# An Integrated RFID and Sensor System for Emergency Handling in Underground Coal Mines Environments

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**Abstract.** Mobile communication system for underground coal mines is far more behind the one on surface for the unique underground tunnel environment and safety requirements. Though our previous CDMA System V1.0 can solve the problems of coal mine communication well in regular environments, it still remains a challenging issue for emergency handling. In this paper, we propose a novel integrated RFID and sensor system for emergency handling in underground coal mines environments.

**Keywords:** Coal mine, emergency handling, emergency response system, RFID, wireless sensor networks, mobile agent.

## 1 Introduction

China is a country short of oil and gas but rich in coal, its economy relies too much on coal industry. According to the country's official statistic in 2004, China's coal consumption accounted for 74 percent of all energy resources. However, as the production increases, coal mine accidents happened very frequently, the number of death per million ton in China is about 100 times of that in the US, 30 times of that in South Africa and 10 times of that in India, it has caused huge economic loss and serious negative impact on social influence.

In order to reduce the accidents, communication in coal mine plays a key role. However, mobile communication system for underground coal mines is far more behind the one on surface for the unique underground tunnel environment and safety requirements. The length of underground tunnel (some of them in China are up to 100km long), the complex structure, gassy atmosphere creates huge problem in planning and designing of radio signal propagation solutions, and all the equipments used in underground must meet the requirements of intrinsic safety [1] and explosion-proof features. According to "Listing of available Mine Safety and Health Administration (MSHA) Approved Communications and Tracking Products" [2], present mobile communications systems in USA can be leaky feeder, RFID, WiFi/wireless MESH, each of them can only provide limited communication in the local area. Therefore, there is no mobile communication system whose radio signal can cover the whole underground tunnel and provide all functions required by coal mines except our CDMA solution, as shown in Fig. 1.

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Cooperated with Global Star Solutions (Formerly known as UTstarcom Canada before July 2008), an ALL-IP CDMA infrastructure solution provider, Confederal Technology Corporation started the R&D of this CDMA system early in the year 2006, and began to deliver its System V1.0 to coal mine market in August 2007. The CDMA System V1.0 is composed of a main system, a RTCS subsystem and a series of CDMA terminals. RTCS is mainly deployed in underground tunnel to provide radio signal coverage, which is composed of a dedicated optic transmission network and a radio coverage network. The CDMA terminals include Intrinsic Safety mobile phones, data terminals and image terminals. The whole system structure is as the following:

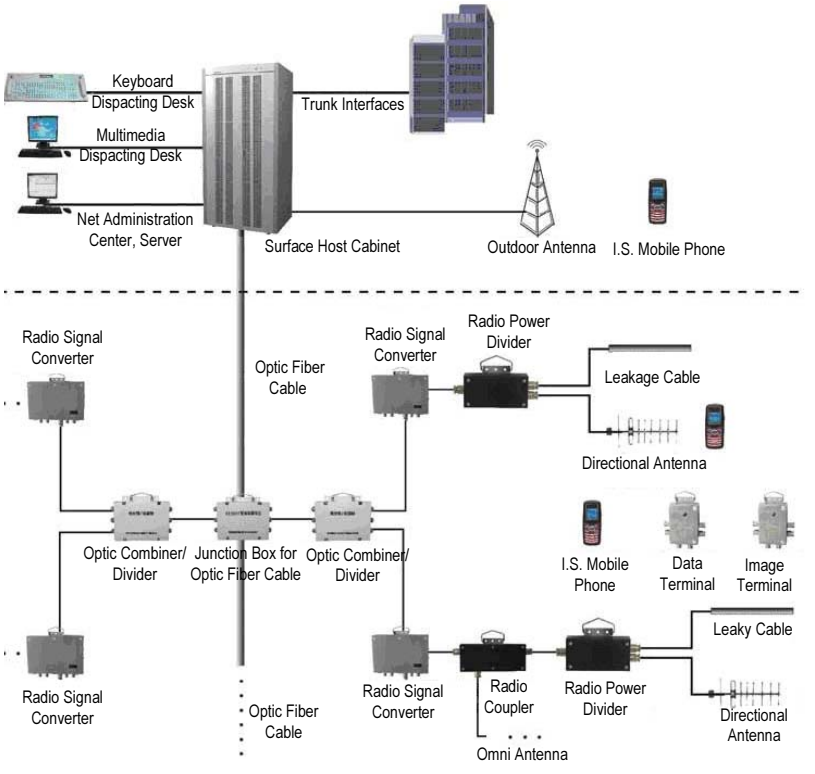


**Fig. 1.** The CDMA System V1.0 architecture for underground coal mine communication

Though the proposed CDMA System V1.0 can solve the problems of coal mine communication well in regular environments, it still remains a challenging issue for emergency handling. When coal mine accidents happen, the gas density increases and the damaged electricity wires likely ignite the gas to exacerbate the disaster. Thus, surface personnel have to cut off the power supply of CDMA base station for the sake of safety, while isolating the communication between rescue team and the miners stuck inside the coal mine tunnels. Without the communications between underground and surface, rescuers can not be aware of the positions of the stuck miners and the situation of a disaster. Thus, effective rescue strategy is hard to be made.

Due to the importance and difficulty of emergency handling for coal mines, China Coal Research Institute (CARI) sets up a special group of Emergency Response System (ERS) to attempt to solve the problem. However, the main solution is to deploy telephone wired lines while excavating the collapsed tunnel, as traditionally done.

However, in traditional schemes, the critical gaps exist in the collection and subsequent handover of vital underground miner's information to the surface rescue team that can place the miner's life at very high risk. In order to solve above problems, this paper proposes a novel integrated RFID and sensor system for emergency handling in underground coal mines environments. Our main contributions have two-folds:

- when CDMA system is down due to loss of power, the communication between surface and underground is cut off in the collapsed tunnels. The underground wireless sensor system will self-organize to form an isolated network, which can push the critical information of miners to its network edge. Typically, the network edge covers much larger area than the group of stuck miners, and thus increasing the possibility of stuck miners to be found in an early time.
- In emergency response, the situation of underground disaster is keeping change. The separately located RFID readers are utilized to deliver the mobile agents to the network edge through wireless sensor networks. The mobile agents, which reflect the up-to-date strategies to save life, are delivered by underground miners through the RFID tags attached with them. A RFID tag contains a simple transmitter chip and antenna. Identification information can be saved in the tag attached to a miner. However, when encountering a dynamic environment such as a disaster in underground coal mine, the identification information is useless since the link between a database and a RFID reader is broken. In this paper, we propose the installation of a mobile agent (including miner's identification and dynamic strategic information) to the RFID tag to handle the emergency situation.

In contrast to the traditional methods for emergency handling, our scheme has the following features:

- the role of sensor networks is changed from sensory data collection to emergency information delivery.
- we propose an innovative auto-identification technology, called mobile agent based RFID system to close the information gap in emergency response system.
- we do not increase the hardware cost while enhancing the capability to handle the underground emergency. Usually, the RFID system is deployed for attendance management, while sensor system is deployed to report underground environmental parameters, such as gas density, temperature and humidity in the tunnels.

## 2 Related Works

Our work is closely related to the communication system in coal mines, RFID technology and mobile-agent based data dissemination in WSNs. We give a brief overview of the existing work in these areas.

CDMA system for coal mine is quite different from that for telecom carrier. For those who work on wireless network we all know that a CDMA network consists of a radio network and a core network. Typical core network includes at least one MSC and one HLR, which can support high capacity, but it's huge size, expensive cost and hard to integrate coal mine dedicated functionalities make it unusable and unaffordable for coal mine customers. Therefore it's necessary to build a cost-effective and size compact core network for this project. Secondly, a comprehensive application server, which can provide dispatching, PTT (Push to Talk), mobile voice/SMS (Short Message Service), mobile data/video monitoring, positioning and tracking service will be developed to meet the need of coal mine production control. Thirdly, a new radio coverage solution will be worked out to cover the very long, dump, dust and high gas underground tunnel with CDMA RF signal. Lastly, all the equipments including network elements and terminals which will be used in underground tunnel must get mine safety certificates.

