless communication in these transmission-limited environments is the twenty years old so-called “leaky feeder” system. This system requires an extensive installation of a bulky, hard-to-install, 5/8” diameter cable in all the paths, tunnels and rooms where communication is needed. The general response to the survey was that this was the best system available, but the system suffers from many shortcomings that render it unsatisfactory. The user must be in line-of-sight of the cable and within 30 to 80 feet from it; there is interference between channels; there are many “dead” spots; and there are too frequent unplanned downtimes that render the system unreliable. As for wireless communication between the surface and the mine interior, there was available a one-way communications system that sends messages from the surface into the mine. The message appears as an LCD display. No voice communication was possible. No response, and therefore no “message received” acknowledgement from inside the mine to the surface was possible to ensure that communication was successful. The in-mine and the through-the-earth communication systems were separate from each other and could not function as one entity.

Transtek approached the challenge of providing reliable, satisfactory wireless communication in an underground mine transmission-limited environment by addressing the overall problem of voice and data communication through the earth, inside the mine, and tracking in a comprehensive way from a new perspective. Electromagnetic energy transfer through the earth must be done at very low frequencies, on the order of a few kilohertz. Attenuation caused by losses due to the medium (earth overburden) at higher frequencies is severe and becomes overwhelmed by electric noise making the signal undetectable. Compensation for the losses by transmitting at higher energy levels from inside the mine is impossible because of the danger of an explosion caused by high energy levels

in the methane and coal dust atmosphere inside the mine. On the other hand, we found through experimentation inside mines that electromagnetic energy transfer inside mines occurs best at UHF frequencies of several hundred megaHertz. While considering a comprehensive communications system, the different frequency ranges required separate studies, dividing the project into sub-tasks. Throughout the study, the condition that the systems must be able to function seamlessly as a single system through proper interfacing was considered a necessary condition in order to be able to accommodate all working conditions. At the same time it was recognized that the systems should also be able to function separately, independently of one another as in some mines one of the subsystems may be all that is needed to meet communication requirements..

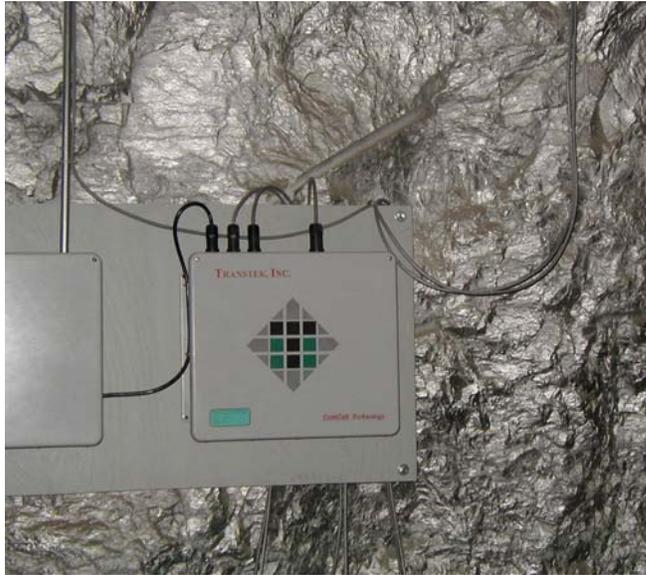
Accordingly, we divided the comprehensive system into three subsystems that resulted in three products:

