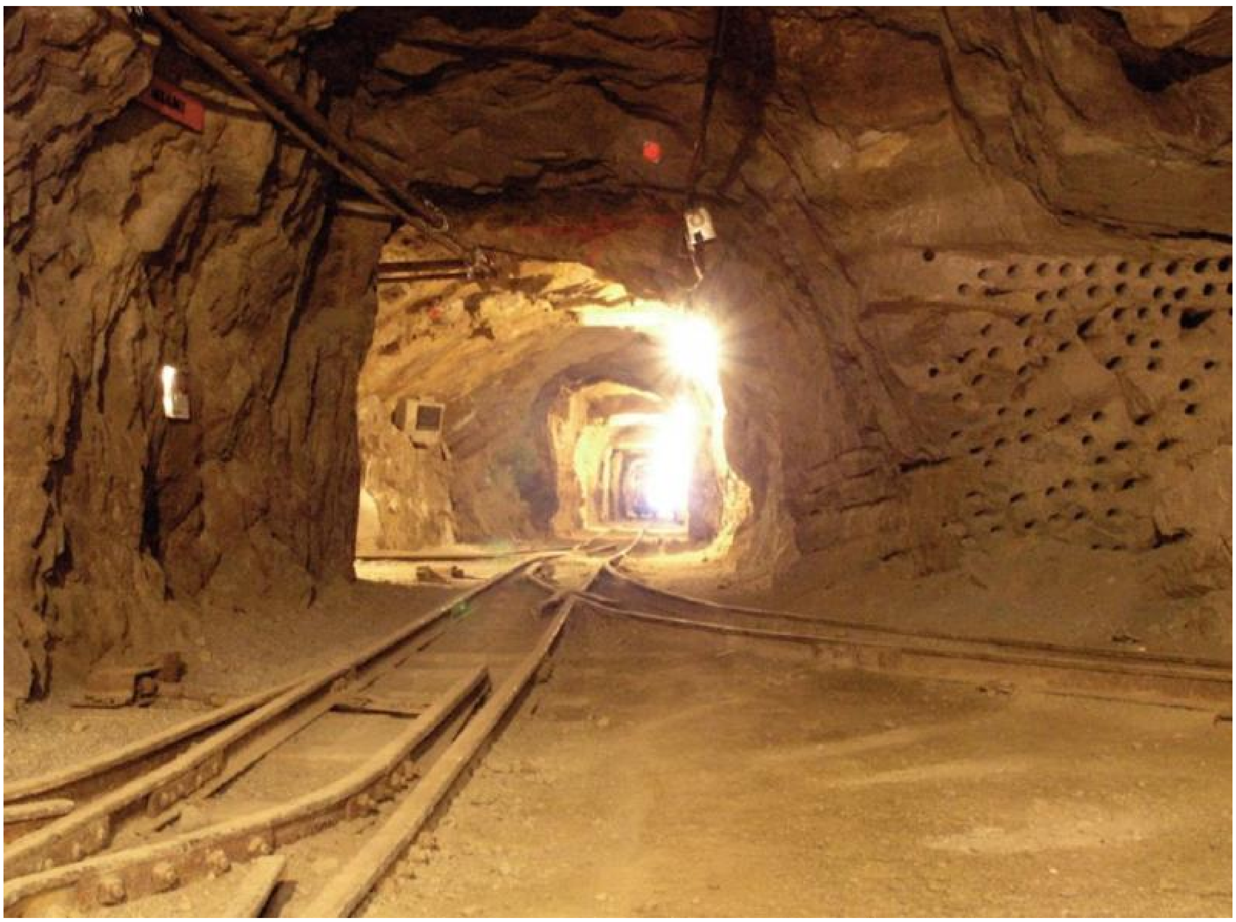
Deep underground, smartphones can save miners' lives

October 27 2016, by Sudeep Pasricha



It’s easy to get lost in here. Credit: Sudeep Pasricha/Colorado State University, CC BY-NC

American mining production increased earlier this decade, as industry sought to reduce its reliance on other countries for key minerals such as coal for energy and rare-earth metals for use in consumer electronics. But mining is dangerous – working underground carries risks of explosions, fires, flooding and dangerous concentrations of poisonous gases.