RFID networks are composed of tags, readers, and backend system. A RFID tag usually stores an identifier and uses radio frequency energy to communicate with the RFID reader. Active tags embed an internal battery, which continuously powers both their internal processes and their RF communication circuitry. Readers can thus transmit very low-level signals while tags reply with high-level signals resulting in long read range. In contrast, passive tags have no internal power supply with a smaller size and limited capabilities, and thus cheaper than active tags. The semi-passive tags communicate with the readers like passive tags while embed an internal battery that powers their internal circuitry. The role of RFID reader is to obtain the information stored in RFID tag. When a RFID tag comes within the proximity of a RFID reader, the information stored in the tag is transferred to the reader. The information is forwarded from the reader to a backend system, which can be a computer employed for processing the information and/or controlling the operation of other sub-system(s). Recently, RFID is being incorporated into a wide range of industrial and commercial systems [4], including manufacturing and logistics, retail, item tracking and tracing, inventory monitoring, asset management, anti-theft, electronic payment, anti-tampering, transport ticketing, supply-chain management, etc.

Mobile agents have been found particularly useful in facilitating efficient data fusion and dissemination in WSNs [6]. The traditional data dissemination method follows the client/sever based paradigm, where the occurrences of certain events trigger surrounding source nodes to individually collect and then send data to the sink. In the client/server paradigm, the number of data flows is generally equal to the number of the source nodes, leading to high bandwidth and energy consumptions, especially when the sensor data is highly redundant. Furthermore, this approach could lead to unbalanced energy consumption in the network, due to the fact that nodes closer to the sink forward more data on behalf of other nodes. In the MA based approach, the sink node sends an MA to the target region to visit the source nodes one after the other. The sensed data can be compressed and aggregated by the agent and then sent back to the sink as instructed by the MA, yielding a single traffic flow instead of multiple ones. The motivations for using MAs in WSNs have been extensively studied in [7].

# 3 Integrated RFID and Sensor System for Emergency Handling

## 3.1 Overview of Traditional Emergency Handling

As shown in Fig. 2, the slope of the main tunnel from surface to underground is typically 2Km. When coal mine accidents happen, the collapse usually blocks the slope of the main tunnel, and damage the electricity wires. In order to avoid the ignition of the dense gas by the damaged electricity wires, surface personnel will cut off the power supply and abandon the CDMA communication system.

In such critical situation, the main goal of rescue team is to communicate with stuck miners in a timely fashion. Traditionally, rescue team carry telephone lines with enough length. First, rescue team excavates a small path segment towards underground coal mine, then, they lay telephone lines to cover that path segment. The procedure is repeated until they reach the stuck miners by face to face meeting.

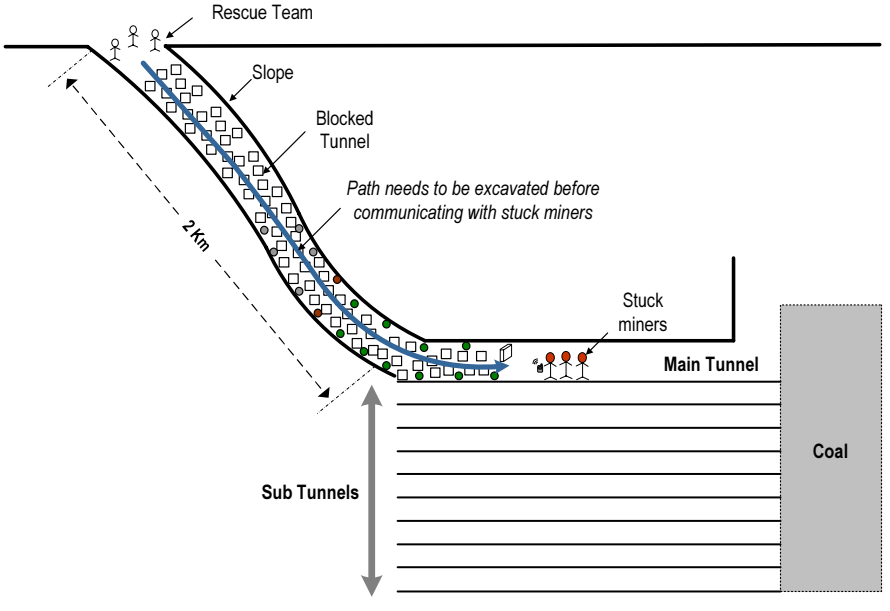


**Fig. 2.** Illustration of traditional emergency handling scheme

## 3.2 The Proposed Emergency Handling Scheme

In traditional emergency handling scheme, without underground and surface communications, the stuck miners only can passively wait for the coming of the rescue team. By comparison, both rescue team and stuck miners can make efforts to shorten the time to connect with each other in the proposed scheme, as shown in Fig. 3. We divide the procedure of emergency handling into two parts:

– *Underground part*: In regular situation, the RFID tag attached to a miner is used for attendance management and personal positioning. The role of the tag changes in an

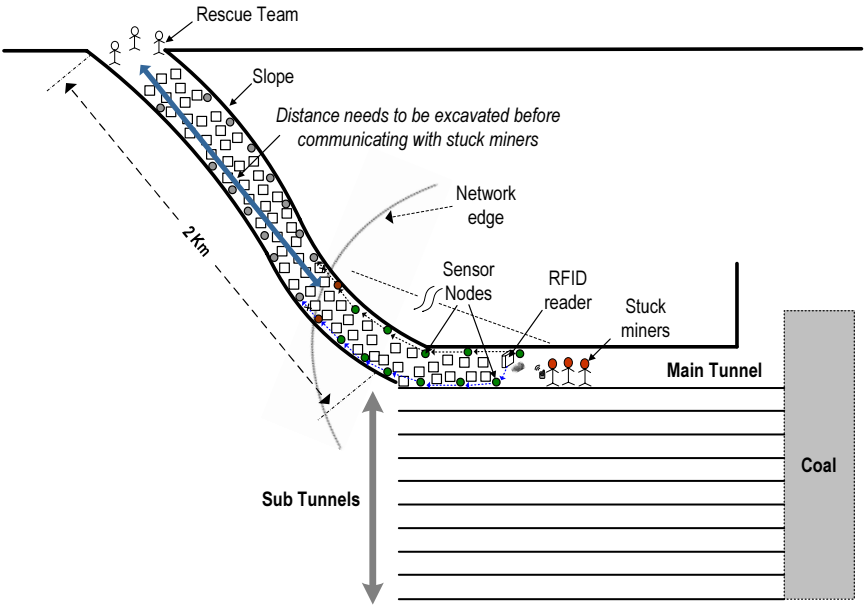


**Fig. 3.** Illustration of the proposed emergency handling scheme

emergent situation. According to the up-to-date situation of underground disaster, miner installs a mobile agent to the RFID tag which reflects the dynamic strategic information. When the miner comes within the proximity of an available RFID reader, the mobile agent information stored in the tag is transferred to the reader which is connected to a nearby sensor node. Though, the power supply is cut off and communication to the surface is impossible, the battery operated sensor nodes still can self-organize to form an isolated network in underground coal mines. The sensor networks will perform the miner specific task through the intelligence carried by the mobile agent, and push the critical information of miners to its network edge. Compared Fig. 3 to Fig. 2, it can be observed that the sensor network edge covers much larger area than the group of stuck miners, and the path that the rescue team needs to excavate is shortened.

– *Surface part*: This procedure performed by the rescue team is similar with that of the traditional scheme. However, the rescue team do not need to meet the stuck miner face to face. Instead, once the sensory signal is captured around the network edge, the goal of restoring communication is achieved.

Compared to the traditional scheme, the proposed emergency handling scheme has four advantages:

– Due to the enabling of bidirectional efforts by both rescue team and stuck miners, the communication is restored faster.
– The stuck miners can "tell" the sensor network to have the correct actions with the occurrence of specific situation of disaster.

- The length of the telephone lines need to be laid by the rescue team is shorten. Since small scale collapse is still likely happened along the excavated path, the shorter telephone lines need to be laid actually decrease the possibility of being cut off again.
- Due to the less path needs to be excavated, the burden of the rescue team is lightened.

## 4 Conclusion

The successful deployment of our previous CDMA communication system in underground coal mine has helped to improve the safety condition and increase production efficiency for China coal mine industry. However, it still remains a challenging issue for emergency handling when the power is cut off to avoid the ignition of the dense gas by the damaged electricity wires. In this paper, we propose the installation of a mobile agent (including miners identification and dynamic strategic information) to the RFID tag to handle the emergency situation. The critical information of miners is pushed to to the network edge of the self-organized underground wireless sensor system. Due to the enabling of bidirectional efforts by both rescue team and stuck miners, the communication is restored faster than the traditional scheme.

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