- Through-The-Earth (TTE) communication – Trademark *TeleMag*



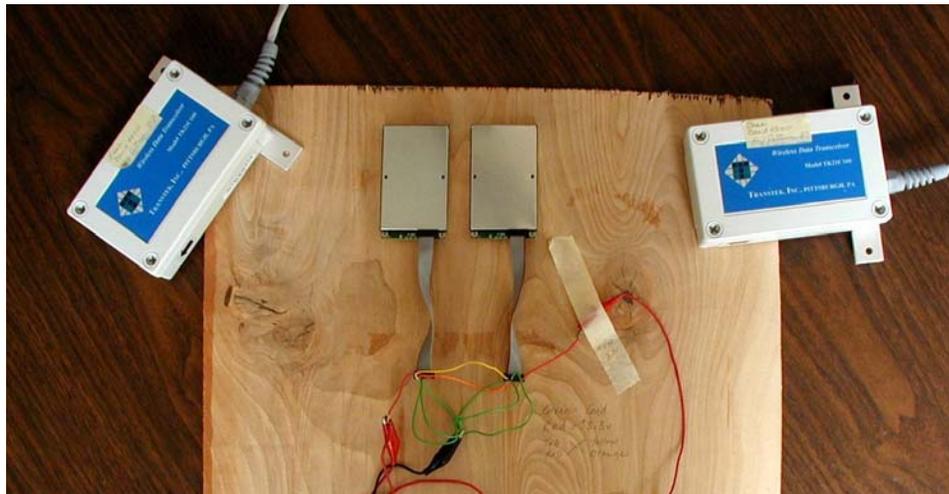
TeleMag module offers two-way radio, telephone-like handset and panel-mount microphone/speaker communication modes

- In-Mine (IM) communication – Trademark *ComCell*



ComCell Control Module installed inside underground mine

- Tracking (TR) communication



Laboratory set-up. Left - transponder
Center – beacon and repeater
Right - receiver connected to ComCell
Module (ComCell module not shown)

As a result of interaction with miners and mining companies and cooperation with NIOSH, we also developed a spin-off product that is a portable, battery operated communication and lifeline system specifically designed for rescue teams:

- Rescue system – Trademark *ResQCom*



ResQCom offers rescue teams four communication modes

These systems may be interfaced wirelessly in any combination to fill particular needs. For voice communication, the systems may be configured to allow persons, using wireless two-way radios, to communicate from anywhere inside the mine in the area covered by the system with any other person in the covered area as well as with persons above ground. Similarly, using the data transmission feature of the system, output from sensors (such as methane or carbon dioxide monitors) can be transmitted wirelessly to antennas of the in-mine subsystem, processed and displayed on a video monitor inside the mine or the surface. The tracking system uses digital beacons and transponders and communicates wirelessly with antennas of the IM subsystem. The rescue system can be interfaced wirelessly with the TTE system to communicate with a support group above ground.

Field Tests

During the research and development program, before we commercialized the systems and before we installed systems in customers' mines, we carried out experiments and we tested systems in mines that were made available to us by our collaboration partners, and one mine that is used for tours and education.

The Table below lists the mines in which we carried out experiments and indicates what experiments were performed.

MINES USED FOR EXPERIMENTATION

Mine Name	Mine Type	Tests Performed
TourEd	Coal	Through-the-earth communication: evaluation of mathematical model
Gateway Commerce	Lime Stone	Two-way through-the-earth & in-mine – power line communication systems
Bruceston	Coal	In-mine RF wave propagation patterns
Lake Lynn	Lime Stone ¹	Through-the-earth, in-mine, and rescue communication systems
Enlow Fork	Coal	In-mine RF wave propagation patterns

¹ A section of the mine is excavated to simulate the structure of a longwall coal mine

Comments:

TourEd is a coal mine in Natrona Heights, Pennsylvania that has been set-up to accommodate tours and educational trips for high school students. We had access for our experiments to locations 30 feet and sixty feet below ground.

Gateway Commerce Center is an excavated limestone mine that is being used for underground storage. We performed experiments for propagation through 280 feet overburden, and across several thousand feet inside the mine

Bruceston is a coal mine owned by NIOSH. It is used by NIOSH to conduct experiments.

Lake Lynn Laboratory is a lime stone mine owned by NIOSH. It has sections of a room-and-pillar structure, and other sections mined to simulate the structure of a longwall coal mine. It is used by NIOSH for experimental studies.