Mine accidents have killed tens of thousands of mine workers worldwide in just the past decade. Most of these accidents occurred in structurally diverse underground mines with extensive labyrinths of interconnected tunnels. As mining progresses, workers move machinery around, which creates a continually changing environment. This makes search and rescue efforts even more complicated than they might otherwise be.

To address these dangers, U.S. federal regulations require mine operators to monitor levels of methane, carbon monoxide, smoke and oxygen – and to warn miners of possible danger due to air poisoning, flood, fire or explosions. In addition, mining companies must have accident-response plans that include systems with two key capabilities: enabling two-way communications between miners trapped underground and rescuers on the surface, and tracking individual miners so responders can know where they need to dig.

So far, efforts to design systems that are both reliable and resilient when disaster strikes have run into significant roadblocks. My research group's work is aimed at enhancing commercially available smartphones and wireless network equipment with software and hardware innovations to create a system that is straightforward and relatively simple to operate.

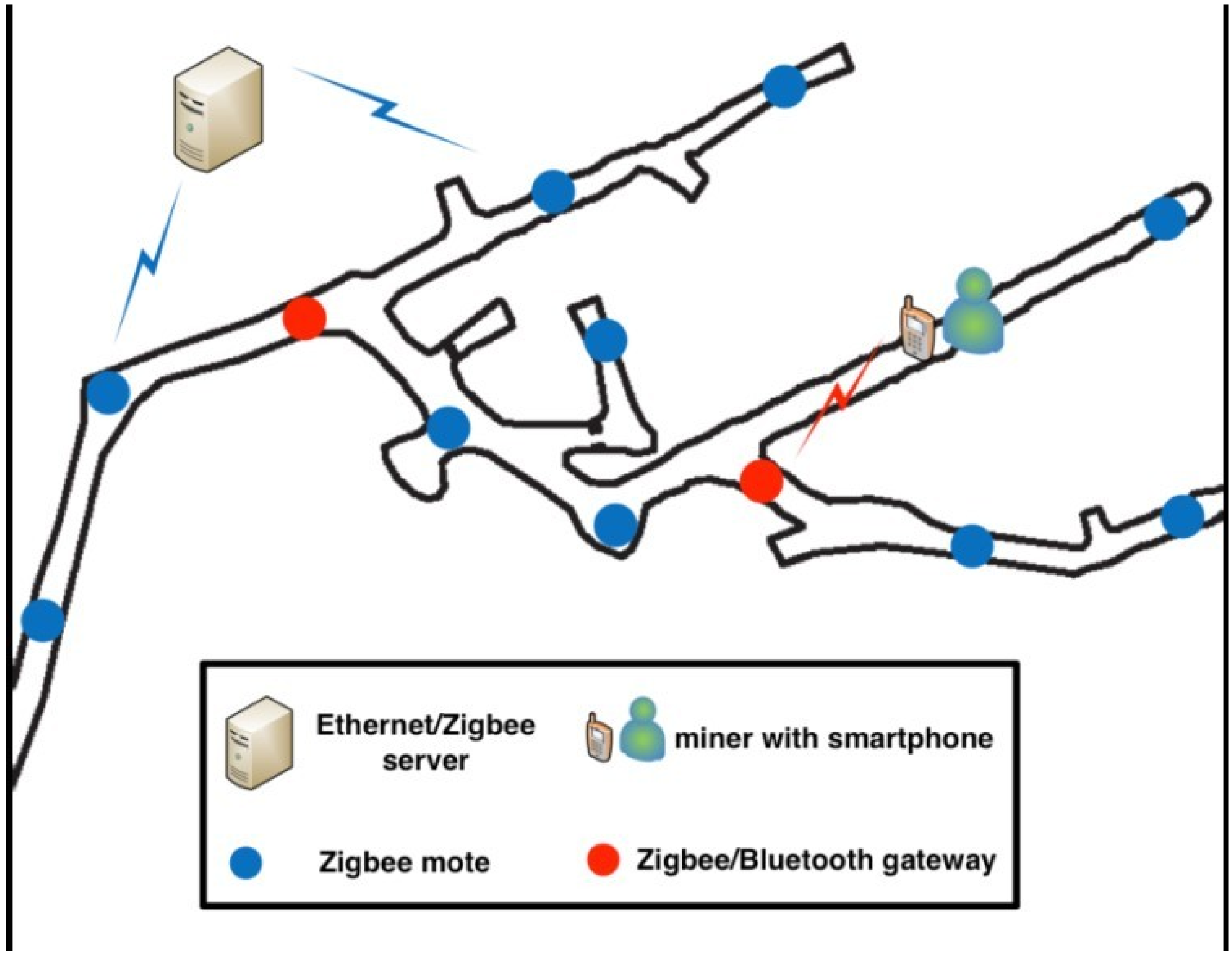
Existing connections

The past decade has seen several efforts to develop monitoring and emergency communication systems, which generally can be classified into three types: through-the-wire, through-the-Earth and through-the-air. Each has different flaws that make them less than ideal options.

Wired systems use coaxial cables or optical fibers to connect monitoring and communications equipment throughout the mine and on the surface. But these are costly and vulnerable to damage from fires and tunnel collapses. Imagine, for example, if a wall collapse cut off a room from its connecting tunnels: Chances are the cable in those tunnels would be damaged too.

Systems that send signals through the Earth use large loop antennas to send low-frequency radio waves through dirt and rock. The signals can't carry much information beyond simple texts or sensor readings, and the equipment is expensive and bulky.

Airwave setups use wireless links, like cordless phones or Wi-Fi signals, to span distances of 1,000 to 2,500 feet. But these have limitations too. They depend on wired base stations distributed throughout mines, which are very like the wired-only systems and have similar cost and connectivity problems.



A proposed system layout for underground mine monitoring, tracking and communication. Credit: Sudeep Pasricha/Colorado State University, CC BY-ND

Tracking underground

Because they have to track individual miners' movements underground, all of these systems also require every worker to carry expensive custom sensing units. The costs involved have meant that so far, most mines today use equipment that provides the bare minimum amount of safety required. This includes manually tracking miners' locations using two-way pagers or video surveillance.