Enlow Fork is an active long wall coal mine in Pennsylvania owned by Consol Energy.

Collaboration

Transtek received cooperation from its partners in government, universities, and industry.

Professor El Jaroudi of the Department of Electrical Engineering, University of Pittsburgh, an expert in digital signal and data processing, helped solving information processing problems.

The late Ron Conti and others of the National Institute of Occupational Safety and Health (NIOSH) gave us access to their Bruceston and Lake Lynn Laboratory mines in Pennsylvania. They participated actively in experimentation and evaluation of our systems for through-the-earth communication as well as in-mine communication. They also elaborated on the needs and expectations of the mining industry.

Mr. Randy DeBolt of Consol Energy gave us access to their Enlow Fork coal mine in West Finley, Pennsylvania. His associates assisted us in evaluating electromagnetic wave propagation near the coal face and access paths.

Mr. Michael Garves of the Gateway Commerce Center allowed us extensive use of their limestone mine in Wampum, Pennsylvania. This mine was particularly useful in studying through-the-earth communication between the interior of a mine and the surface, and in studying the power line, in-mine wireless communication system..

Mr. John Whitfield of Victor Products USA, a wholly owned Federal Signal Company, helped in the commercialization of our products.

The Pennsylvania Ben Franklin Partnership provided some cost-sharing funds, and supported an underground mining communication survey conducted by the Business School of the Carnegie Mellon University.

Commercialization

We sold and installed systems in Pennsylvania and Wisconsin. The installations are in stone mines and sand mines. For installation in coalmines, the products must be Mine Safety and Health Administration (MSHA) certified. This certification is a lengthy and expensive process. If any change is made to a certified product, the product must undergo a new certification process. Therefore, we decided to field-test the products extensively and make needed adjustments before applying for certification. The commercial installations are summarized in the Table below.

COMMERCIAL MINES HAVING TRANSTEK'S WIRELESS COMMUNICATIONS SYSTEMS.

Mine Name¹	Mine Type	System type	User comments regarding productivity, safety, energy savings²
A	Lime Stone	In-mine	70% improvement
B	Lime Stone	In-mine	Substantial improvement
C	Sand	In-mine	Substantial improvement
D	Lime Stone	Rescue	Very important

¹ See key to names below

² See detailed comments in paragraphs below

Mine A: Creekside Mushrooms Ltd., Worthington, Pennsylvania

Mine B: Iron Mountain, Branchton, Pennsylvania

Mine C: Fairmount Minerals/Wisconsin Industrial Sand, Maiden Rock, Wisconsin

Mine D: Lake Lynn Laboratory – NIOSH, Uniontown, Pennsylvania

Mine A is an excavated limestone mine used for mushroom farming. There are 300 workers underground. The mine has offices above and below ground. Transtek installed there an in-mine ComCell system having four channels. Two channels are being used for voice communication among workers, one channel is used for paging, and one channel is used to access the company's telephone network. This allows workers using two-way radios to initiate and respond to phone calls. Telephone communication is possible both between persons inside the mine as well as between inside the mine and the outside.

The ComCell system is used to coordinate all activities of the operation allowing instant response to changing circumstances and having equipment and people where they are needed when they are needed. Before Transtek's system was installed, the mine depended on a paging system and hard-wired, wall-mounted telephones. Mr. Allen Leard in charge of the operation said that he estimated that the introduction of the ComCell system increased the operation productivity by 70 percent. While they did not document measurements, unplanned downtime and waste were reduced considerably, reducing the energy requirements for operations.

Mine B is an underground storage facility in an excavated limestone mine. Transtek installed there a ComCell system for use mainly by security and maintenance personnel. The use of the system streamlined and improved operations so much that the management issued several repeat orders to increase communication area coverage as well as to add channels. Interfacing the system with the telephone network is presently under consideration.

Mine C is an active sand mine producing high-grade sand for industrial applications, primarily frac sand for the oil & gas industry. About 22 people and eight pieces of mobile equipment are in operation at the mine around the clock. Keeping track of progress at the mine face and the underground wash plant had become a time-consuming chore for the crew. Before the installation of Transtek's ComCell system, they were relying on spotty contact with truck drivers using conventional mobile radios and were making frequent

trips into the mine in order to validate status and coordinate operations. The ComCell system accepts signals from handheld or dashboard-mounted radios or from a base station in the mine office and relays those signals to all the working areas of the above and below ground operations. The restricted range that previously retarded communications has been replaced by a virtual range that is limited only by the number of control modules installed.

Tim Stauffer, Plant Manager at the Fairmount Minerals Maiden Rock mine reported “We are seeing improved productivity as a direct result of the ComCell system, and we expect to expand the system as the mine geometry changes with continuing operations.” Stauffer further said “The ComCell system provides clear, reliable voice communication with operating and maintenance personnel, including drivers above and below ground. With ComCell we can quickly obtain the status of people and equipment almost anywhere in our operation. We are able to deploy resources instantly in response to changing conditions or new information from outside plant workers or mine management. Most importantly, I feel it was a big safety boost for our employees.” The instant response results in less idling machinery, and energy savings. Six months after the system was installed, the mine placed a second order to expand the system coverage.

Mine D, operated by NIOSH, is a limestone mine with sections excavated to simulate a long wall coal mine. Transtek carried out extensive tests in this mine to study the TeleMag and ComCell systems. At the advice of NIOSH Transtek also developed the ResQCom system designed specifically for rescue teams. This system provides a lifeline and a communications system to link the rescue team with its support groups. NIOSH purchased a ResQCom system and uses it in the regular rescue team training courses they offer to the mining companies. This system provides a major improvement in the rescue teams operations.

Technical Challenges

Several technical hurdles were overcome during the project period. The difficulty to transmit electromagnetic energy through the mine overburden (earth, rocks, shale, coal, water) is that the

overburden, due to its high electric conductivity, retards the propagation of electromagnetic waves. The situation is exasperated by the limit on permissible transmission energy imposed inside the mine to protect against accidental methane or coal dust explosion. Thus increased energy cannot be used to overcome transmission losses.

We were able to build a system that transmits voice wirelessly down link and up link hundreds of feet through the earth within permissible energy limits through proprietary signal processing, filtering, and judicious physical design parameters. No previous technologies were able to do this. The system was designed to allow the user to select any combination of three modes of operation. The user can communicate using two-way radio handsets, telephone-like handsets, or panel mounted microphone and speaker.

We achieved data communication through the earth using a very low transmission rate of 30 Baud. The low rate does not hinder applications in a real mine situation. Data needs to be collected only at fixed intervals. The data transmission is brief. Thus, data can be collected at the conventional 9600 Baud rate, stored, and transmitted at a lower Baud rate through the earth.

We began to study and evaluate concepts with a *laboratory* prototype. A first generation *production* prototype was then built. This system was mechanically rugged and electrically industrial grade, and it was enclosed in a waterproof NEMA Type 4 enclosure. It was left in a mine environment for months and continued working flawlessly.

We have developed a mathematical model that predicts the voltage induced in the receiving antenna as a function of geometrical parameters and physical variables of the mine environment and physical applied quantities.

The induced voltage, V_R , in the receiving antenna is given as

$$V_R = \text{fcn}(I, a, N, g, h, n, f, r, \mu, \sigma)$$

where, I = transmitting antenna current
 a = transmitting antenna radius, receiving antenna radius
 N = transmitting antenna number of turns
 g = the distance between mine's roof and mine's floor
 h = The distance from the surface to the mine's roof
 n = receiving antenna number of turns
 f = frequency of the transmitting antenna current
 r = the eccentricity between the transmitting and receiving antennae axes
 μ = the permeability of the overburden
 σ = the conductivity of the overburden

The induced voltage is subject to the transmitting antenna voltage and energy constraints imposed by the operating conditions inside mines, and applicable safety regulations.

$$W \leq W_1$$

$$V_T \leq V_{T1}$$

where, W_1 and V_{T1} are the maximum permissible values of the transmitting antenna energy and voltage, respectively.