If newer methods for tracking, sensing and communication could be developed, we could detect precursors to mishaps (such as noxious or combustible gas level concentrations in certain parts of a mine), and better aid rescue efforts in the aftermath of an accident. In my research, we're trying to use regular consumer smartphones and smart wireless devices to solve these problems. This sort of system takes advantage of the facts that most people have phones with them all the time, and that modern smartphones have a wide range of sensors already built in.

Some prior work of mine found a way to use smartphones to navigate indoor spaces. We started by measuring the strength of the Wi-Fi signals the phone was receiving to approximate the distance the phone was from known transmitter locations. We factored in measurements from the phone's inertial sensors to determine speed and direction of movement. And we applied a mathematical technique called Kalman filtering to determine other useful information from additional sensors – such as number of steps taken.

When all these data were processed by machine learning techniques, we could determine a user's location within one to three meters, despite noisy or erroneous readings from Wi-Fi radios and inertial sensors. That was much better than prior methods for indoor location-sensing based on inertial sensor readings and fingerprinting. But these studies were done above ground.

Doing the same thing underground is much more difficult. Not only are Wi-Fi signals unavailable underground, but other wireless signals, such as those from cellphone towers, are also not present. Even what signals are there, from communications equipment in the mine, bounce off uneven surfaces, are absorbed by earthen walls and must pass equipment and other obstacles in tunnels of varying dimensions. These complexities make determining a specific location even harder for an electronic device.

Moreover, sensors and smartphones used in mines must be particularly energy-efficient because recharging stations are scarce. And they must not use much power, to avoid igniting subsurface gases.

A new approach

Our research involves designing a wireless network made up of many low-cost stationary Zigbee or Bluetooth sensors deployed strategically around the mine, creating a web or mesh network that can connect with smartphones carried by the miners. We'll design the exact location of the fixed sensors based on an analysis of how radio signals travel in complex, changing and noisy underground mines.

We're also working to design new software algorithms and filtering techniques that can work on smartphones. When connected to the wireless mesh network, they will be able to accurately and efficiently calculate location in mines, despite the highly unpredictable nature of wireless signals.

Our hope is that we'll figure out how to build a combination cyber and physical system for monitoring, communication and tracking in underground mines under normal conditions. Such a setup would also be helpful in emergency response and rescue operations. This could not only improve the safety of hundreds of thousands of American miners, but also offer new opportunities for communications and improving human safety in a variety of extreme environments.

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