We validated the model through tests in the TourEd mine in Natrona Heights, Pennsylvania. We further tested the system in a 250 ft deep mine of the Gateway Commerce Center in Wampum, Pennsylvania and in the 300 ft deep NIOSH Lake Lynn mine. We used both mines to demonstrate the operation of the system to interested potential users.

Based on the mathematical model the system can be designed for 1000 ft deep mines, or deeper, with practical design parameters.

The through-the-earth communications system (*TeleMag*) can be interfaced wirelessly with our in-mine communications system (*ComCell*) providing seamless two-way communication between anywhere inside the mine and the surface. In the two-way radio communications mode, the person on the surface can be at any needed distance from the antenna. For example, a person in the manager's office can talk to underground persons anywhere in the mine. Similarly, using the data transmission option, data from sensors anywhere in the mine can be displayed on a monitor in the office above ground. Through a company's Internet connection, the data can be read anywhere in the world.

For in-mine communication, we developed two approaches. In the first approach we used an easy-to-install cable for the infrastructure of the system. In the second approach we made use of existing power lines inside the mine for the infrastructure. The use of power lines saves the cost of additional cable and the labor cost for system installation. Furthermore, power lines are built and installed in a rugged, MSHA approved manner. But this approach posed two challenges that we overcame successfully. There must be no interference between the power energy and the communications energy flowing in the same wires. Furthermore, the power lines inside an underground mine usually consist of several, non-connected networks, fed from separate transformers that are not interconnected. For the communications signal to flow through the system, the power lines must be connected for the signal frequencies, but continue to appear non-connected for the power frequency. For just two separate networks, the required interconnection can be achieved through capacitor-resistor bridging networks. We found, however, that when this technique is applied to bridging a third network or more, the cumulative effects cause distortion of the signal, causing the voice to become corrupted and unintelligible.

We met this challenge by designing a proprietary circuit to implement the bridging. This bridge is more expensive than the conventional capacitor-resistor bridge. We found that the overall cost can be contained by alternating between the two bridge types when connecting successive separate networks.

A considerable amount of logic overhead was included in the software program to guarantee error-free communication. Since a power line is a narrow bandwidth transmission medium, the voice was compressed by a 12/1 ratio to reduce the throughput rate. The transmission was done in packages or “spurts”. This is normal procedure for data transmission. For voice transmission the information was sent in packages, but was smoothed at the receiving end before it was applied to a speaker. Without this process at the receiving end, the voice message would have sounded corrupted and unintelligible.

The in-mine communications systems, whether it uses a power line infrastructure or a dedicated network infrastructure, has several advantages over previous technologies. Some mines still use hard-wired wall-mounted telephones. The disadvantage of this technology is the obvious necessity that the user cannot be mobile. The user must be stationed at a telephone. To reach this person, the caller must page the person who must then go to a wall-mounted telephone that may be a long distance away and in the case of an accident the telephone may be inaccessible to the injured person. An earlier technology for wireless communications in mines, uses the so-called Leaky Feeder technology. This technology requires a relatively stiff, hard-to-install cable, about 5/8” in diameter, to be installed everywhere where communication is desired. To communicate the user must be in line-of-sight of the cable and not more than thirty or eighty feet away from the cable. Consequently, the cable must meander throughout all paths and tunnels where communication is required. When multi-channels are used, interference between channels is common. The ComCell system either uses existing power lines, or when dedicated lines are used, the network consists of easy-to-install, flexible, 1/4” in diameter wires. The length of wire needed is typically 1/10 or less than the wire length needed for leaky feeders. The system, due to its digital design, inherently prevents multi-channel interference. The system contains strategically positioned antennas. The user can typically communicate from anywhere within a radius of 600 feet from an antenna.

We developed a technique whereby we can quickly survey a mine to know where to position the antennas. We built self-activated transmitters and typically move five such transmitters in a methodical

way through certain areas in the mine to determine appropriate antenna locations. Prior to the survey, we study the mine map and decide on tentative antenna positions using the drawing board or a computer.

In the beginning of this project, the in-mine system exhibited certain problems in the field in underground mine installations. These problems included damage to equipment caused by lightning storms, especially troublesome near boreholes; occasional communication errors caused by the poor “electrical ground”, a common condition in underground mines; and occasional interference among antennas caused by frequency drifts. All these problems were analyzed and solved satisfactorily. To prevent lightning damage to our systems, we installed high-grade lightning arrestors that discharge electric charges very gradually to the ground causing relatively small potential imbalances. To eliminate grounding effects, we installed a proprietary board in the system control modules that make ground references independent of ground potentials at neighboring control modules. Finally, the occasional interferences between antennas were eliminated by installing proprietary equalization circuits. Transtek has several systems installed in underground mines. They function to the full satisfaction of the mine owners and users.

Under this project, Transtek also developed a vehicle and people tracking system that conveys the collected information to a central station through Transtek’s communication systems. This was accomplished by building beacons and transponders that interface with the in-mine system. When an object carrying a transponder passes at certain locations, transceivers mounted at the locations transmit a signal wirelessly to a receiver linked to the in-mine communications system. The signal that contains the identification of the moving object and the location is transmitted through the in-mine network and if applicable through the through-the-earth communications system to a computer and the information is displayed on a video screen.

The mine-wide communications system uses UHF (ultra-high frequency) for RF communication. To prevent interference between this system and the tracking system, we chose for the tracking system spread-spectrum RF communication at a frequency half an

order of magnitude higher than the frequency used for the in-mine system.

It should be noted that this tracking system is applicable when there are specified paths where vehicles or people will be passing. The beacons are then lined up along these paths. A universal system would be able to determine positions of vehicles and people anywhere in the mine without having beacons at the particular locations. The development of such a system is recommended to pave the way for the use of autonomous machines.

Recommendations for the “next steps”

A GPS-like (Global Positioning System) for underground mines would serve an extremely useful function in saving energy in mining operations. Autonomous (i.e. unmanned) machinery has been a long-standing objective of the mining industry as expressed in several National Mining Association (NMA) reports. This would move miners from underground mines to the surface from where they would remotely control mining operations. Extremely important is to note that such a move would allow shutting off the energy-guzzling fans, which would result in large amounts of energy savings.

GPS technologies above ground depend on line-of-sight communications between the transceivers on vehicles and the reference satellites. Positions are computed from the time-of-flight of communication signals between transceivers and satellites. An analogous situation in mines is impossible. Because of the structure of mines, in general, direct line-of-sight communication can occur only over short distances. A magnetic wave can propagate only a few tens of feet before being absorbed, refracted, or reflected from a wall or other object. Along tunnels, the distance is somewhat longer. We can assume an average distance of 100 feet. If we were to replace GPS satellites with antenna cells in the mines, this would require hundreds or thousand such cells which would make such systems entirely impractical, not only because of the astronomic cost, but also because such installations would be entirely too complicated.

It is noteworthy that we at Transtek made preliminary tests using a different technology to obtain “positioning” of objects, or GPS-

like results, in an underground mine environment using a small number of reference points. The results were very encouraging. Because of its cell-based technology, the ComCell in-mine system lends itself naturally to adaptation to achieve an in-mine positioning system. It is strongly recommended that this avenue be pursued in order to increase safety, productivity and reduction in energy used by the mining industry.

Spin-off product

There was also a spin-off product resulting from the project. This product is a portable communication and lifeline system for mine rescue teams. Rescue teams work in groups of five miners who advance into the disaster area plus a sixth miner who is positioned at a safe area called the FAB or Fresh Air Base. In addition, there is a Command Center located at some distance away from the FAB. The command center can be underground or aboveground. For an effective rescue operation, it is important to maintain communication between the advancing team and their support groups. This rescue system – Trademark *ResQCom* - makes possible wireless communication separately among the rescue team members, between the rescue team and the fresh air base, between the fresh air base and the Command Center, and communication among all of the above. This provides the ideal communication capabilities as specified by the late Ron Conti who was in charge of NIOSH (National Institute of Occupational Safety and Health) rescue team training programs.

Before the ResQCom system was built, rescue teams used a voice-activated system that made communication possible only between the FAB and the team captain. This single mode of communication did not meet the requirements for ideal rescue operations.

Transtek systems are used by NIOSH in their training programs conducted for underground mining rescue teams. The in-mine communication system was used in April 2002. The rescue team communication system was used in October 2003, and is scheduled to be used again in April 2004.

Patent protection

Techniques introduced by Transtek are protected by Patent No. 6,370,396 issued by the U.S. Trademark and Patent Office to Transtek on April 9, 2002. Other patents and an international patent are pending. Preparation for additional patent applications is in progress.

Recognition

Transtek systems received recognition in the mining industry. Articles describing the systems were published in national and international magazines. Examples are:

- “Saving with Cellular”, a subtitle heading for a section describing Transtek’s systems in an article titled “Making the Connection” published by the Engineering and Mining Journal in the March 2001 issue;
- An article “Transtek eye up coal communications” published by International Longwall News in the September 2003 issue;
- An article “New Lifeline technology to save lives”, describing Transtek’s rescue team system, published by International Longwall News in the December 2003 issue;
- An article “New communications system for mine rescue” published by Coal Age Magazine in the February 2004 issue.

MSHA certification

Use of Transtek’s systems in coalmines requires Mine Safety and Health Agency (MSHA) certification because of the methane and coal dust presence in these mines. Transtek has had several meetings with MSHA examiners and Transtek’s designs were carried out with MSHA regulations in mind. MSHA certification involves a lengthy and expensive process. If any design or construction change

is made to a certified device or equipment, a new certification process must be initiated. Therefore, Transtek decided to have the systems operate for some length of time in non-coalmines in order to evaluate the systems and to decide about modifications, if any, that should be made before applications for certification are submitted to MSHA.

We have talked with coalmine operators. The need for our systems is clear. We believe that once MSHA approval is obtained, the coalmining market will welcome our systems.

Transferable technologies

The in-mine communications technology developed by Transtek can be used advantageously in fields other than mining. Two-way radios do not function well in high-rise buildings and other steel-reinforced structures. Security and maintenance people cannot reach each other in many locations in high-rise buildings and other structures. The same problem exists for first responders in disaster situations in these environments.

The problem is well known, but no satisfactory solution is available. Some jurisdictions have already introduced ordinances requiring property owners to provide means in their buildings to make two-way radio communication possible. One approach that has been taken uses a high-powered repeater at a central location in the building. Experience has shown that this approach is lacking in coverage. There are many blind-spots in the building where the signal does not reach. Another approach suggested is to extend wireless methods used in offices, such as the “blackberry” system, to full building coverage. This approach is also unsatisfactory. It requires a large number of signal splitters and amplifiers. Wires must be strung on each and every floor and it provides only a digital display. There is no voice. Other so-called distributed antenna systems (DAS) were also suggested. They all require a very elaborate, expensive installation rendering them impractical.

We tested and demonstrated Transtek’s system in a 44-story building at 1250 Park Avenue in New York, NY. We got full coverage including all “difficult” locations pointed out to us by the security and maintenance people. Our installation requires a minimal

infrastructure, it is easy to install and is extremely cost effective. The price would be about one third, or less, the price of other approaches.

A second system, our rescue team system, is applicable to use by fire fighters, police, medics, and other first responders. The situation in a collapsed building, is similar to a disaster condition in mines.

RESULTS AND DISCUSSION

This project has resulted in wireless communications systems for the mining industry that are technically sound and reliable and commercially feasible. We have installed systems in underground mines. The systems function to the full satisfaction of the customers and are being used by NIOSH in training classes. Certain hurdles were overcome to make the systems essentially maintenance free. Other features, such as the use of optical fibers and video transmission, can be added to the systems that would make them more versatile. This will require additional research and development work. The project also led to a spin-off product and points the way forward to a new technology that could result in a GPS-like system for underground mines. Such a system would make autonomous machines for the underground mining industry a reality. This would result in considerable energy savings in mining operations.

CONCLUSIONS

The objectives of the project were met successfully in a commercially viable manner. As technology advances, the designs should be periodically reexamined as in future designs certain functions may be achievable at a lower cost and it may be possible to add certain features to the systems. Systems were installed in the field and tested over time. The systems continue to function satisfactorily. The project was successful not only in meeting the stated objective, but also in leading to additional products and pointing the way to future research and development directions.

Appendix
Excerpts from the Ben Franklin Study conducted by
Carnegie Mellon University

The following comments are summarized from a study report compiled under the direction of Dr. John Mather of Carnegie Mellon University and Stephan Mueller and Brian McGeehan of Innovation Works. The study was funded by the Ben Franklin Technology Center of Western Pennsylvania, now represented in Pittsburgh by Innovation Works.

Comments in quotation marks are direct quotes from respondents in the mining industry.

When respondents were asked how well current systems meet the needs for mining communication, 62 percent replied negatively. None of the respondents thought that mining communication needs were being met extremely well.

“Overall we cannot communicate well with miners.”

“There is the issue of battery, phone and wiring maintenance.”

“Safety in an emergency is still an issue.”

“Foreman (sic) definitely need a better way to communicate.”

Respondents were asked, “How urgent is the need for better communication in underground mines?” 53 percent thought this need is urgent or extremely urgent.

The leaky feeder systems have a poor reputation for performance and reliability

“There are too many dead spots with leaky feeders.”

“The new leaky feeder systems have the reputation of not working consistently.”

“I have seen a leaky feeder system, but it only went 600 feet deep.”

The trend in data transmission seems to be the same as the trend in data communication anywhere. The emphasis is on speed

“The trend toward automated machines will increase the demand for wireless communication,” said one respondent. This comment was echoed from several of the experts. Some companies are already using remote control devices to control robots.

Respondents were asked if Transtek’s communication capability would be “valuable to your underground mine.” The answer was a convincing “Yes.” 94 percent of respondents answered in the top-two response choices. Three-fourths of the respondents answered that the technology is “very valuable” for underground mines.

“This may be valuable for productivity, safety automation and data.”

“I wish it was ready for my mine now.”

“Extremely valuable for safety reasons.”

“It could replace the leak-feeder system and the PED system with better features.”

The effect on wireless data monitoring seems to be a niche that would allow for significant cost savings for mines. For each one of the sensors the mines need to run hardwire to monitor this sensor. Each mine may have miles of hardwire for this purpose. When asked if Transtek’s technology would be useful in transmitting data for continuous monitoring, 79 percent thought that it would be useful. The main usefulness that was expressed was that of minimizing expenses.

“This would be a great niche if the transmission is fast enough. It would save a significant amount of installation cost.”

Respondents were optimistic about the likelihood of selling Transtek's technology to mines.

"If the technology can allow for transmission up to approximately 1000 feet it will definitely be a hot technology that mines will buy."

"It has a very good chance of succeeding because it has the advantages of the leaky-feeder and the PED with better range."

"Miners are a conservative group and will not try something unless it is proven. Once it is 'proven' mines will be more likely to try it."

"Mines are looking to find such a system. It would become universal over time due to safety, a decrease in down time and an increase in productivity."

